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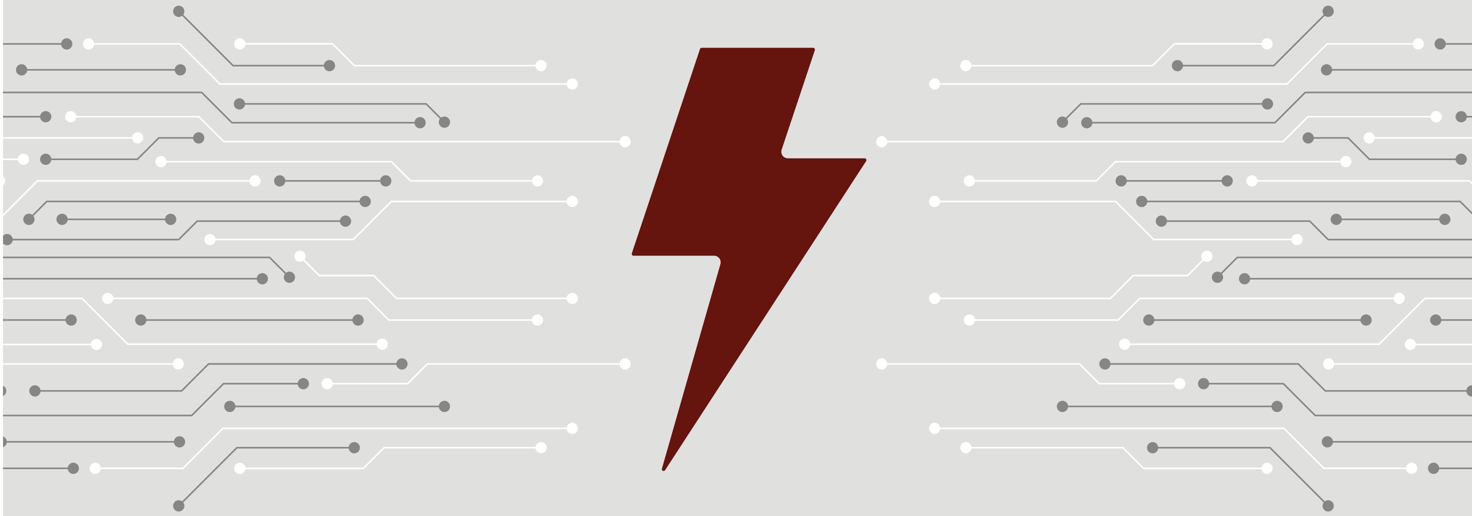
Dorothee Hillrichs, Anita Wölfl



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Complexities and Dependencies in the Global Semiconductor Value Chain[1]

Dorothee Hillrichs and Anita Wölfl

ifo Institute, Munich, February 2025

Abstract

This EconPol Report sheds light on the global supply of semiconductors. Our analysis of value-added data for the US underscores the importance of semiconductors for advanced economies. Using global trade data and an extensive list of semiconductor-related goods, we provide a detailed description of the global semiconductor economy. We show that while final chip exports have been dominated by Taiwan, China, and Korea at an aggregate level since the early 2010s, export leadership varies substantially across chip types. Moreover, we identify nine core countries in North America, Europe, and Asia that dominate semiconductor-related trade including material inputs and equipment. The nine countries exhibit substantial mutual trade dependencies due to the fragmentation of semiconductor production. Against the backdrop of a rise in policy interventions affecting semiconductors since 2021, we end this report by flagging open questions about the economics of semiconductor production.

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[1] We thank Michael Stelzig for outstanding research assistance. This research agenda is co-funded by Infineon.

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Executive Summary

Semiconductors play a critical role for modern societies, …
Semiconductors are literally everywhere. They are used directly in computers, smartphones, and cars. They are also used as an intermediate input to produce other goods or services along all stages of the value chain. As such, semiconductors also feed into national defense by being embedded in communication and transport equipment, navigational instruments, as well as in software and scientific research services.

… but not all chips are the same
The umbrella term "semiconductors," also known as "chips," really refers to a heterogeneous group of products. Semiconductors differ in their functionality, from memory chips that store data, to logic chips that process data, to power transistors that control electronic current. The subgroups can be further differentiated, for instance by their maturity, material, or end-use application.

Chip production is characterized by a complex value chain …
At an aggregate level, semiconductor production can be split into three big steps: design, manufacturing, and, finally, assembly, testing, and packaging (ATP). Each of the three stages relies on its own specific set of equipment, material, and service inputs, which have their own complex value chains. The detailed economic forces binding the different production stages together can differ strongly between chip types.

… on a highly globalized scale
Semiconductor production is highly globalized. In 2022, about 70 countries participated in semiconductor-related trade, generating about USD 1.2 trillion of trade. Final chips make up the lion's share of global semiconductor-related trade, and within this group, logic and memory chips are the largest groups. The second most important category is semiconductor-related equipment, where dedicated semiconductor machinery stands out as the largest group.

Global semiconductor trade is highly concentrated
Global semiconductor trade shows an extreme geographic concentration, with three players – China, Taiwan, and Korea – accounting for about 50 percent of global final chip exports. The trio's leadership derives from integrated circuit exports, but it is contested by the US, Germany, and Japan in power and optical semiconductors as well as in sensors. Overall, only nine countries appear consistently as a top-3 supplier for final chips, material inputs, or equipment. The concentration of chip

exports reflects the importance of comparative advantage thanks to technology, skill, and capital for producing these very complex goods, as well as to the importance of economies of scale in chip production.

Chip production is also globally fragmented, giving rise to multilateral dependencies

The global semiconductor value chain is geographically rather fragmented. While Korea, Taiwan, and China stand out as the key exporters of final chips, the US and Japan, but also Germany and the Netherlands, stand out as net exporters of chip-related equipment. Due to this global fragmentation, multilateral dependencies arise.

Semiconductors are disproportionately targeted by government interventions

Most of the key semiconductor countries have been reacting to a chain of supply shortages of chips in 2021 with a set of industrial and trade policies that are disproportionately targeting semiconductors. The intention behind such government interventions is to achieve technological sovereignty and to strengthen the economy's competitiveness.

The complex global chip value chain warrants a nuanced policy debate

However, in light of the complex global semiconductor value chain and, in particular, the multilateral dependencies arising from it, a more nuanced policy approach is warranted for truly effective policies. A set of open questions makes it difficult to define the scope of government interventions needed to achieve a viable semiconductor industry.

1 Introduction

Semiconductors, also known as chips, are everywhere. From cars, computers, or smartphones to electricity, health services, or military equipment, semiconductors are essential for the functioning of modern societies. While demand is ubiquitous, production is concentrated in a few countries. A combination of unexpected demand shifts and multiple local weather-related events – a fire in Japan, a drought in Taiwan, and a storm in Texas – led to semiconductor shortages worldwide in 2021 (US White House 2021). Geopolitical tensions between the US, Taiwan, and China and the threat of weaponizing the supply of critical goods raised national security concerns. Governments across the globe are thus racing to shore up semiconductor manufacturing. Policymakers pursue a twin goal: to reach technological leadership and to secure their countries' technological sovereignty.

The localization efforts target some of the most complex products to make. Key phases in the production of semiconductors are the design, the manufacturing, and the assembly, testing, and packaging (ATP) stages. Each step has its own complex value chain, and interlinkages abound. What's more, the economics of semiconductor production varies between types. Designing effective and efficient policies to shift the industry is a Herculean task.

This report provides important input into the ongoing debate about transformations in the semiconductor industry. To set the stage, we illustrate the economic importance of semiconductors using input-output data. We then describe the complexity of the global chip value chain and analyze trade data to highlight bilateral linkages in chip production and trade. Finally, we suggest avenues for advancing the debate and highlight open questions about the economics of the semiconductor value chain.

2 The Importance of Semiconductors

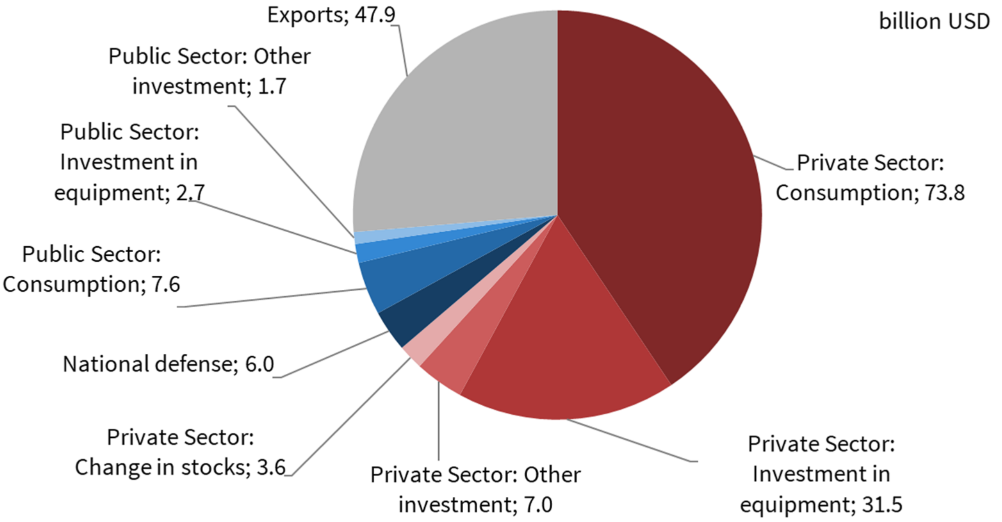
The umbrella term "semiconductor" really refers to a heterogeneous group of products. Semiconductors differ in their functionality, from memory chips that store data and logic chips that process data to power transistors that control electronic current. The subgroups can be further differentiated, for instance by their maturity, material, or end-use application. The World Semiconductor Trade Statistics, an industry survey, distinguishes roughly 75 different chips.

Semiconductors are literally everywhere – this is because semiconductors are located relatively upfront in the value chain of goods and services. They are used directly, for instance, in computers, communication equipment, and consumer goods like cars, fridges, or microwaves. But semiconductors also make an indirect contribution as they are embedded in other goods that are in turn used as intermediate inputs in the production of goods and services for final demand. For instance, semiconductors are an important component in optical or electromedical instruments. These, in turn, are used by pharmaceutical companies to produce drugs. Sticking to this example and moving further down the value chain, semiconductors thus also make an important indirect contribution to healthcare services.

Data on the input-output linkages helps measure these direct (first level) and indirect (second level) contributions of the semiconductor industry for the economy. Input-output data provides information on the role of industries' goods and services as intermediates in the production of other industries, on the one hand, and on their role for final consumer and investment demand as well as for exports, on the other.[2]

Figure 1: Direct and Indirect Contributions of the Semiconductor Industry to the Economy

In value added terms, USA 2022



Reading example: To produce all goods and services private households consume, the economy requires 73.8 bn USD worth of semiconductors.

Source: Bureau of Economic Analysis; calculations by the ifo Institute.

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[2] For a more detailed description of the data and method used in this analysis, see the appendix.

Figure 1 emphasizes the importance of semiconductors for the economy, using input-output data for the United States.[3] The figure shows how much the semiconductor industry contributes in terms of value added across different uses along the value chain. For instance, to produce all the goods and services that private households consume, the economy requires USD 73.8 billion worth of semiconductors. This is particularly driven by private demand for motor vehicles, computer and communication equipment, as well as telecommunication services, but also for education and health services. In total, the US economy uses semiconductors worth about USD 182 billion; this is 2.4 times as much as the value added directly produced in the US semiconductor industry.

Semiconductors also feed into national defense by being embedded, for instance, in communication and transport equipment, navigational and other control instruments, as well as in software and scientific research services. In 2022, direct and indirect value added from the semiconductor industry used for US national defense was about USD 6 billion (Figure 1). While this was only roughly 1 percent of total demand for national defense, it is of great importance for the functioning of this highly technology-intensive industry.

3 The Semiconductor Value Chain

At an aggregate level, semiconductor production can be split into three big steps: first, design; second, manufacturing; and, finally, assembly, testing, and packaging (ATP). In the first step, the **design stage**, engineers develop patterns of transistors (the chip “architecture”) to be etched onto so-called wafers in the manufacturing process. Designs can be specific to the end use or generic. The key inputs in the design stage are R&D expenses, the human capital of engineers, and the electronic design software. Depending on the application, past design modules, referred to as semiconductor intellectual property (SIP), can be re-used and adapted. Thanks to intellectual property rights protection, the design step can be separated from the manufacturing stage (Bown and Wang 2024), facilitating the emergence of “fabless’’ companies. This lowers entry costs into design significantly. At the same time, designers cooperate closely with “foundries,” the chip manufacturers.

End usage critically shapes the design stage. For instance, quality requirements on the design vary depending on the end use, with much more stringent requirements

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[3] Input-output data on such a detailed industry breakdown such as to separate the semiconductor industry is publicly available for only a few countries (see OECD 2023). The US is one of the countries that makes very detailed data publicly available. At the same time, the US is one of the leading countries as regards semiconductor production.

in military or automotive applications compared to consumer electronics goods (US White House 2021). End use and application specificity also affect the degree of competition in the design stage (US White House 2021). The less specific that designs are to the application, the higher the competition among design suppliers. Major players in the design stage, notably Nvidia, Qualcomm, and Arm, are or belong to corporations headquartered in the US, Korea, and Japan. However, the workforce might be located elsewhere. Due to a lack of granular services trade data, little is known about dependencies in the design value chain, and we exclude design from our subsequent analysis.

In the second step, the **manufacturing stage**, the designs are sent to production sites. Foundries like TSMC and GlobalFoundries are contract manufacturers producing for third parties only. In the case of so-called integrated device manufacturers (IDM), e.g., Intel, the design is passed on in-house. The designs are mapped onto what are known as wafers, typically made of the purest silicon, using a process involving lithography and etching. The electronic properties of the silicon are then modified in a process called “doping” (Varas *et al*. 2021). Key inputs are the raw materials (specialized chemicals), highly sophisticated machinery, vast amounts of energy and water for cooling, and high-skilled labor. Entry costs in leading-edge production are high due to the high capital expenditures required to install equipment, reaching multiple billions of USD.

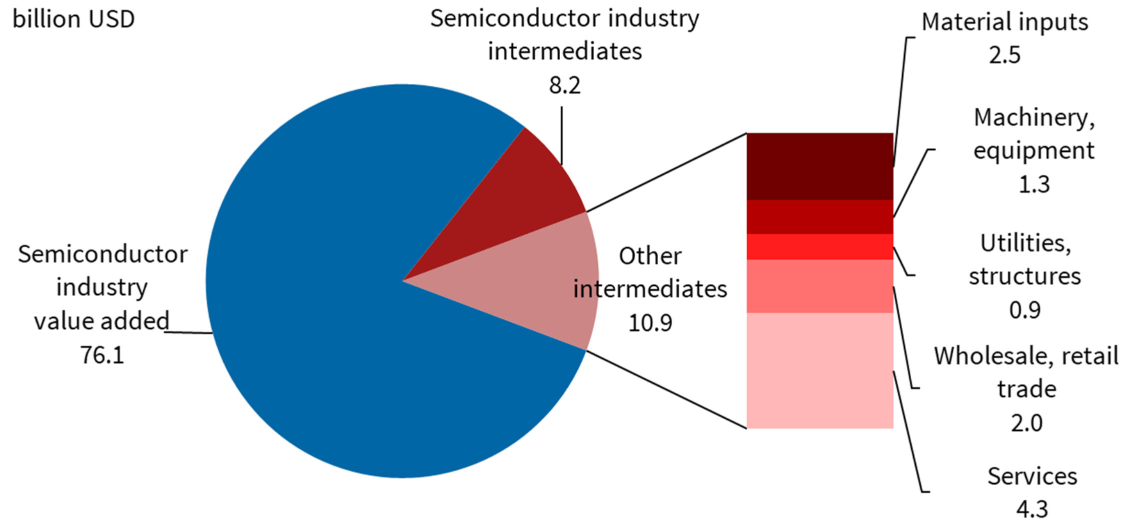
In the third step, the **assembly, testing, and packaging (ATP) stage**, the wafers are sawn into unpackaged (bare) chips, known as “dies.” To benefit from the advantage of producing a large set of chips in parallel on one wafer, the dicing of the wafer is put to the final stage of chip production. The dies are then interconnected with wires to form printed circuit boards and packaged for protection from environmental impacts in the future. These final chips undergo rigorous testing procedures for their functionality and durability. The ATP process is generally highly automated and requires relatively low-skilled labor, which made it the first step to be outsourced in the production chain (US White House, 2021). Yet, the miniaturization trend requires R&D for advanced packaging methods such as stacking chips, interconnection materials, and improved equipment (TU Dresden 2025). Notably, the stacking of chips provides a complementary avenue for shrinking the size of the chips to increase the density of transistors.

Finally, to bring all inputs together, semiconductor production relies on highly specialized trade as well as transport and logistics companies. However, due to a lack of granular services data, this part of the value chain is hardly scrutinized. Still, further calculations based on the US input-output data used above suggest these services account for about one-fifth of total intermediate inputs from outside the semiconductor industry.

Figure 2 summarizes these broad production stages by decomposing the value added directly embedded in the output of the US semiconductor industry.[4] Semiconductor manufacturing relies heavily on its own output, as semiconductors are a key component for semiconductor manufacturing equipment. However, 20 percent of the value added comes from intermediates. Notable examples of material inputs are metals such as silicon, germanium, and gallium arsenide. In addition, a large set of different process chemicals are required to manufacture semiconductors. These materials are typically used in the manufacturing process and do not remain in the final chips (American Chemistry Council 2024). Within the services part, it is primarily IT and computer design services as well as professional services such as research and development, but also transport and logistics services that are important for semiconductor production (Figure 2).

Figure 2: Decomposition of Inputs Used in Semiconductor Production

In value added terms, USA 2022



Source: Bureau of Economic Analysis; calculations by the ifo Institute.

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[4] For a more detailed description of the data and method used in this analysis, see the appendix.

While semiconductor production can be summarized into these three broad stages, in reality it is rather characterized by a very complex global value chain. This is mainly linked to three factors: First, each of the three stages relies on its own specific set of (material) inputs, equipment, and services, which have their own complex value chain. Second, the detailed economic forces binding the different production stages together can differ strongly between chip types. Third, the semiconductor industry has developed into a highly globalized industry, characterized by multiple interdependencies. This complexity of the semiconductor value chain highlights the importance of a nuanced debate when designing industrial and trade policies. For this aim, a better understanding of these complexities and interdependencies along the global supply chain is necessary.

4 The Global Chip Economy

We leverage bilateral trade data from CEPII (Gaulier and Zigango 2010) to analyze the global linkages in the semiconductor industry. We identify 72 semiconductor-related 6-digit products in the 2022 Harmonized System classification building on OECD (2023) and UK DSIT (2024), Li et al. (2025). We distinguish 16 material inputs such as raw materials, chemicals, and wafers from 29 goods in equipment and 27 final chips.[5] While the trade data distinguish between chip types and equipment for different production stages, we cannot zoom in on within-chip type or within-equipment versions (e.g., distinguishing CPUs from GPUs)[6]. Thus, export shares tend to understate the concentration of exports in very narrowly defined goods. Trade data also does not capture domestic absorption of production, *i.e.,* sales of a Chinese chipmaker to a Chinese smartphone maker. Nonetheless, compared to production capacity data or company financials, trade data has the advantage of recording the global location of both supply and demand for a granular set of goods. It is thus ideally suited for the analysis of global production linkages.

Semiconductor production is highly globalized. 70 countries participated in semiconductor-related trade in 2022.[7] Globally, semiconductor trade amounts to USD 1.2 trillion. For comparison, global oil and gas exports account for USD 3.3 trillion of global trade. Overall, integrated circuits rank third in terms of global trade volume. Figure 3 decomposes global 2022 trade in semiconductor-related goods into the products' shares. The figure shows a product's share of total semiconductor

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[5] We provide a full list of semiconductor-related goods considered in this study in the appendix.

[6] European trade data has a higher level of granularity but covers only trade involving European countries, limiting its usefulness for the purpose of this study.

[7] We impose a minimum threshold of 1 percent global exports (imports) by product for data cleaning purposes.

exports for final chips in red, for equipment in blue, and for material inputs in yellow. The larger the box, the larger the export share of this particular item in global semiconductor-related trade. Within each of the three categories, darker areas indicate a higher Herfindahl-Hirschman index (HHI), which means that a smaller number of exporters account for a larger share of global product exports.

Comparing the three categories with each other, final chips make up the lion's share of global semiconductor-related trade, and within final chips, logic and memory chips are the biggest categories. The second most important category is equipment, where dedicated semiconductor machinery stands out as the largest group. The boxes for equipment tend to be more equally sized compared to the ones for final chips, which shows the range of products needed to produce chips. Finally, the most important group within the export category "material inputs" are wafers.

To some degree, it is not surprising that the more downstream products, machinery and final chips, make up the highest trade shares as they embody the value of their inputs, a caveat when using (gross) trade compared to value added data.

Figure 3 also presents the products' export HHI. The index summarizes the degree of export concentration on supplier countries: the higher the value, the more concentrated the market. At maximum concentration, i.e., in the case of a monopoly, the HHI would be equal to 1; the more suppliers in a market, the closer the HHI is to 0. Exports of photographic plates are the most concentrated, with an HHI of 0.4. In total, nine countries export photographic plates, but Japan alone has a market share of more than 60 percent of world sales. Printed circuit boards are the most concentrated in the final chip category, followed by memory chips. Another good supplied by very few countries is the pure silicon of the input category.[8] Least concentrated are resistors, with an HHI of 0.06. Resistors are exported by 20 countries, with the biggest exporter, China, accounting for 13 percent of global exports. Across all goods, the largest two exporters typically make up 46 percent of global trade per good while the largest two importers account for 37 percent on average.

These numbers show an extreme geographic concentration of much of the semiconductor industry. That concentration reflects the importance of comparative advantage thanks to technology, skill, and capital for producing these very complex goods. The concentration also points to the importance of economies of scale in production: companies need to generate sufficient revenues to operate profitably due to the high fixed costs of setting up and maintaining a production site. These

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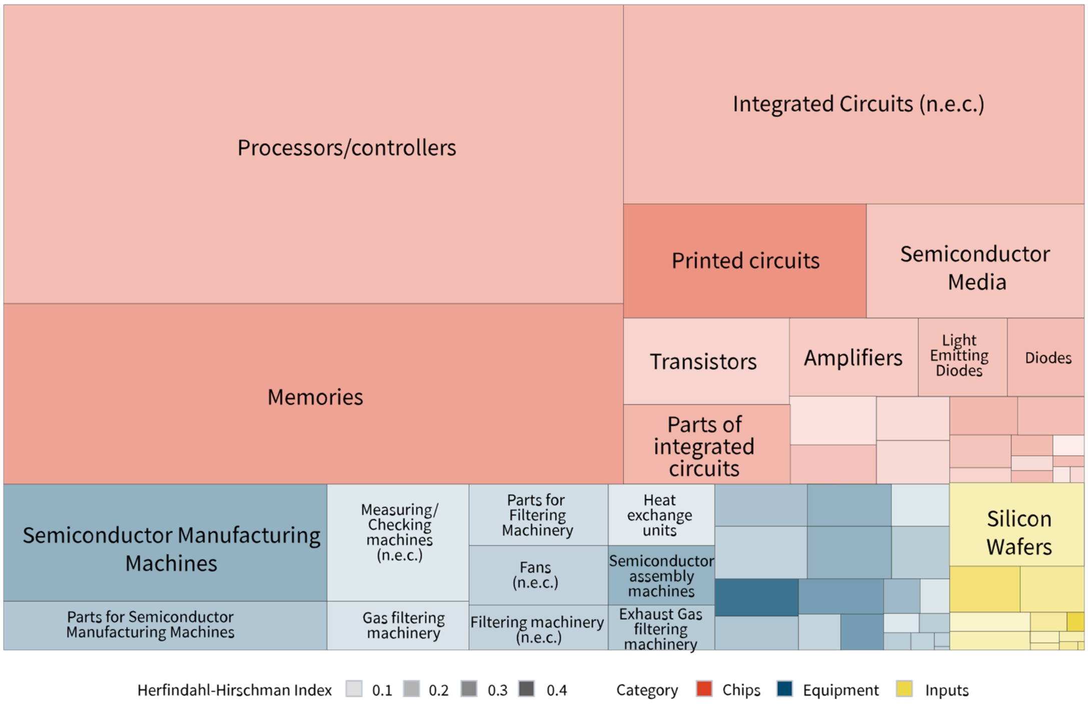
[8] See, for instance, Lippelt et al. (2021) for the importance and implications of a highly concentrated supply of silicon.

factors make market entry difficult for new players and lead to consolidation of existing players.

Figure 3: Product Share and Concentration in Global Semiconductor Trade

Global Product Export Shares for Chips/Equipment/Inputs



Note: The figure shows a product's share of total semiconductor exports in 2022 for final chips (red), equipment (blue), and inputs (yellow). Darker areas indicate a higher Herfindahl-Hirschman index, which means that a smaller number of exporters account for a larger share of global product exports. Source: CEPII BACI, authors' calculations.

Zooming in on final chips,[9] we find that exports are dominated by few countries. Figure 4 shows the export shares of the nine largest chip exporters, along with a "rest of the world" group, between 2002 and 2022. Korea, Taiwan, and China account for nearly half of all chip exports. The figure clearly shows that much of the shift toward Asia, notably China's gain in export shares, occurred back in the 2000s. Korea has expanded notably since the early 2010s. Germany is the biggest EU exporter of chips, accounting for about one-third of all chips sold by an EU economy. Ireland and France rank second and third among EU countries, accounting for another third of EU sales approximately.

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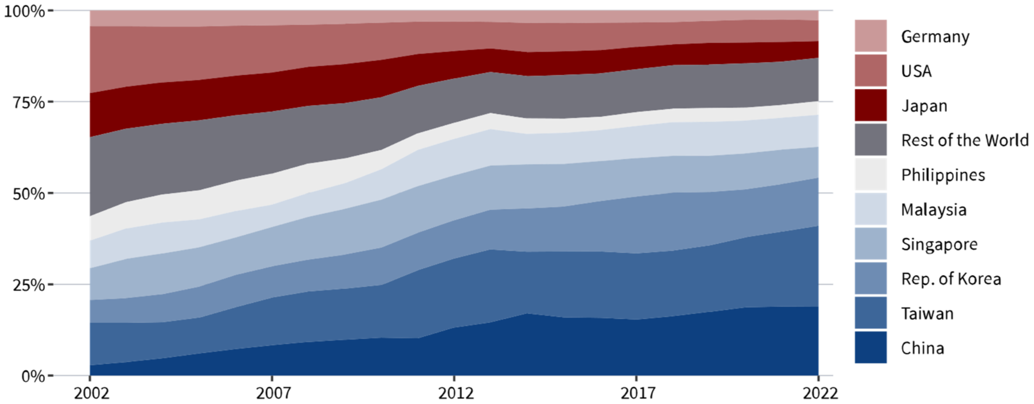
[9] Chips here refer to products under categories HS 8541 and HS 8542: integrated circuits, power and optical semiconductors.

Figure 4: Country Distribution of Semiconductor Exports Over Time

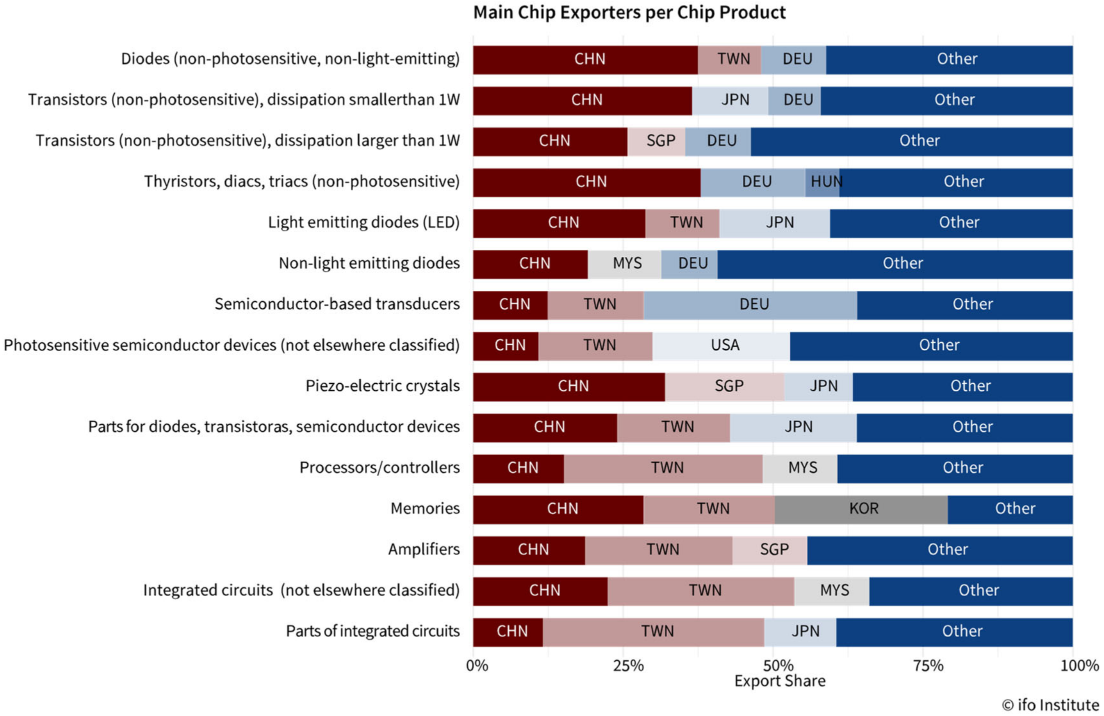
Export Shares of Main Semiconductor Producers



Note: The figure shows export shares in final chips (HS 8541 and HS 8542) between 2002 and 2022. To account for misreporting between years, we plot a 3-year moving average.
Source: CEPII BACI, authors' calculations.

Looking in more detail at the country distribution by individual product groups, Figure 5 further emphasizes the importance of Taiwan and China in semiconductor trade: these two countries are the top two exporters in all integrated circuit types except for memory chips, where Korea is leading. The Sino-Taiwanese dominance is contested by the US, Germany, and Japan, however, in power and optical semiconductors as well as in sensors. The latter point highlights how an analysis of semiconductors at a disaggregated level can provide important additional insights for the debate about dependencies and vulnerabilities.

Figure 5: Country Distribution in Chip Exports by Product Groups



Note: The figure shows export shares in final chips (HS 8541 and HS 8542) in 2022.
Source: CEPII BACI, authors' calculations.

5 Dependencies Along the Fragmented Chip Chain

A broader view including the upstream supply chain shows furthermore that semiconductor production is geographically rather fragmented. Japan and the US are the major upstream players at an aggregate level. The more upstream (toward initial stages of the value chain) the analysis extends, the more countries contribute to chip production, for instance by providing parts to the production of machinery. According to Figure 3, "parts of semiconductor machinery" is the second most traded good in the equipment category, a first indication for the fragmentation of the global semiconductor value chain.

One of the key pioneering events for the global fragmentation of chip production was the opening of TSMC in Taiwan in the late 1980s, a foundry that manufactures semiconductors for third parties. Taiwan's relatively lower labor costs offered a comparative advantage in the manufacturing stage. Yet, a lack of high-skilled designers (at the time) prevented entry using the IDM business model (Gilbert and Rosenthal 2021). This skill composition necessitated a new business model. The development was facilitated by the subsidies from the Taiwanese government, as had been the case previously in Japan and Korea (Bown and Wang 2024). The increasing specialization was aided further by the 1997 Information Technology Agreement, an agreement on reducing tariffs to zero for a wide range of high-tech goods including semiconductors, as well as the TRIPS (Trade Related Aspects of Intellectual Property Rights) Agreement of 1995. The protection of intellectual property rights decreased the risk of licensing designs to foundries (Bown and Wang 2024).[10] The specialization in different production steps decreased costs and facilitated innovation (Varas *et al*. 2021).

The flip side of the rewards of specialization is the risk of supply chain disruption. Earthquakes, storms, droughts, power outages, and fires caused semiconductor shortages between 2020 and 2021 alone (Hess and Kleinhans 2021). These had a significant impact, for instance, on the automotive industry, leading to furlough for workers and increasing delivery time for customers in the US and Germany (Grossman 2021; Arnold and Miller 2021 – see Bown and Wang 2024). Possibly the most forceful driver behind the increasing activism of governments, however, are geopolitical tensions involving China and Taiwan as well as China and the US. The concern is that dependencies on political adversaries' output can be abused for economic coercion.

Yet, because of the global fragmentation of the value chain, international dependencies are not unilateral. Figure 6 illustrates this point, showing the net trade share for a country pair. The columns refer to an exporting country, the rows to the destination partner country. Tiles are colored in shades of blue if the exporter has a trade surplus with the importer and in shades of red if the exporter has a trade deficit with the importer. The darker the shades, the higher the trade surplus/deficit. The matrix is symmetrical and structured like a mirror image along the diagonal. We constrain the set of countries included to countries that are a top three exporter of a product making up at least 1 percent of global semiconductor trade.

The three top chip exporters – Korea, Taiwan, and China – have trade deficits with the Netherlands, Japan, and the US, as the block of red tiles in the upper right part of the figure immediately reveals. Japan has a trade surplus with each of the major exporters, save for the Netherlands. This is reflected in the column for Japan with blue tiles for almost every importer country. The Netherlands has the biggest trade surplus with Taiwan, in line with the anecdotal evidence of the ASML-TSMC business partnership. The Dutch trade deficit with Germany points to the supply chain for

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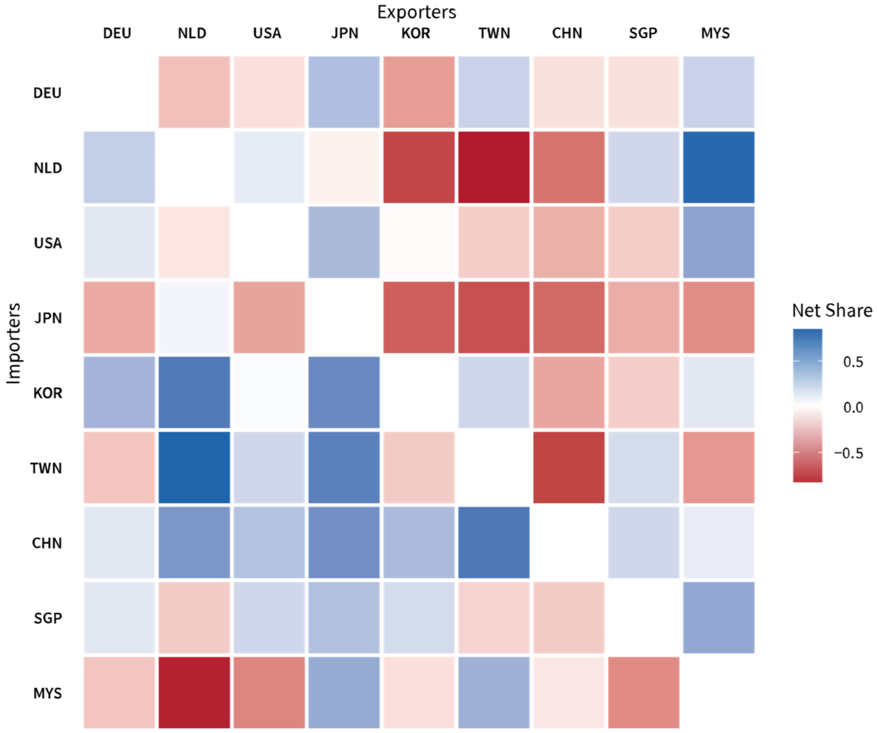
[10] The Biden- administration invoked violations of intellectual property rights by China as a justification for tariffs of up to 50 percent on semiconductors in 2024 (USTR 2024).

semiconductor equipment, while Taiwan's trade surplus with China points downstream to the end users of semiconductors.

Figure 6: Trade Balance Between the Main Semiconductor Producers

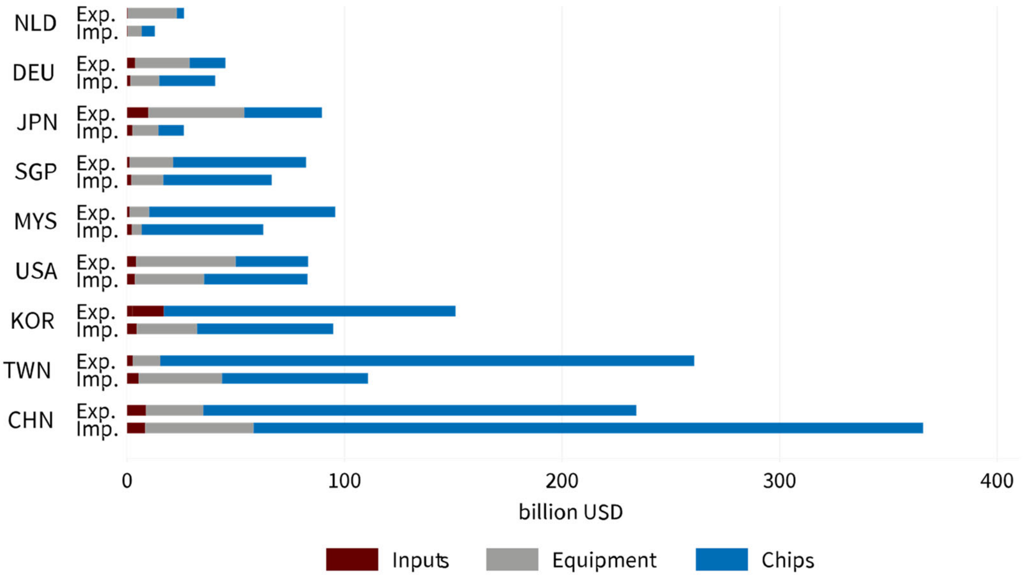


Note: The figure shows the net exports as a share of total bilateral trade between the core semiconductor countries (net share = (exports-imports)/(exports + imports)). For example, the top right light blue tile indicates a small trade surplus in semiconductor products of Malaysia with Germany. The countries are selected as the top 3 exporters in goods comprising at least 1 percent of total semiconductor trade.

Source: CEPII BACI, authors' calculations.

The bilateral trade balances reflect the position of the various countries along the value chain. Figure 7 shows a decomposition of the nine core countries' exports and imports by product category. As noted above, China, Taiwan, and Korea account for the bulk of final chip trade. All three countries run trade deficits in inputs and equipment, however. China is the only country with an overall trade deficit due to its enormous chip imports. The trade imbalance is most pronounced for logic chips, of which China, the second largest exporter, sells 14 percent while it imports about 40 percent. In contrast, China exports 35 percent of "thyristors, diacs, and triacs" while it imports only 8 percent of these. Moving up the chart, the figure reveals the US and Japan as the major equipment suppliers. For the US, trade in semiconductor-related goods is nearly balanced thanks to its substantial equipment exports. These outbalance the small trade deficit in final chips. Japan has the biggest trade surplus in equipment. The Netherlands appears in the list of core countries primarily due to its supply of equipment.

Figure 7: Composition of Exports and Imports of Core Semiconductor Exporters



Note: Total imports/exports by country and category in 2022.
Source: CEPII BACI, authors' calculations.

6 Open Questions for Effective Policies

The high concentration of final chips exports in East Asia is perceived as a threat to technological sovereignty by governments globally. As Figure 8 shows, semiconductors have been targeted disproportionately by a combination of industrial and trade policies since 2020. The US is the country that imposed the most distorting interventions in 2023, according to data from the Global Trade Alert Database. But other major semiconductor economies like the EU and Korea are also highly activist. The exceptions are Taiwan, Singapore, and Malaysia. Among our core countries, exports in these three are most dependent on semiconductor-related goods. Semiconductor-related goods reach shares as high as 57 percent (Taiwan), 30 percent (Singapore), and 26 percent (Malaysia) of total exports.[11]

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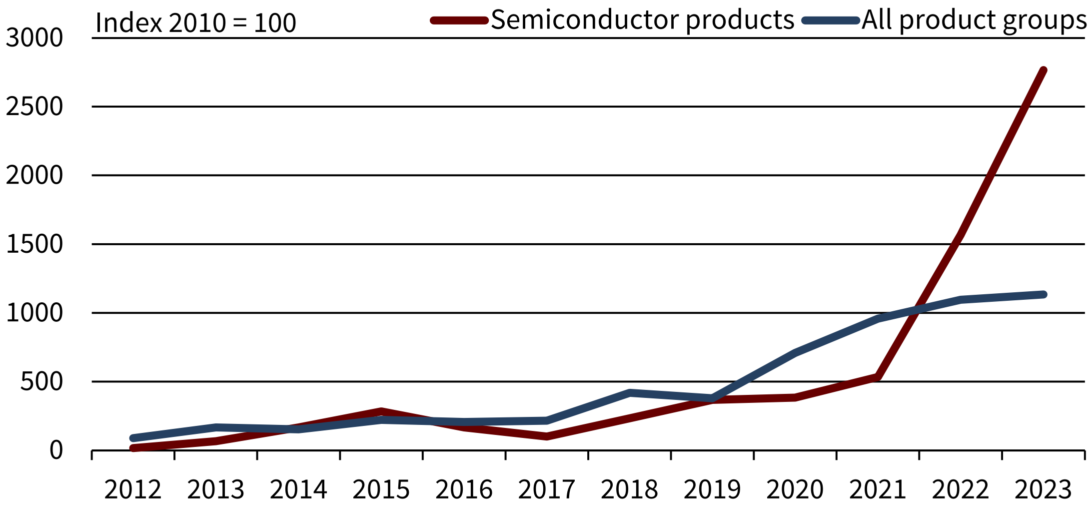
[11] For detailed analyses of the industrial and trade policies implemented see OECD (2019), Goldberg et al. (2024), Bown and Wang (2024), Hufbauer and Hogan 2025. Notably Goldberg et al. (2024) point out and address the difficulties in assessing Chinese government interventions which are likely understated in the Global Trade Alerts Database.

Figure 8: Policy Interventions Distorting Trade

Panel A: Number of Policies Targeting Semiconductors vs. All Products Over Time



Source: Global Trade Alert; reporting lag adjusted.

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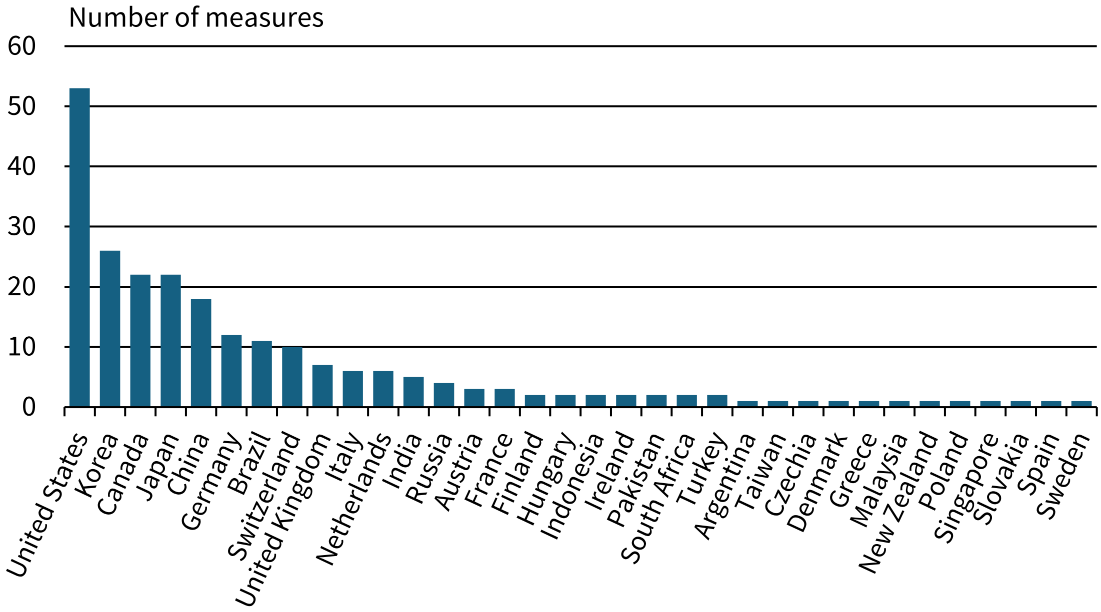
Panel B: Policies Targeting Semiconductors by Implementing Country 2023



Source: New Industrial Policy Observatory (NIPO).

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The intention behind the government interventions is to lure production “back home,” with initial results now visible. This should strengthen an economy’s competitiveness, protect its supply chains from disruption, and insure the country against geopolitically motivated coercion. The policies are indeed justifiable by market failures. For instance, private companies do not internalize the negative externalities on the wider economy of supply chain disruptions, nor do they consider the positive productivity and knowledge spillovers of their investments to the local economy (Baldwin and Freeman 2022; Elliot et al. 2022; Juhasz and Lane 2024; Goldberg et al. 2024). Policymakers need to trade off these considerations against the costs of diversifying global semiconductor production, including forgone economies of scale.

However, a nuanced approach is warranted in the pursuit of technological sovereignty and strategic competitiveness for three reasons:

First, assessing vulnerabilities is complicated (Baldwin and Freeman 2022; Mejean and Rousseaux 2023). Our analyses make clear that dependencies are two-sided. High import shares of final chips from one country do not necessarily imply a low bargaining power vis-à-vis that country. If the importing country is also an exporter and supplies inputs for final chip production, bargaining power is shared. Moreover, trade data can only hint at the indirect dependence on upstream countries. For instance, if China imports Taiwanese chips produced with Dutch machinery, China depends to some degree on the Netherlands. Dependence is also not only a supply-side problem. Concentrating demand endows bargaining power, too. As policymakers seek to move the power balance in their favor, a better understanding of the determinants of bargaining power at each step along the value chain is needed. Such analysis should take the heterogeneity of chips and their economic idiosyncrasies into account.

Second, while governments aim to strengthen their economy's competitiveness and to create high-paying jobs that have positive spillover effects to the rest of the economy, it is not self-evident where to start and how to achieve technological leadership. Take the example of innovation: the chip node size, determining the number of transistors edged on a chip, has received much public attention as “the’’ innovation frontier – so much so, in fact, that node size has lost its technological meaning and become a marketing term (The Economist 2024). Yet, innovation matters not only in the manufacturing stage. Innovations in packaging can substitute for innovations in node size to achieve more power on a smaller surface (US White House 2021). Nor is size the first-order concern for all applications. Instead, durability and resilience to extreme temperatures matter more in defense equipment, cars, and machinery (US White House 2021; Bown and Wang 2024), making material innovation more urgent. None of the designs of ever-smaller node size can be manufactured without innovation in equipment such as lithography machinery. As ever with industrial policies, “picking winners” is no easy job.

Third, building a viable semiconductor industry means in part overcoming entry barriers. Yet, these barriers are not well defined. Prominently discussed are the enormous amounts of investment needed to build a semiconductor production site.

However, how investment costs vary across chips, or which role the financial sector plays in financing investments, has received scant attention so far. An often-quoted entry barrier is the need for a semiconductor “ecosystem.” Kleinhans (2021), for instance, argues that the lack of chip designers in Europe prevents the profitability of European chipmaking because of lock-in effects between designers and foundries. Production settings, the argument goes, are tailored to one design. Design companies have no incentive to switch foundries, since months pass until product validation is successful and yield rates are economically viable due to the complexity of the process. Does this argument apply to every chip type? After all, technology evolves quickly, especially for chips used in fast-changing consumer goods like smartphones. Open questions like these make it difficult to define the scope of government interventions needed to build a semiconductor industry.

7 Conclusion

Semiconductors are tiny but their importance for individual economies can hardly be overerestimated. Semiconductor production involves a highly geographically fragmented value chain with several international forward and backward linkages. A first sketch of such linkages has been illustrated by this study leveraging granular trade data. Going forward, the rewards from cost savings thanks to international specialization must be weighed against the risks arising from dependencies. The complexity of the semiconductor value chain and the complexity of different types of semiconductors summarized in this study highlight the importance of a more nuanced debate when designing policies to reduce dependencies.

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Appendix

Data and Method Used for Measuring Production and Use of Semiconductors

Using data on input-output linkages allows us to measure how specific goods and services feed through the value chain up to (final) demand for other goods and services. In the sense of the so-called Leontief model of backward linkages, this means we analyze how much production from industry *i* is required to meet final demand, i.e., consumption, investment, and export demand, for goods or services from another industry *k*.

Thereby, the model not only takes into account that industry *k* may directly purchase inputs from industry *i*, but also that industry *k* may purchase inputs from another industry *j*, which – in turn – had used inputs from industry *i* before or provided intermediate trade or transport services for it. In addition to the direct (first level) linkages between industry *i* and *k* (purchases of intermediate inputs of industry *i* by industry *k*), there are hence also indirect (second level) linkages along the entire value chain (e.g., from industry *i* to industry *k* via industry *j*).

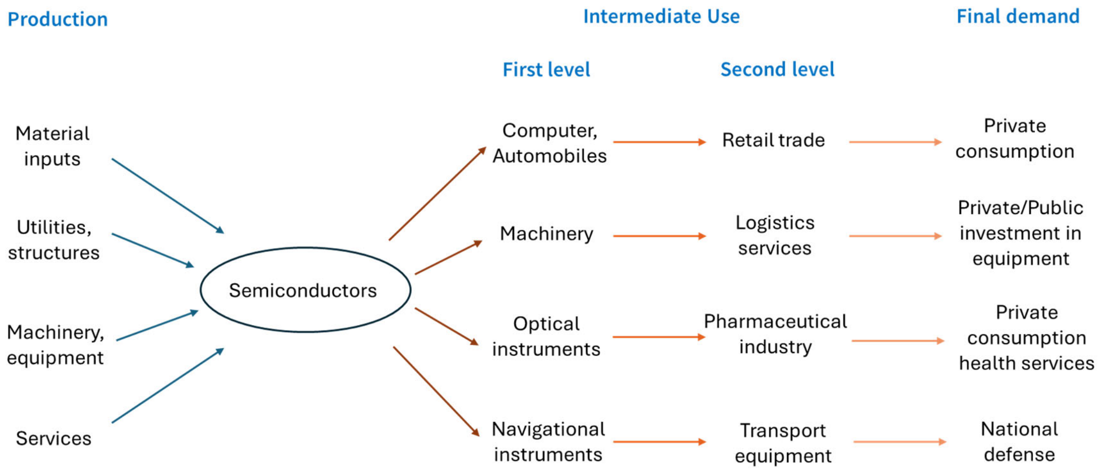
For the analysis at hand, we look at the role of semiconductors in the value chain from two perspectives (Figure A1). We ask

a) which inputs are used to produce semiconductors (production, direct effects),
b) how semiconductors feed through the value chain being embedded as input in the production of other goods and services (use, direct and indirect effects).

It is important to note, though, that semiconductors are located very much upstream in the value chain. In other words, semiconductors are almost solely used as inputs in the production of other goods; they are not directly consumed by private households nor are they directly used as investment goods. Hence, when analyzing the production side of semiconductors, we limit ourselves to the direct production effects as shown in Figure A1.

Being located very upstream implies, though, that semiconductors affect the value chain at several stages. Examples of such different channels are given in Figure A1. Hence, for the second question, the use side of semiconductors, we apply the Leontief model: we start from (final) demand for goods and services and go – so to say – backward to see how many semiconductors are required to meet this demand for these different goods and services.[12]

Figure A1: Schematic Illustration of the Semiconductor Value Chain



Source: ifo Institute

Finally, in order to trace back the exact role of one particular industry for other goods or services, we want to measure the value added that this particular industry contributes. Hence, in the analysis at hand, the intermediate input flows are weighted with the share of value added in gross output of the input producing industry to achieve the industry contributions in value-added terms as presented in Figures 1 and 2 above.

For this analysis, we use data for the input-output accounts for the United States from the US Bureau of Economic Analysis (BEA 2024a). There is detailed data available for 134 industries and/or commodities following the 4-digit level of the North American Industry Classification System (NAICS). The advantage of this detailed breakdown is that it provides information on the semiconductor industry as a separate unit. The most recent data available and used in this analysis is for the year 2022.

We make one main adjustment, though. This is linked to the particular nature of the semiconductor industry as described above: semiconductor production draws heavily on software design, research, and development as well as computer services. However, since the introduction of the 2008 System of National Accounts, R&D expenditures and computer software are no longer considered as intermediate inputs but as investment assets (Intellectual Property Rights) (UNSD 2009). As a

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[12] In the input-output data used, exports are considered as “final” demand, even though they may be used as inputs for production in the importing country.

consequence, a large part of the output of these services is attributed to the final demand vector of the use table and the input-output table, respectively. Hence, these services would show up only to a very small extent, if at all, as inputs in semiconductor production if measured based on input-output tables.

To reflect the role of these knowledge-intensive services for semiconductor production, we have reattributed a part of their output as intermediate inputs in the sense of license or royalty payments. To this end, we have made two assumptions with respect to a) the part of IPR to be reattributed and b) the rule with which these amounts are attributed to the individual industries:

- Regarding the first assumption, we take the so-called 25 percent rule as a proxy: for licensing agreements it is often suggested that the licensee pay a royalty rate equivalent to 25 percent of its expected profits for the product that incorporates the IP at issue (Goldscheider et al. 2018).
- Regarding the second assumption, we consider that more technology-intensive industries also tend to acquire more IPR licenses. Technological intensity can, in turn, be proxied by R&D intensity per industry. For this, data on private expenditures in R&D by industry is publicly available for the US at the same aggregation level as the supply-use tables (BEA 2024b).

List of Material Inputs, Equipment, and Final Chip Products Used in the Analysis

Table A1: Harmonized System Codes for Material Inputs

HS Code	HS Product
280429	Rare gases[3]
280461	Silicon (>= 99.99% GHT)[1,3]
280490	Selenium[3]
282560	Germanium[1]
284920	Carbides[1]
370130	Photographic plates and film[1]
370199	Photographic plates and film (non-color photography)[1]
370710	Photographic goods; sensitized emulsions[3]
370790	Photographic goods (not elsewhere classified)[1]
381800	Silicon wafers[,3]
811231	Hafnium (unwrought)[1]
811239	Hafnium (wrought)[1]
811241	Rhenium (unwrought)[1]
811249	Rhenium (wrought)[1]
811292	Gallium (unwrought)[1]
811299	Gallium (wrought)[1]

Source: Product codes from [1] OECD (2019), [2] UK DSIT (2024), and [3] Li et al. (2025).

Table A2: Harmonized System Codes for Machinery and Equipment

HS Code	HS Product
841470	Gas-tight biological safety cabinets[1]
841950	Heat exchange units[1]
842129	Filtering/purifying machinery (not elsewhere classified)[1]
842132	Gas filtering/purifying machinery for exhaust gases from internal combustion engines[1]
842139	Gas filtering/purifying machinery[1]
842199	Parts for filtering/purifying machinery[1]
844319	Printing machinery (not elsewhere classified)[2]
844391	Printing machinery (parts/accessories)[2]
845611	Laser-operated machine tools[2]
848610	Semiconductor boules/wafers manufacturing machines[1,2,3]
848620	Semiconductor devices/integrated circuits manufacturing machines[1,2,3]
848640	Semiconductor assembly machines[1,3]
848690	Semiconductor manufacturing machines (parts and accessories)[1,2,3]
900120	Optical elements; polarizing material[1,3]
900190	Optical elements; lenses, prisms, mirrors (unmounted)[1,3]
900219	Objective lenses, mounted[1]
900220	Filters; mounted for instruments[1,3]
900290	Mounted optical elements (not elsewhere classified)[1,3]
901110	Stereoscopic compound microscopes[2]
901120	Photomicrography compound microscopes[2]
901190	Compound microscopes (parts/accessories)[2]
901210	Diffraction appartus[1,2]
901290	Diffraction apparatus (parts and accessories)[1,2]
903082	Instruments for measuring semiconductor wafers/devices[1,2,3]
903090	Radiation measurement instruments[2]
903141	Optical instruments for inspecting semiconductor devices[1,2,3]
903180	Measuring/checking instruments (not elsewhere classified)[2]
903190	Measuring/checking instruments (parts/accessories)[2]

Source: Product codes from [1] OECD (2019), [2] UK DSIT (2024), and [3] Li et al. (2025).

Table A3: Harmonized System Codes for Chip Products

HS Code	**HS Product**
852351	Semiconductor media; non-volatile storage devices[1,3]
852352	Semiconductor media; smart cards[1,3]
852359	Semiconductor media; other than smart cards[1,3]
853290	Electrical capacitors[1,3]
853310	Fixed carbon/composition/film resistors[1,3]
853321	Fixed resistors; power smaller than 20W[1,3]
853329	Fixed resistors; power larger than 20W[1,3]
853331	Wirewound variable resistors; power smaller than 20W[1,3]
853339	Wirewound variable resistors; power larger than 20W[1,3]
853340	Variable resistors[1,3]
853390	Resistor parts[1,3]
853400	Printed circuits[1,3]
854110	Diodes (non-photosensitive, non-light-emitting)[2,3]
854121	Transistors (non-photosensitive), dissipation smaller than 1W[2,3]
854129	Transistors (non-photosensitive), dissipation larger than 1W[2,3]
854130	Thyristors, diacs, triacs (non-photosensitive)[2,3]
854141	Light emitting diodes (LED)[2]
854149	Non-light emitting diodes[2]
854151	Semiconductor-based transducers[2]
854159	Photosensitive semiconductor devices (not elsewhere classified)[2]
854160	Piezo-electric crystals[2]
854190	Parts for diodes, transistors, semiconductor devices[2]
854231	Processors/controllers[1,3]
854232	Memories[1,3]
854233	Amplifiers[1,3]
854239	Integrated circuits, not elsewhere classified[1,3]
854290	Parts of integrated circuits[1,3]

Source: Product codes from [1] OECD (2019), [2] UK DSIT (2024), and [3] Li et al. (2025).

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