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On the Restructuring of Global Semiconductor Supply Chains

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Abstract

This paper provides an overview of the ongoing restructuring of global semiconductor supply chains and investigates how long-term developments in competitiveness between trading countries as well as recent changes in trade policies have affected this restructuring. Using as an example the U.S. tariff hikes against China during 2018-19, which serves as a natural experiment, we first confirm that the stylized facts shown in previous studies—that China's exports to the U.S. decreased significantly, while bystander countries not directly involved in the tariff hikes increased their exports to the U.S.—hold true for semiconductor-related products. Then, to further examine the restructuring of global semiconductor supply chains, we calculate the upstreamness—the distance from final use—of each country's exports in the supply chain, and examine how this has evolved over time and how it can be related to wage differences between those countries. We find that export upstreamness is positively correlated with the wage gap between the trading countries and confirm that this tendency existed well before the recent tariff hikes. These observations imply that the restructuring of global semiconductor supply chains is not led solely by the direct consequences of the tariff hikes, but also by the endogenous response to changes in comparative advantage between the countries involved in the supply chain.

JEL classification: F13, F14

Keywords: Tariffs, Semiconductors, Global supply chains, Upstreamness.

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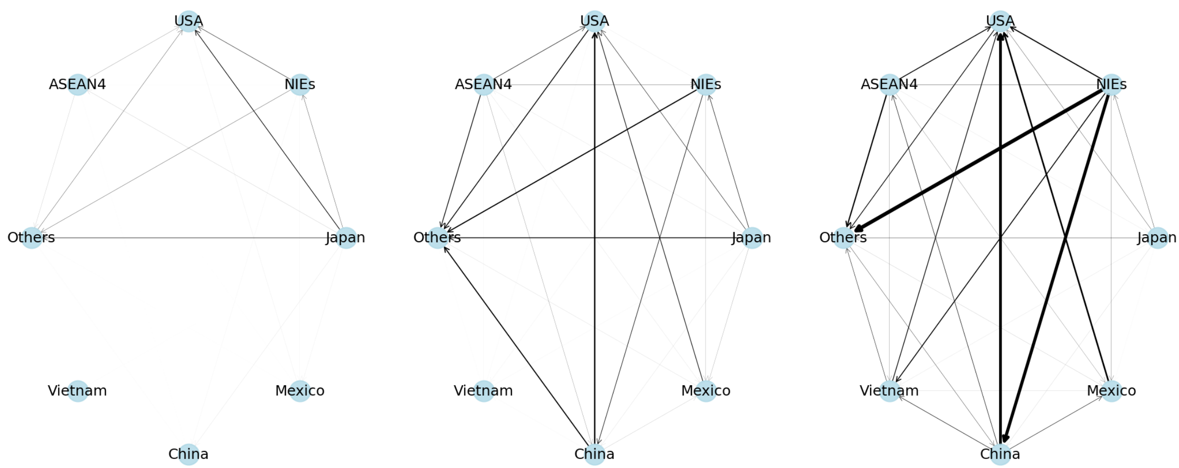
1 Introduction

The semiconductor industry is one of the industries that have benefited greatly from globalization. Over the past few decades, global supply chains for products that make extensive use of semiconductors have been constructed in a way that different countries specialize in different parts of the production process, with materials, intermediate parts, and final products being traded globally.

Figure 1 depicts how the global trade network of semiconductors and related products has developed over time. The nodes represent countries/regions, and the arrows indicate occurrence of trade, where the countries/regions at the origin of the arrows mark a positive amount of net exports against the countries/regions standing at the head of the arrows. We can confirm that the connectivity of the trade network has increased remarkably, meaning that the semiconductor industries in different countries/regions have become more and more dependent on each other. With regard to the composition of players, East Asian economies have come to play a crucial role in global semiconductor supply chains.

Figure 1. Trade network of semiconductor industry



(a) 1990 **(b)** 2006 **(c)** 2022

Source: UN Comtrade.

Notes: Arrows represent net exports, with their thickness proportional to the trade amount. NIEs represents Korea, Taiwan, and Singapore. ASEAN4 represents Indonesia, Malaysia, Thailand, and the Philippines.

Recent changes in trade policies are considered to mark a pivotal shift in this trend in the global division of labor in semiconductor-related industries. A series of recent tariff and non-tariff measures introduced by major economies is likely to affect not only trade between countries directly involved in these measures but also trade linked to bystander countries, due to effects arising from the input-output relationships between directly involved countries and bystanders.

One notable instance of such policy changes is the sequence of U.S. tariff hikes starting in 2018 against imports from China of a wide range of manufactured products, including semiconductor-related products. Besides former U.S. President Trump's desire to protect domestic industries and workers, the ultimate goal of these tariffs against technological products seems to have been to reduce the economic interdependence between the U.S. and China for national security reasons. As we will show in this paper, the result of the tariff hikes was a significant decline in China's exports of semiconductor-related products to the U.S.

The impact of the tariff hikes is not limited to trade between the two countries. Several recent studies indicate that trade reallocation from China to other bystander countries is taking place. However, it remains unclear whether the tariffs have actually reduced the dependence of the U.S. on supply chains linked to China, since China is increasing its presence in countries such as Vietnam and Mexico, who have increased exports to the U.S. significantly in recent years (Alfaro and Chor 2023). It might be the case that the pre-existing trend of globalization is still forceful enough to link the U.S. and China in an indirect manner, even though the tariffs themselves have forced a shift in trade flows within global supply chains.[1]

In this paper, we attempt to provide an assessment on how events associated with changes in trade policy have affected global supply chains, using U.S. tariff hikes during 2018-19 as an example, which serves as a natural experiment. In our analysis, we focus especially on the semiconductor industry for the following two reasons. First, as semiconductors have become essential for a broader range of industrial products, with many countries involved in their supply chains, understanding the dynamics of the supply chains and evaluating the costs and benefits of the changes in trade policies is crucial

[1] Qiu et al. 2023 find that while supply chains have recently lengthened especially for supplier-customer linkages from China to the U.S., this lengthening of supply chains has not so far reversed the long-running trend toward greater regional integration of trade in recent decades, especially in Asia.

from both an academic and a policy perspective. Second, since the consequences of policy changes could be uneven across countries, it is of great interest to Asian economies, which have recently become significant players in global semiconductor supply chains, how the restructuring of supply chains could either benefit or damage their economies.

We investigate the restructring of the semiconductor-related industry through the lens of international trade flows. We start our analysis by confirming that the stylized facts shown in previous studies—that the tariff hikes in 2018-19 did indeed reduce the reliance of the U.S. on direct imports from China, while other Asian economies such as Vietnam and Taiwan have increased their share of U.S. imports—hold true for semiconductor-related products. More specifically, Taiwan increased exports of products that were targeted by the tariff increase, whereas Vietnam increased exports of non-targeted products as well. These observations echo existing studies showing that bystander countries have benefited from the trade friction.

Then, we further examine shifts in product-by-product trade flows. We show that Taiwan, Vietnam and some other Asian economies have increased their share of U.S. imports for the same products that China lost its share of U.S. imports. We also show that Mexico gained a disproportional share of U.S. imports as China lost its share, taking advantage of its geographical proximity to the U.S. We then test whether these product-by-product substitutions away from China can be explained by bypassing trade through third countries. We find that the evidence is rather limited, both in terms of magnitude and the range of countries.

Nonetheless, we show that China has continued to increase its export of semiconductor-related products to the global market even after the U.S. tariff increase. To further investigate what has brought such resilience to China's exports and the shift in supply chains, we define and measure the upstreamness of each country's semiconductor-related exports in global supply chains. We also examine how each country's upstreamness has evolved over time. We find that China had been significantly increasing exports of upstream products to Vietnam and other neighboring Asian economies well before the introduction of the U.S. tariffs, while reducing its exports of downstream products. It is worth emphasizing that this trend has continued even after the tariff hikes. Furthermore, we find that the export upstreamness is positively correlated with the wage gap between trading countries—upstream products flow from higher-income countries into lower-income countries—and this tendency is especially strong between China and its neighboring Asian economies. These findings imply that the loss in efficiency from the tariff increase may not be as large as was initially anticipated, since the subsequent changes in the supply chains are not merely the result of the tariff hikes on U.S.-China bilateral trade, but also of the endogenous response to changes in comparative advantage between China and other countries.

Our study contributes to the literature from two distinct aspects. First, we extend the literature by assessing the impact of recent changes in trade policies on the shape of global supply chains. Many of the preceding studies examine the effect of trade friction on a specific country, mostly on the U.S. or each of the bystander countries. In contrast, we document how the flow of products has changed from a global viewpoint by concentrating on a specific industry and leveraging qualitative information on the detailed structure of its supply chains. We show that while the U.S. has shifted its import sources of downstream electronic products from China to other Asian economies, China remains connected to the global supply chain that leads to the U.S. by manufacturing and exporting upstream products to those Asian economies.

Second, we shed light on the underlying forces, other than the trade measures, that have affected supply chains from a longer-term perspective. While many existing studies focus on recent trade measures as the drivers of changes in supply chains, we empirically show that these changes are also likely to be driven by more general longer-term dynamics of the international division of labor, even in an era of drastic changes in trade policy. More specifically, we argue that changes in global semiconductor supply chains may also be a consequence of developments in wage differences and the resulting shift in manufacturers' global resource allocation strategies.

The rest of the paper is organized as follows. Section 2 provides a brief overview of the recent example of trade friction and the related literature. Section 3 analyzes how the recent tariff hikes by the U.S. on its imports from China has affected global trade patterns. Section 4 investigates the underlying forces that have prompted the restructuring of the global supply chains from a longer-term perspective. Section 5 concludes.

2 Overview of recent changes in trade policies and the related literature

In this paper, we take the U.S. tariff hikes against its imports from China during 2018-19 as an example of the recent changes in trade policies that have affected global semiconductor supply chains. Before proceeding to our regression analyses, we first provide a brief overview of the U.S. tariff hikes. Then we proceed to describe some stylized facts on international trade in semiconductor-related products, focusing on changes in trade patterns since the introduction of the tariff. In addition, as the tariff hikes have spurred a number of studies investigating the economic consequences of the trade measures, we also provide a quick review of the related literature.

2.1 A brief overview of the tariff increase between the U.S. and China

In this subsection, we first provide an outline of the tariff increase under the Trump administration, while delegating a more detailed discussion of the matter to exisiting studies.[2]

While there have been episodes of U.S. presidents introducing protectionist measures in their first terms, the breadth and force of the measures taken by the Trump administration was unprecedented (Amiti et al. 2019). Starting in 2018, the U.S. drastically raised tariffs on a number of products, with the aim of protecting domestic industries and workers. The series of tariff increases consisted of two different phases. In the first phase, the tariff was applied to almost all trading partners, while it was targeted at specific products (e.g. washing machines, solar panels, steel, and aluminum). In the second phase, however, the tariff increase was targeted solely at China, and was applied to a broader range of its products.

The second phase of the tariff increase, which is the central focus in our paper to identify the effect of trade measures on supply chains, has been implemented in four consecutive waves. In July 2018, the U.S. introduced a 25% tariff on approximately 800

[2] Bown 2021 provides a comprehensive description of the definitions, timing, and scale of the products subject to the tariff increases, and our outline relies heavily on his study.

items imported from China, which were of worth \$34 billion annually.[3] The list of items—currently known as "List 1"—included products such as robots and automobiles. China immediately responded to this tariff increase by imposing 25% tariffs on about 500 items imported from the U.S., worth \$34 billion annually.

The U.S continued to expand the target of the tariff increase. In August 2018, the U.S. imposed 25% tariffs on approximately 300 items worth \$16 billion annually, including semiconductors (List 2). In September 2018, 10% tariffs were imposed on about 5,700 items worth \$200 billion annually, including products such as furniture and electrical appliances (List 3). At this point, tariff rates had been increased on roughly half of the total imports from China.

The tariff increases by both the U.S. and China continued to escalate and entered a fourth wave in May 2019. The tariff rate for items in List 3 was raised from 10% to 25%, and the U.S. initiated the process of imposing tariffs on the remaining imports from China worth \$300 billion, which made the coverage of the tariff almost 100% of imports from China.[4] China responded against these U.S. tariff increases with countermeasures, raising tariff rates on approximately 70% of its imports from the U.S.

In January 2020, the situation finally started to moderate, and both the U.S. and China began to cut the tariff rates. For example, the U.S. reduced tariffs on products from China, such as consumer electronics and clothing, worth \$112 billion annually from 15% to 7.5%. China also reduced tariffs on products from the U.S. worth \$75 billion annually from 5-10% to 2.5-5%. While there are some exceptions, tariffs on many of the products from China have remained in place even after the transition to the Biden administration in 2021.[5]

[3] Figures for the amount of imports are as of 2018.

[4] For electronics, in addition to the tariff increase, the U.S. introduced measures to cut off business with Chinese companies in principle, such as the National Defense Authorization Act, which went into effect in August 2018. The act prohibited government agencies from using products from five Chinese companies, including Huawei and ZTE. In addition, a decision was made in May 2019 not to sell semiconductors or software to Huawei without government approval.

[5] Although the trade friction has intensified again since October 2022, we skip examining this episode since our data set does not cover sustained periods during which the impact of such measures would become evident. We note the fact that, since 2022, export controls have focused on advanced semiconductors and chipmaking equipment bound for China, and this has motivated our study to focus especially on the semiconductor industry.

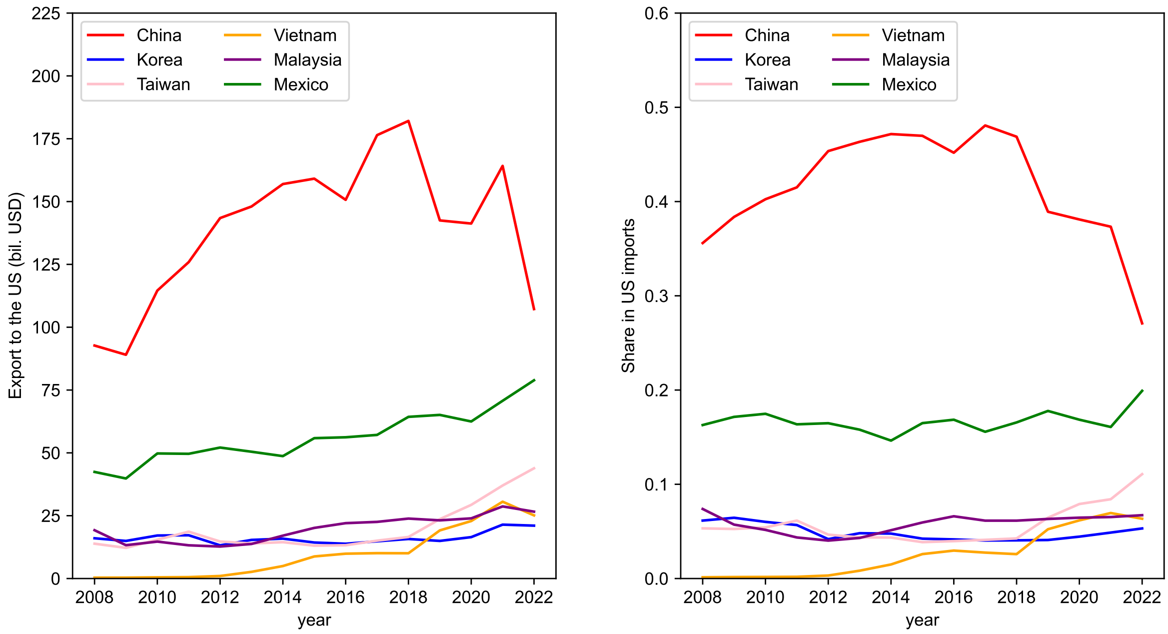
2.2 Stylized facts associated with the 2018-19 tariff hikes

In this subsection, we show some stylized facts on the global trade in semiconductor-related products, and we attempt to associate these facts with the consequences of the U.S.-China tariff episode.

First, as shown in Figure 2, an aggregation of U.S. imports of semiconductor-related products from various countries/regions reveals that the U.S. has significantly reduced its imports of semiconductor-related products from China after the tariff increase in 2018.[6] In contrast, U.S. imports from Asian economies such as Vietnam and Taiwan and near-shore countries such as Mexico have steadily increased. This implies that there were no significant negative effects on imports from non-targeted countries/regions, but rather, there were positive effects for such bystander countries/regions.

However, Figure 3 shows that China's overall exports of semiconductor-related products to the world has continued to increase, even though its exports to the U.S. have diminished considerably. The pace of the increase in China's exports since 2018 almost

Figure 2. U.S. imports of semiconductor-related products



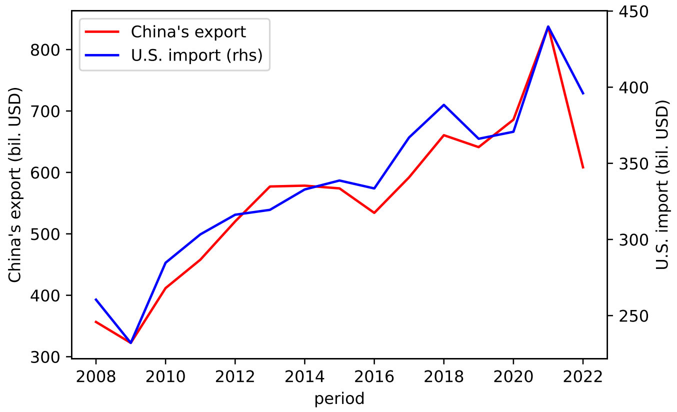
(a) Amount of U.S. imports

(b) Share of total U.S. imports

Source: UN Comtrade.

[6]This aggregation is calculated using product-by-product trade data derived from the UN Comtrade database. We will postpone our description on the details of the UN Comtrade database, which we will use throughout this paper, to Section 3.1.

Figure 3. Semiconductor-related products trade



Source: UN Comtrade.

matches that of U.S. imports. This indicates that China still plays the role of the world's major supplier of semiconductor-related products. Attributing this fact solely to bypassing activities by China to circumvent the tariffs may not be a plausible explanation, and researchers are prompted to examine a broader set of hypotheses to understand the restructuring of global semiconductor supply chains in response to the tariff hikes.

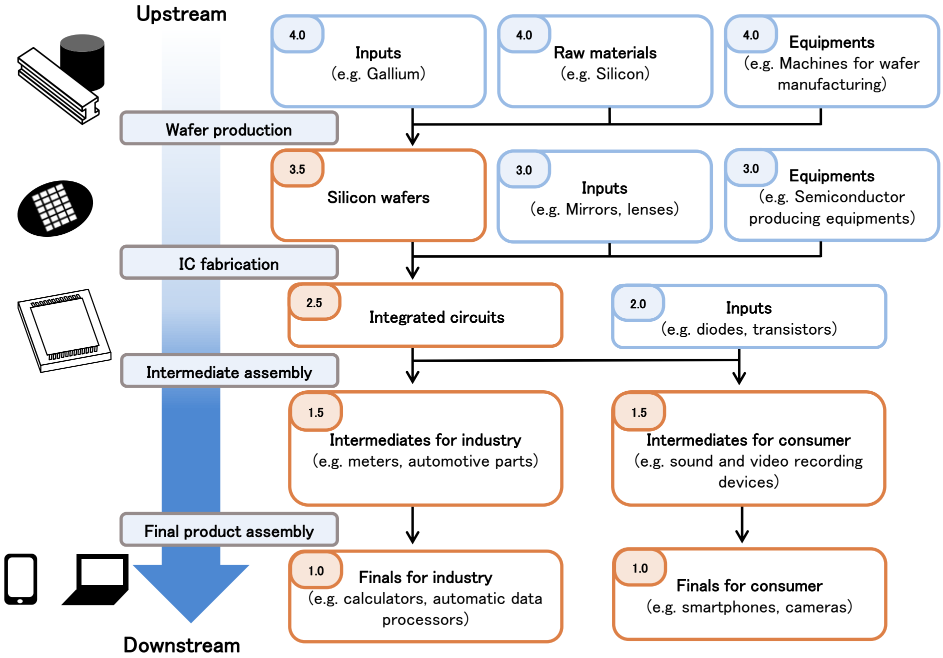
To obtain a better understanding of the restructuring of global semiconductor supply chains, we examine product-by-product trade, and in particular we pay attention to the production flow of semiconductor-related goods: The supply chains of semiconductor-related goods are highly segmented and specialized, and the production flow from upstream stages to downstream often involves cross-border trade.

To identify the supply chains and the trade associated with them, we take advantage of qualitative information regarding the production flow of semiconductors and related products. Specifically, we follow OECD 2019 and locate the position of each semiconductor-related product in the supply chains, where products flow from the upstream stages to the downstream.

Figure 4 illustrates the concept of the chain of products. The number shown at the top left corner of the frame of each product shows the upstreamness: The larger the number, the more upstream the product is located in the production stage.[7] A typical chain can be summarized into roughly four steps of the production process, as follows: First, raw materials (e.g. silicon carbide) are processed to form silicon wafers. Second, those wafers are printed with hundreds of units of electronic circuits and diced into each

[7] Our definition of the upstreamness is described in detail in Section 4.1.

Figure 4. Example of the supply chain in the semiconductor industry



Source: OECD 2019.

unit of integrated circuits (ICs). Third, those ICs are combined with other electrical apparatus to form intermediate parts with more specific functions (e.g. meters, controlling instruments, etc.). Fourth, those parts are assembled into final products (e.g. computers, smartphones). Note that, in addition to inputs and materials, we also consider various equipment used for semiconductor production, which is located in the upstream stage of the global supply chain.

Figure 5a shows from which countries/regions to which countries/regions the products at each stage of the supply chains are exported, where products flow from upstream on the left to downstream on the right of the figure. The figure visualizes the supply chains as of 2022, the most recent year for which granular data is available.

Among the numerous paths from the most upstream to the most downstream, we can find a major flow that occupies a large share in each of the stages. It first flows from developed countries to emerging economies in the upstream (from the left to the middle of the figure) and flows back to developed countries, which are the final demand centers (the right part of the figure).[8] Looking more closely at this flow, silicon wafers (upstreamness

[8] It is worth noting that since these figures only capture the flow of products that are traded internationally, we cannot identify the supply chain flowing within one country/region.

of 3.5) are exported from Japan and China to NIEs, and these wafers are processed into ICs (upstreamness of 2.5). Most of these ICs are exported back to China and are further processed into final products. Completing the flow, these final products are then exported to the U.S. and other end-use countries. Looking along this flow, we can see that developed countries like Japan and the U.S. are responsible for upstream processes including the production of semiconductor manufacturing equipment (upstreamness 4.0 and 3.0), NIEs for the intermediate processes of manufacturing ICs from silicon wafers and other inputs, and China for the downstream process of assembling products using those ICs.

Next, we observe how global supply chains have evolved with recent changes in trade policy. Figure 5b illustrates the increase and decrease in trade flows from 2017 to 2022 with red and blue arrows, respectively.

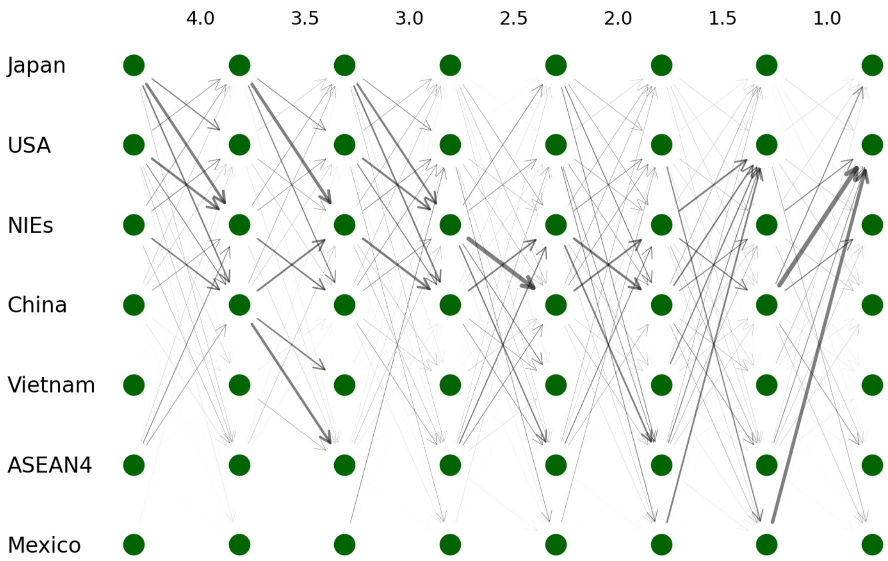
When viewed in the context of the U.S. tariff hikes against imports from China, it is evident from the figure that the share of the U.S. sourcing from China has decreased, especially for products in the downstream. Instead, the share of U.S. imports in the downstream from NIEs, Vietnam, ASEAN4, and Mexico has increased. These observations give a higher resolution to the aggregate numbers shown in Figure 2.

The figure also shows that there has been an increase in the share of exports from China to Vietnam and ASEAN4 countries, especially in trades of upstream products such as silicon wafers and ICs. This seems to explain why China's export of semiconductor-related products has overall been resilient to the tariff hikes by the U.S.: China has increased its degree of upstreamness in the global supply chain in response to the tariffs, thereby increasing trade with bystander countries/regions. We will examine the underlying forces and what makes such a transition possible later in Section 4.

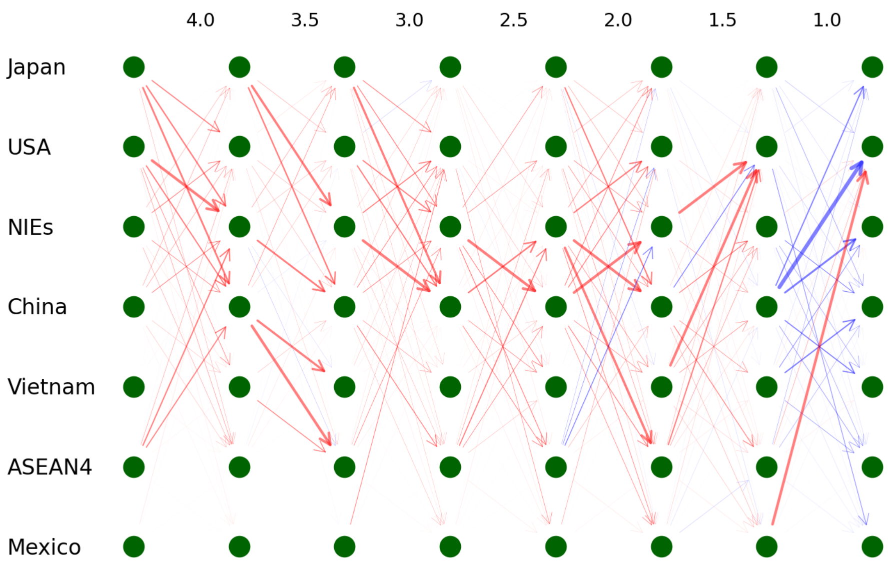
2.3 Related literature

The outbreak of U.S.-China trade friction has spurred a vast number of studies to explore how the friction has affected the U.S., China, and the rest of the world. Although our study is related to the huge literature regarding international trade, in order to stay focused on recent developments, we will discuss only studies that target the U.S. tariff hikes against its imports from China starting in 2018.

Figure 5. Global semiconductor supply chain



(a) Supply chains as of 2022



(b) Changes in supply chains (2017-22)

Sources: OECD 2019; UN Comtrade.

Notes: Nodes represent countries/regions labeled in the left of the figure. Arrows in (a) represent exports of products of the upstreamness labeled at the top of the figure. Arrow width is proportional to the share of the export amount in the total trade amount of products of each upstreamness. Arrows in (b) represent changes in exports of products of the upstreamness labeled at the top of the figure from 2017 to 2022. Red/blue arrows indicate increases/decreases in the export amounts, respectively. Arrow width is proportional to the change in the share of the export amount in the total trade amount of products of each upstreamness. NIEs represents Korea, Taiwan, and Singapore. ASEAN4 represents Indonesia, Malaysia, Thailand, and the Philippines.

Tariff pass-through and impact on prices

Generally, whether tariff increases are passed on to export prices or prices faced by consumers is not clear (Irwin 2019). This is because, in many cases, tariffs are placed on intermediate products and it is therefore difficult to trace the price impact through the supply chain.

Despite such practical difficulties, several studies have attempted to investigate the quantitative impact of a tariff increase using examples since 2018. Flaaen et al. 2020 focus on the tariff increase against washing machines which took place in early 2018 and find that washing machine prices increased by 12% after the tariff increase. Moreover, they find that the price of dryers, which were not subject to tariffs, also increased by an equivalent amount.

Studies focusing on the tariff increase against China find that the tariff increase has been fully passed on to U.S. prices. Cavallo et al. 2021 use microdata collected at the border and the store. At the border, they find that the import tariff pass-through is much higher than exchange rate pass-through. At the store, price impact is more limited, suggesting that retail margins have fallen. They conclude that their results imply that the impact of the tariffs has fallen in large part on U.S. firms.

Jiang et al. 2023 investigate the effect of the tariff increase using Chinese export data and find that the decrease in exports to the U.S. can be explained by the decrease in quantity, while export prices remained relatively unchanged. This indicates that the tariff increase has been passed on to U.S. import prices, which is consistent with the findings in other studies from the U.S. side.

Impact on U.S. welfare

The impact of the tariff on welfare depends on how much the tariff is passed on to prices. Amiti et al. 2019 show that the tariff increase has fallen on U.S. domestic consumers and importers, and their estimates imply a reduction in aggregate U.S. real income of $1.4 billion per month by the end of 2018. Fajgelbaum et al. 2020 estimate the welfare impact of the tariff hikes by the U.S. and China and show that the resulting losses to U.S. consumers and firms that buy imported goods was $51 billion, or 0.27% of GDP. They further embed the estimated trade elasticities in a general-equilibrium model of the U.S. economy and find that, after accounting for tariff revenue and gains to domestic producers, the aggregate real income loss was $7.2 billion, or 0.04% of GDP.

Reallocation to bystander countries

While the evidence on whether reallocation from China to bystander countries has occurred or not is mixed so far, a growing number of studies suggest that bystander countries have benefited from the U.S.-China trade friction. Cigna et al. 2022 confirm a strong negative direct effect of U.S. tariffs on its imports from China, while they do not find evidence of significant short-term trade diversion effects towards bystander countries.

More recently, Fajgelbaum et al. 2024 find that many bystander countries increased their exports to the rest of the world (i.e., countries other than the U.S. and China). They further demonstrate that countries that operate along downward-sloping supplies whose exports substitute for the U.S. and China are among the largest beneficiaries of the trade friction. Dang et al. 2023 investigate the drivers of the reallocation from China to other countries and find that countries with a greater revealed comparative advantage in a product have benefited from the trade friction.

While the above studies have shown that reallocation has taken place, Freund et al. 2023 claim that this reallocation has been restricted to rather specific countries, which is consistent with the "China+1" strategy, where one alternative supplier has been the main beneficiary within a product category, while China has remained an important trading partner even in the products where decoupling has occurred.

A growing number of studies have focused on these specific bystander countries who have benefitted from the trade friction, especially Vietnam and Mexico. Rotunno et al. 2023 and Mayr-Dorn et al. 2023 focus on Vietnam and find that exports from Vietnam to the U.S. increased significantly after the tariff increase. Moreover, using microdata from the national labor force survey, both studies find that the increase in exports had a positive effect on labor market outcomes such as employment and wages. Utar et al. 2023 show that increased import protection in the U.S. against China had a significant positive impact on Mexican firms' trade with the U.S., and the positive impact is driven by firms operating globally, especially those in skill-intensive manufacturing industries.

Our study echoes these existing studies and shows that Vietnam and other Asian economies have increased their presence in U.S. imports. However, our findings also suggest that this reallocation has been accompanied by increased exports of upstream products from China to bystander countries, which had started well before the introduction of the tariff hikes starting in 2018. Therefore, our study contributes to the literature by showing that the reallocation towards bystander countries is not a simple outward shift from China but a reconstruction of supply chains with China still playing an important role. We will discuss this point in detail in Section 4.

3 Impact of tariff hikes on semiconductor supply chains

In this section, we investigate changes in the international trade in semiconductor-related products following the U.S. tariff hikes against China during 2018-19 and confirm that the stylized facts stated in previous literature on the effects of the tariff hikes on trade in a broad range of products also hold true for trade in semiconductor-related products. We first show empirical evidence that U.S. imports of semiconductor-related products from China experienced a sharp decline after the tariff increase, while bystander countries increased exports to the U.S. significantly. We then examine the possibility of bypassing activities, where products manufactured in China are exported to the U.S. via a third country without any value added in that country.

3.1 Trade Data

In this study, we make use of granular trade data compiled by UN Comtrade. As mentioned earlier, rather than examining changes in trade patterns for all products, we limit our target to the products of semiconductor-related industries. In identifying products that constitute semiconductor supply chains, we rely on the list of products proposed by OECD 2019. The entire list of HS codes used in the rest of the analysis can be found in Appendix B. Although this may not be a comprehensive list of products included in semiconductor supply chains, it does provide us with a useful benchmark for what products are incorporated into the supply chains. In addition, we can identify which product is used in each stage of the supply chain.[9]

Throughout the analysis, we use data at the granularity of 6-digit level HS codes. Since the tariff has been imposed at the 8-digit level, some of the 6-digit product category

[9] In the rest of the study, "semiconductor-related products" refers to the collection of products listed in the Table B1. Therefore, these are not necessarily restricted to chips, but also include raw materials, equipment for chip production, and final products such as smartphones and computers.

includes both targeted and non-targeted products. To simplify our analysis, we regard a 6-digit product as targeted if it includes at least one targeted product at the 8-digit level.

3.2 Impact of the tariff increase

To investigate the impact of the tariff increase on U.S. semiconductor imports in a concrete manner, we conduct a simple panel regression in the following specification:

$$y_{g,t}^{i/US,IM} = \alpha_0^i + \alpha_g^i D_g + \alpha_t^i T_t + \beta_t^i \mathit{Tariff}_g \times T_t + \varepsilon_{g,t}^i, \qquad (1)$$

where $y_{g,t}^{i/US,IM}$ denotes the share of country i in U.S. imports of products with HS code g in year t. D_g and T_t are the product and time dummy, respectively, and Tariff_g is a tariff dummy, which takes the value of 1 if and only if the product g was a target of the tariff increase. α_t^i captures the time specific effect for both targeted and non-targeted products, while β_t^i captures the effect only on targeted products. We regress the share of U.S. imports rather than the amount of imports to control factors irrelevant to the U.S. sourcing policy such as changes in semiconductor prices.[10] The estimation period is set from 2014 to 2022, including both before and after the tariff increase.

Table 1 shows the results of the panel regressions for China and another 11 major countries/regions engaged in semiconductor trade. The table shows that China's coefficient for the tariff-targeted products (β_t^{China}) starts to decline clearly after the tariff increase in 2018 and becomes negative and statistically significant for 2021 and 2022. This implies that the tariff increase had a cumulative negative effect on U.S. imports of targeted products from China, and China lost roughly 10% of its share of U.S. imports on average, relative to non-targeted products, by the end of the estimation period. It is worth noting that no country except China shows a significant decline in its share of U.S. imports for tariff-targeted products.

The table also indicates that Vietnam's coefficient for the time dummies ($\alpha_t^{Vietnam}$) takes significantly positive values after the tariff increase from 2019 to 2022. This indicates that the country's recent rise in the U.S. import share is not confined to tariff-targeted products, but can be observed in a broader range of products. In addition, Taiwan is

[10]Using log level instead of import share does not alter our main results, while they occasionally disagree partly because raw trade amounts are more susceptible to price changes and because of the impact of COVID-19, especially in China. The results of the robustness check are provided in Appendix A

Table 1. Impact of U.S. tariff increase against China

	U.S. import share					
	China	Vietnam	Malaysia	Thailand	Taiwan	Korea
T_{2015}	-0.003	0.004	-0.001	-0.002	0.008	0.003
	[0.041]	[0.011]	[0.014]	[0.019]	[0.020]	[0.012]
T_{2016}	-0.037	0.002	0.008	-0.003	-0.061***	0.017
	[0.041]	[0.012]	[0.015]	[0.018]	[0.019]	[0.012]
T_{2017}	0.007	0.004	-0.001	-0.006	-0.021	0.002
	[0.049]	[0.012]	[0.016]	[0.019]	[0.024]	[0.014]
T_{2018}	-0.001	0.006	-0.002	-0.005	-0.023	-0.000
	[0.049]	[0.012]	[0.016]	[0.019]	[0.023]	[0.014]
T_{2019}	-0.013	0.038***	-0.001	-0.005	-0.021	-0.004
	[0.049]	[0.012]	[0.016]	[0.020]	[0.023]	[0.014]
T_{2020}	-0.035	0.052***	-0.000	-0.007	-0.019	-0.011
	[0.049]	[0.012]	[0.016]	[0.020]	[0.023]	[0.014]
T_{2021}	0.002	0.038***	-0.001	-0.008	-0.020	-0.011
	[0.049]	[0.013]	[0.016]	[0.019]	[0.023]	[0.014]
T_{2022}	0.006	0.035***	-0.001	-0.010	-0.016	-0.003
	[0.052]	[0.013]	[0.016]	[0.020]	[0.024]	[0.015]
$Tariff_g \times T_{2015}$	-0.001	-0.001	0.002	0.006	-0.010	-0.005
	[0.042]	[0.012]	[0.015]	[0.020]	[0.021]	[0.012]
$Tariff_g \times T_{2016}$	0.029	0.003	-0.004	0.009	0.059***	-0.023*
	[0.042]	[0.012]	[0.015]	[0.018]	[0.020]	[0.013]
$Tariff_g \times T_{2017}$	-0.006	-0.001	-0.000	0.010	0.023	-0.007
	[0.050]	[0.013]	[0.016]	[0.020]	[0.024]	[0.014]
$Tariff_g \times T_{2018}$	-0.003	-0.002	0.002	0.007	0.027	-0.005
	[0.050]	[0.013]	[0.016]	[0.020]	[0.024]	[0.014]
$Tariff_g \times T_{2019}$	-0.040	-0.033***	0.008	0.012	0.034	0.002
	[0.050]	[0.013]	[0.016]	[0.021]	[0.024]	[0.014]
$Tariff_g \times T_{2020}$	-0.050	-0.037***	0.011	0.020	0.044*	0.012
	[0.050]	[0.013]	[0.016]	[0.021]	[0.024]	[0.014]
$Tariff_g \times T_{2021}$	-0.097*	-0.019	0.012	0.024	0.050**	0.013
	[0.050]	[0.013]	[0.016]	[0.020]	[0.024]	[0.014]
$Tariff_g \times T_{2022}$	-0.108**	-0.012	0.012	0.030	0.056**	0.006
	[0.053]	[0.013]	[0.017]	[0.021]	[0.025]	[0.015]
# of obs.	1378	933	1178	1091	1312	1286
# of HS codes	162	138	153	150	160	159
R^2	0.171	0.165	0.038	0.045	0.124	0.019

Source: UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

Table 1. Impact of U.S. tariff increase against China (cont.)

	U.S. import share					
	Singapore	Mexico	India	Germany	Netherlands	Japan
T_{2015}	-0.002	-0.000	-0.006	0.003	-0.007	0.002
	[0.007]	[0.027]	[0.013]	[0.018]	[0.009]	[0.022]
T_{2016}	-0.002	0.010	-0.006	0.044**	-0.002	0.017
	[0.007]	[0.027]	[0.013]	[0.018]	[0.009]	[0.022]
T_{2017}	-0.002	0.004	-0.005	0.014	-0.009	0.003
	[0.008]	[0.031]	[0.015]	[0.022]	[0.011]	[0.027]
T_{2018}	-0.003	0.005	-0.005	0.012	-0.010	0.003
	[0.008]	[0.031]	[0.014]	[0.022]	[0.011]	[0.027]
T_{2019}	-0.005	0.009	-0.005	0.012	-0.006	0.001
	[0.008]	[0.031]	[0.015]	[0.022]	[0.011]	[0.027]
T_{2020}	-0.005	0.015	-0.004	0.012	-0.008	0.002
	[0.008]	[0.031]	[0.015]	[0.022]	[0.011]	[0.027]
T_{2021}	-0.005	0.015	-0.005	0.011	-0.007	0.000
	[0.008]	[0.031]	[0.014]	[0.022]	[0.011]	[0.027]
T_{2022}	-0.005	0.017	-0.005	0.009	-0.006	-0.005
	[0.009]	[0.031]	[0.015]	[0.023]	[0.012]	[0.028]
$Tariff_g \times T_{2015}$	0.002	-0.003	0.012	0.002	0.007	-0.007
	[0.008]	[0.028]	[0.014]	[0.019]	[0.010]	[0.023]
$Tariff_g \times T_{2016}$	0.000	-0.009	0.018	-0.045**	0.000	-0.021
	[0.008]	[0.028]	[0.014]	[0.019]	[0.009]	[0.023]
$Tariff_g \times T_{2017}$	0.000	0.001	0.005	-0.017	0.010	-0.003
	[0.008]	[0.032]	[0.015]	[0.022]	[0.011]	[0.028]
$Tariff_g \times T_{2018}$	0.001	0.003	0.008	-0.014	0.012	-0.012
	[0.008]	[0.032]	[0.015]	[0.022]	[0.011]	[0.028]
$Tariff_g \times T_{2019}$	0.005	0.012	0.008	-0.015	0.007	0.004
	[0.008]	[0.032]	[0.015]	[0.022]	[0.011]	[0.028]
$Tariff_g \times T_{2020}$	0.004	0.001	0.007	-0.014	0.010	-0.001
	[0.008]	[0.032]	[0.015]	[0.022]	[0.011]	[0.028]
$Tariff_g \times T_{2021}$	0.004	-0.003	0.008	-0.012	0.008	0.004
	[0.008]	[0.032]	[0.015]	[0.022]	[0.011]	[0.028]
$Tariff_g \times T_{2022}$	0.004	-0.004	0.011	-0.012	0.008	-0.003
	[0.009]	[0.031]	[0.015]	[0.023]	[0.012]	[0.029]
# of obs.	1134	1215	1198	1368	1257	1374
# of HS codes	155	160	156	161	158	162
R^2	0.004	0.020	0.019	0.010	0.004	0.010

Source: UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

likely to have benefited from the tariff increase, while in contrast to Vietnam, Taiwan has increased exports to the U.S. specifically of targeted products.

While our study focuses only on semiconductor-related products, our results are in line with existing studies. From the early assessment by Nicita 2019 to a more recent study by Cigna et al. 2022, there is a broad consensus regarding the negative effect of the tariff increase on the amount of products imported from the targeted country. Our observation that Vietnam experienced an increase in exports for a broad range of products is also consistent with existing studies that point out the possibility of colocation effects. For example, Dang et al. 2023 find that products not included in the target also experienced a rise in U.S. imports. They explain that the colocation effect occurs because various functions such as distribution systems and advertising campaigns tend to unify across their entire product lines when international firms expand into foreign markets. As a result, any trade diversion among targeted products subsequently impacts the exports of non-targeted products by bystander countries. As we confirm in Section 4, it is likely that reallocation to Vietnam has taken place for a broad range of products along with the expansion of supply chains.

Our results indicate that Taiwan, on the other hand, increased exports to the U.S. specifically for the targeted products. One possible explanation for the difference from Vietnam is that, because the semiconductor industry in Taiwan specializes in producing sophisticated semiconductors, unlike in Vietnam, the colocation effect accompanying the change in supply chains did not take place in Taiwan after the U.S. tariff hikes.

3.3 Cross-sectional evidence on the reallocation

In the previous subsection, we confirmed that China's share of U.S. imports decreased significantly after the tariff increase, and at the same time, other countries/regions such as Vietnam and Taiwan increased their share. In order to investigate whether products for which China lost its share of the U.S. import actually corresponds to those for which Vietnam and other economies have gained share, we take an approach similar to Alfaro and Chor 2023 and conduct the following cross-sectional analysis for semiconductor-related products:

$$\Delta y_{g,t}^{i/US,IM} = \beta_0^i + \beta_1^i \Delta y_{g,t}^{China/US,IM} + \beta_2^i \Delta y_{g,12-17}^{i/US,IM} + \varepsilon_{g,t}^i, \tag{2}$$

where $\Delta y_{g,t}^{i/US,IM}$ denotes the percentage point change in country i's share of U.S. imports from the previous year, which is regressed on the change in China's share of U.S. imports at the same period ($\Delta y_{g,t}^{China/US,IM}$), as well as the change in country i's share in the five-year period before the tariff increase, from 2012 to 2017 ($\Delta y_{g,12-17}^{i/US,IM}$). We set the estimation period from 2017 to 2022, which results in a five-year sample of the dependent variable. The lagged term on the right side ($\Delta y_{g,12-17}^{i/US,IM}$) is included to control the pre-existing trends regarding each country's market share in the U.S., which might reflect factors independent of the tariff increase, such as the stage of development in the country's semiconductor industry or the deepening of trade partnership between the two countries. In this specification, significantly negative β_1^i implies that the country i increased its share of U.S. imports for the loss of China in the U.S. import share.

Table 2 shows the estimation results for the same 11 countries/regions as in Section 3.2. Vietnam and Taiwan have clearly increased their share of U.S. imports of products the more China has lost market share. In addition, other Asian economies and Mexico also seem to have taken China's share of U.S. imports. Our estimation results focusing on semiconductor-related products are consistent with findings of Alfaro and Chor 2023, which analyzes trade in all goods and shows that Vietnam and Mexico, as well as Asian economies have replaced China.[11] Though they occupy different positions in the semiconductor supply chain, Korea and Taiwan possess advanced semiconductor fabs and therefore may have been successful in dealing with the excess demand transferred from China to them.

3.4 Possibility of bypassing activity by bystander countries

As we have confirmed so far, Asian economies, especially Vietnam and Taiwan, have increased their share of U.S. imports by filling the place of China. However, it is not obvious whether this gain in import share has led to direct economic benefit for these countries/regions. For example, Freund et al. 2023 points out that countries who expanded exports of electronics at the granularity of 2-digit HS codes to the U.S. after the U.S. tariff increase tend to have increased imports of electronics from China, which indicates the existence of bypassing activity via third countries.

[11] A possible caveat of this framework of analysis is that the coefficient β_1^i tends to be negative since, by definition, a decrease in China's share translates to an increase in the share of the rest of the world. However, what is notable here is that these benefits are skewed rather than common to all countries.

Table 2. Change in U.S. import share

	Change in share of country/region i in U.S. imports					
	Vietnam	Malaysia	Thailand	Taiwan	Korea	Singapore
Δ share of China	-0.053***	-0.054***	-0.106***	-0.181***	-0.022**	-0.041***
	[0.015]	[0.015]	[0.018]	[0.019]	[0.011]	[0.011]
Δ share of i (12-17)	-0.021	-0.066***	0.124***	0.014	-0.013	0.043
	[0.055]	[0.021]	[0.034]	[0.036]	[0.022]	[0.028]
# of obs.	360	575	507	658	655	532
R^2	0.033	0.041	0.089	0.118	0.007	0.031

	Change in share of country/region i in U.S. imports				
	Mexico	India	Germany	Netherlands	Japan
Δ share of China	-0.151***	-0.003	-0.030	-0.014	-0.165***
	[0.027]	[0.006]	[0.019]	[0.011]	[0.023]
Δ share of i (12-17)	-0.056***	-0.130***	-0.049**	0.114***	-0.123***
	[0.020]	[0.031]	[0.020]	[0.030]	[0.021]
# of obs.	593	557	722	622	712
R^2	0.066	0.033	0.012	0.025	0.109

Source: UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

To investigate more precisely the possibility of such bypassing activity in electronics by third countries, we conduct a cross-sectional analysis in the following specification for each country, using the trade data of 6-digit HS codes:

$$\Delta y_{g,t}^{China/i,IM} = \beta_0^i + \beta_1^i \Delta y_{g,t}^{US/i,EX} + \beta_2^i \Delta y_{g,12-17}^{China/i,IM} + \varepsilon_{g,t}^i, \tag{3}$$

where $\Delta y_{g,t}^{China/i,IM}$ denotes the percentage point change in China's share of country i's imports from the previous year, which is regressed on the change in the U.S. share of country i's exports in the same period ($\Delta y_{g,t}^{US/i,EX}$) and the lagged term of the dependent variable ($\Delta y_{g,12-17}^{China/i,IM}$) to control the trends. We set the estimation period from 2017 to 2022, which results in a five-year sample of the dependent variable. Countries engaged in bypassing activities are expected to have positive and significant β_1^i.

Table 3 displays the estimation results for the same list of countries/regions as in the previous subsection. Vietnam is the only country that has a significant and positive association between the changes in the U.S. share of its exports and the change in China's

Table 3. Possibility of bypassing activity by bystander countries

	Change in share of China in country/region i's imports					
	Vietnam	Malaysia	Thailand	Taiwan	Korea	Singapore
Δ share of U.S.	0.053*	-0.061*	-0.031	-0.092***	0.038	-0.247***
in i's exports	[0.028]	[0.034]	[0.033]	[0.033]	[0.025]	[0.035]
Δ share of China	-0.085***	-0.045*	-0.064***	-0.055**	-0.038**	-0.071**
in i's imports (12-17)	[0.022]	[0.024]	[0.023]	[0.026]	[0.018]	[0.028]
# of obs.	432	609	618	649	679	676
R^2	0.041	0.011	0.014	0.019	0.010	0.076

	Change in share of China in country/region i's imports				
	Mexico	India	Germany	Netherlands	Japan
Δ share of U.S.	-0.052	0.001	-0.021	-0.032	0.019
in i's exports	[0.041]	[0.033]	[0.042]	[0.048]	[0.034]
Δ share of China	-0.113***	-0.048**	-0.058***	-0.020	-0.056***
in i's imports (12-17)	[0.029]	[0.024]	[0.022]	[0.022]	[0.017]
# of obs.	572	655	709	664	673
R^2	0.029	0.006	0.010	0.002	0.017

Source: UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

share of its imports at the product level. Since this analysis is conducted using trade data at the 6-digit level granularity of HS codes, the result is indicative of Vietnam's passing very similar products imported from China to the U.S.

On the potential bypassing activity involving China and Vietnam, we should also note that the magnitude may not be sizable: The coefficient β_1^i for Vietnam being the positive of 5bps implies that only 5% of the increase in Vietnam's export to the U.S. may be attributable to bypassing of Chinese products through Vietnam, given the fact that Vietnam's import and export amount roughly balances.

Moreover, for other countries/regions, there are no significant signs of bypassing activity. Rather, some countries show that an increase in exports to the U.S. is associated with a decrease in imports from China. As we have confirmed that many countries have in fact increased exports to the U.S., these results imply that these countries have reduced bilateral trade with China.

Since we have confirmed that the evidence of bypassing is limited to a specific country, and the magnitude of bypassing is small even for that country, in the next section, we further investigate what is behind these bystander countries' improvement in their position in U.S. imports, as this will presumably explain what is left unexplained by the hypothesis of bypassing activity.

4 Long-term dynamics underlying supply chain restructuring

In the previous section, we confirmed that the tariff increase starting in 2018 has led to a significant decline in China's share of U.S. imports and to an increase in the shares of bystanders such as Vietnam and Taiwan. In addition, our results indicate that the possibility of bypassing activity is rather limited.

In this section, we investigate the long-term dynamics underlying the restructuring of the semiconductor industry through the lens of the flow of products from upstream to downstream of semiconductor supply chains. To this end, we first define the upstreamness of each product within the supply chain based on information on the relationship between products constituting the supply chain. Then we describe how different countries have behaved since before the introduction of the 2018-19 tariff hikes, in terms of their exports' upstreamness, and consider what has been driving these developments.

Our study is distinct from the existing literature in that we pursue a more comprehensive understanding of the ongoing changes in global semiconductor supply chains at the country-pairwise level using our knowledge of the qualitative input-output structure of semiconductor-related products. Our largest contribution therefore lies in measuring the upstreamness of each bilateral trade relation and associating its dynamics to changes in comparative advantage between the trading partners.

4.1 Defining upstreamness

As global supply chains have developed, whether a product is positioned in the upstream or downstream is particularly important to supply chain management. For example, Antràs et al. 2012 suggests measuring upstreamness of production and trade flows by calculating the weighted average of the distance from the final use of an industry's output in the input-output table.

An alternative method to quantify the upstreamness of a country's exports in the global supply chain is to compute the forward participation rate, the ratio of value added of one country in other countries' exports, using the inter-country input-output table. For example, Hogen et al. 2024 adopt the measure of forward and backward participation as an indicator of the position of a certain country's industry and investigate how this indicator is related to productivity growth in Japan and other advanced countries.[12] In addition to forward and backward participation, Ito et al. 2023 calculates forward and backward centrality based on the inter-country input-output table and explores how these measures are related to patent applications.

While the upstreamness measure of Antràs et al. 2012 is backed by a solid theoretical identity, it is calculated on the premise that a detailed input-output structure is available. Since such a specific input-output structure is not available at the product level for the semiconductor-related industry, we use the qualitative information derived from OECD 2019 shown in Section 2.2 to calculate a simple measure of the upstreamness of each semiconductor-related product in the global supply chain.

Specifically, we define the upstreamness u_g of each product g along the chain as the number of production steps away from the final product. The upstreamness of the final product is defined as 1. As for products that are both outputs from the previous step and inputs to the next step, we define their upstreamness to be the average of the upstreamness of both steps. The upstreamness of a basket of products can be calculated as a weighted average of the upstreamness of each product. For example, the upstreamness of country i's exports to country j at period t can be calculated as follows:

$$U_t^{i \to j} \equiv \frac{\sum_g u_g y_{g,t}^{i \to j}}{\sum_g y_{g,t}^{i \to j}}, \tag{4}$$

where $y_{g,t}^{i \to j}$ is the amount of exports of product g from country i to country j at period t.

Although our measure of upstreamness relies on a restrictive assumption compared to the measure proposed by Antràs et al. 2012, it enables us to summarize a country's relative position in the supply chain even when the complete input-output structure is not available. In addition, since granular trade data is available for almost all pairs of trading countries, our measure of upstreamness could be also calculated for most pairs of countries of interest. We leverage this granularity of information to investigate the

[12]For details of the concept of forward and backward participation, see De Backer and Miroudot 2013 and the OECD TiVA database (https://www.oecd.org/sdd/measuring-trade-in-value-added.htm).

relation bewtween upstreamness and wages in the following analysis.

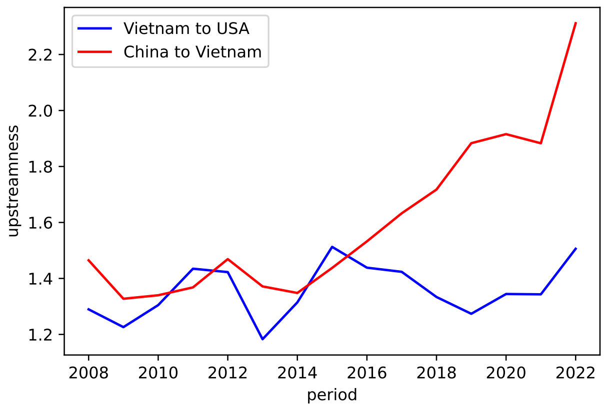
4.2 Wages as the underlying force of restructuring

Having defined the upstreamness of each country's exports, in order to understand the ongoing supply chain restructuring, we investigate how each country's role in the global supply chain has developed over a longer time frame.

Figure 6 shows the upstreamness of China's exports to Vietnam and that of Vietnam's exports to the U.S. As can be seen clearly from the figure, the upstreamness of China's exports to Vietnam increased constantly well before the tariff hikes starting in 2018. This indicates that, given the definition of upstreamness, China has been strengthening its tendency to export upstream products to Vietnam, which in turn implies that China has shifted from labor-intensive production toward more skill-intensive production. These observations that China has increased exposure to neighboring Asian economies are consistent with existing studies such as Alfaro and Chor 2023, who find that China has stepped up its trade and FDI in both Vietnam and Mexico in recent years after the outbreak of the trade friction.[13]

Figure 6 also indicates that bypassing activity is not the main driver of the increase in Vietnam's export to the U.S.: If products manufactured in China were simply passed

Figure 6. Upstreamness of semiconductor-related exports



Sources: OECD 2019; UN Comtrade.

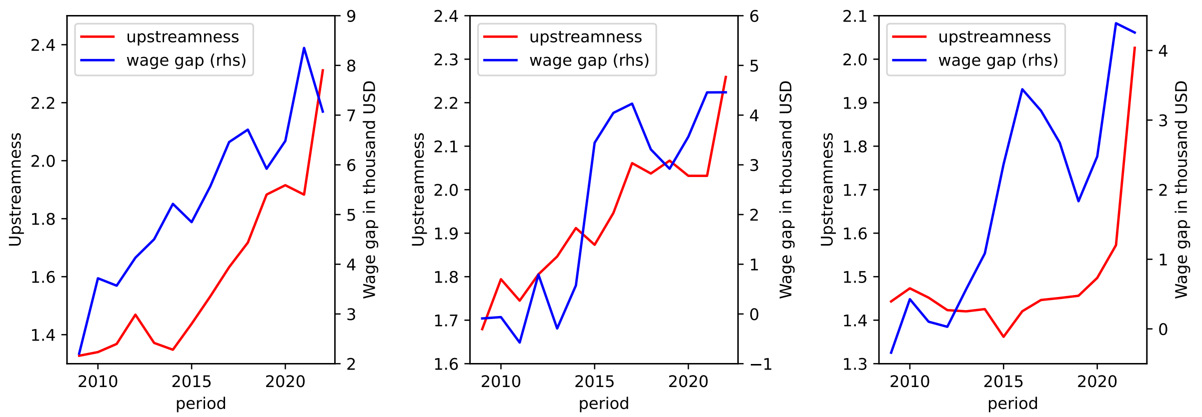
[13] Hogen et al. 2024 also investigate how China's position in the global supply chain has evolved in the long term and show that China's forward participation rate has continuously increased while its backward participation rate has decreased since the mid-2000s. They point out that this change in participation rate has been led by an increase in China's high-value-added exports, which is consistent with our findings that China's export upstreamness has risen.

on to the U.S. via Vietnam, the upstreamness of exports from both China to Vietnam and Vietnam to the U.S. should evolve similarly. However, only the export upstreamnes from China to Vietnam has risen recently, which indicates that trade creation rather than trade diversion has taken place.

What are the drivers of the increase in China's upstream exports? One potential hypothesis is that, with China clearly advancing its technology to produce semiconductors, wages have also rapidly increased. As a result, the downstream production process—which is generally more low value added—has been outsourced to economies with relatively low wages. To test our hypothesis, we focus on the wage gap between Asian economies and the upstreamness of traded products between them. We use the data of labor costs for workers that foreign affiliates of Japanese manufacturing multinational companies face in Asian economies. The data is collected by JETRO (Japan External Trade Organization) for 11 Asian economies: China, Vietnam, Korea, Hong Kong, Singapore, Taiwan, Thailand, Malaysia, Indonesia, the Philippines, and India.[14]

Figure 7 shows how the upstreamness of China's exports to selected countries and the wage gap between these countries have evolved. As wages in China has risen at a higher pace relative to other countries, China has strengthened its tendency to export upstream

Figure 7. Wage gap and the upstreamness of China's exports



(a) To Vietnam **(b)** To Malaysia **(c)** To Thailand

Sources: JETRO; OECD 2019; UN Comtrade.

[14]While the wage data collected by JETRO covers the entire manufacturing industry and is not specific to the semiconductor industry, the survey has been conducted constantly since 2008 (since 2009 for China), and provides a reliable and comparable data over time. Moreover, since semiconductor industries in many Asian economies depend greatly on foreign enterprises, wages for the employees are likely to be similar to those in multinational companies.

products to these countries.

To see whether there is a positive correlation between the wage gap and the upstreamness of export products in a more systematic manner, we conduct a panel regression specified as follows:

$$U_t^{i\to j} = \beta_0 + \beta_1(w_t^i - w_t^j) + \varepsilon_t^{i\to j}, \tag{5}$$

where $U_t^{i\to j}$ is the upstreamness of exports from country i to j, which we have previously defined. $w_{i,t}$ denotes the wage in country i in thousand USD in year t. For the pattern of $i \to j$ in the above specification, the permutation of all 11 countries for which the wage difference can be calculated using the JETRO data are included in our estimation. The estimation period covers from 2008 to 2022.

Table 4 shows the estimation results. Let us start with the simple specification with no other control variable except for the wage gap, as shown in column (1). It can be clearly seen from the table that there is a positive and significant correlation between the wage gap and the upstreamness of traded products. This implies that the wider the wage gap between the two economies is, the more upstream the exports are from the higher-wage economy to the lower-wage economy. Moreover, the estimation result is robust to adding year fixed effects and country-combination fixed effects, as shown in columns (2) to (4) in the table. This is consistent with the implication obtained from Figure 7 that higher-wage countries tend to occupy upstream of the semiconductor supply chain and export relatively upstream intermediates, leaving downstream processes to lower-wage countries.

Having confirmed that China has increased exports of upstream products to neighboring Asian economies, we estimate the model with an additional variable. We include a cross term of the wage gap and a dummy variable (*Dummy*) which indicates the trade between China and a group of three Asian countries; Vietnam, Malaysia, and Thailand. *Dummy* takes the value of 1 if i = China and $j \in$ {Vietnam, Malaysia, Thailand} or $i \in$ {Vietnam, Malaysia, Thailand} and j = China, and 0 otherwise. As we have confirmed in Figure 7, these three countries are neighboring Asian countries who have a significant presence in the semiconductor trade. The estimation results in column (5) shows that the correlation between wage gap and export upstreamness is especially large for these combinations of countries.

These results are in line with the argument in Antràs 2020, which illustrates with simple models that multinational companies in a more developed country have an incentive to

Table 4. Wage gap and the upstreamness of exports

	Upstreamness of exports from country/region i to j				
	(1)	(2)	(3)	(4)	(5)
$w_t^i - w_t^j$	0.0030***	0.0030***	0.0029*	0.0029**	0.0025*
	[0.001]	[0.0006]	[0.0016]	[0.0014]	[0.0014]
$Dummy \times (w_t^i - w_t^j)$					0.0245**
					[0.0115]
time dummy		✓		✓	✓
fixed effect			✓	✓	✓
# of obs.	1630	1630	1630	1630	1630
R^2	0.014	0.046	0.002	0.160	0.162

Sources: JETRO; OECD 2019; UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

outsource their production processes to developing countries where productivity-adjusted labor costs for the process are cheaper than in their home country. With regard to the on-going restructuring of the semiconductor supply chain, exporting electronics from China to the U.S. incurs the additional cost of the elevated tariff. Based on the model in Antràs 2020, this should work as another factor lowering the profitability of production in China and thus prompt multinational companies to shift their production processes to their foreign affiliates.

However, the positive correlation between the upstreamness of exports and the wage gaps, when controlling for fixed effects, implies that a country's shift in position in the supply chain is prompted not only by the tariff increase but also by the relative change in labor costs between countries. These long-term changes in the role of each country in the supply chain might have been causing the shift in trade flows indicated in Section 3.

We must note that our findings do not speak to the causality between wage dynamics and the upstreamness of exports, since the estimation results only indicate a correlation between the two indicators. The natural hypothesis is that the increase in wages and upstream production are both caused by technological advances in China. For example, using Japanese firm and industry data, Ito et al. 2023 show that industries' forward centrality tends to be positively associated with increasing firms' patent applications. Considering additional variables such as patent applications may allow us to further disentangle the causality behind the changes in the global division of labor. We leave such in-depth investigation for future work.

4.3 Discussion on the implications of restructuring

By focusing on the upstreamness of trade activities, we showed that China has increased exports of products in the upstream to Vietnam and other Asian economies, while those Asian economies have increased exports of products in the downstream to the U.S. In other words, China has shifted its relative position in the supply chain to the upstream, with its original downstream position taken over by other Asian economies. This finding supports the dominant view of existing studies that the U.S. is still linked to China via the supply chains. This fact may be one of the reasons why the entire semiconductor industry was able to respond swiftly to the tariff increase without causing major disruptions in the global supply chain.

Furthermore, we have shown that this increase in China's upstream exports started well before the introduction of the U.S. tariff against China and has been positively correlated with the wage gap between China and its neighboring Asian economies. This change in the composition of exported products is consistent with the theoretical prediction that a change in relative labor costs between countries prompts the shifting of production processes, leading to more efficient resource allocation. Taking this into account, it may be the case that the loss in efficiency from the tariff increase may not be as large as was initially anticipated—at least for the semiconductor industry—because the restructuring of the supply chains is led not only by changes in trade policy but also by the endogenous shift in comparative advantage between China and other bystander countries.

5 Conclusion

This paper analyzed changes in the global supply chains of semiconductor-related products from two distinct perspectives. First, we investigated how events associated with changes in trade policy affected the international trade flow of such products, using the recent U.S. tariff hikes against its imports from China as an example. The results echoed those in previous studies showing that increased U.S. tariffs reduced China's share of U.S. imports while increasing the share of U.S imports of several Asian economies—especially Vietnam and Taiwan. This indicates that the procurement structure of U.S. semiconductor-related products has been changed. Moreover, the broad range of products from Vietnam that experienced an increase in exports to the U.S. indicates that the semiconductor industry in Vietnam may also have been significantly affected. The results also suggest that this improvement in the status of third countries was not merely a trend continuing from the past, but was a result of the change in China's status in the U.S. market.

Second, we examined how the flow of products along the global supply chain has changed over time, and its relation to wage developments in Asian economies. We observed that bystander countries, including Vietnam, have come to occupy a crucial position in the middle of the supply chain. They seem to have increased imports of upstream products, largely from China, and exports of downstream products to the U.S. This suggests that the increase in exports to the U.S. is associated with value addition in these economies, rather than mere bypassing activity. We further investigated the relationship between the upstreamness of products traded between Asian economies and the wage differentials between those countries. The results suggest that recent changes in global supply chains may reflect developments in the international division of labor, which are intended to increase efficiency of production. Taking these results together, the ongoing changes in global supply chains may not necessarily reflect forces that reduce efficiency but may also be driven by the rationality of optimizing international resource allocation according to the comparative advantages of economies.

Although we have focused on both the long-term dynamics and the effect of increased tariffs, we have not been able to provide an assessment of recent non-tariff export controls. With advanced chips playing a crucial role in many leading industries, including AI, recent measures may affect the productivity of a country in the long run, which may lead to a further restructuring of supply chains. We leave such investigation to future work.

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Appendix.A Estimation results using log of trade amounts

Table A1. Impact of U.S. tariff increase against China

	U.S. import amount					
	China	Vietnam	Malaysia	Thailand	Taiwan	Korea
T_{2015}	-0.328	0.412	0.221	-0.324	-0.007	0.394
	[0.245]	[0.735]	[0.544]	[0.675]	[0.384]	[0.366]
T_{2016}	-0.490**	-0.221	0.529	-0.113	-0.276	0.283
	[0.245]	[0.770]	[0.559]	[0.619]	[0.368]	[0.381]
T_{2017}	-0.147	-0.829	-0.070	0.322	-0.138	0.426
	[0.295]	[0.796]	[0.592]	[0.675]	[0.457]	[0.431]
T_{2018}	-0.066	-0.242	-0.109	0.014	-0.417	0.634
	[0.295]	[0.796]	[0.614]	[0.675]	[0.443]	[0.431]
T_{2019}	-0.102	1.330*	-0.287	1.559**	-0.595	0.612
	[0.295]	[0.796]	[0.614]	[0.713]	[0.443]	[0.431]
T_{2020}	-0.079	2.056***	-0.310	2.022***	-0.692	0.540
	[0.295]	[0.796]	[0.614]	[0.713]	[0.443]	[0.431]
T_{2021}	0.277	1.912**	0.315	1.084	0.152	0.417
	[0.295]	[0.842]	[0.592]	[0.675]	[0.443]	[0.431]
T_{2022}	0.462	2.662***	0.799	2.184***	0.847*	1.360***
	[0.311]	[0.843]	[0.626]	[0.713]	[0.466]	[0.454]
$Tariff_g \times T_{2015}$	0.339	-0.081	-0.251	0.180	-0.087	-0.464
	[0.255]	[0.764]	[0.558]	[0.691]	[0.396]	[0.380]
$Tariff_g \times T_{2016}$	0.450*	0.691	-0.552	0.076	0.169	-0.514
	[0.255]	[0.797]	[0.572]	[0.637]	[0.382]	[0.395]
$Tariff_g \times T_{2017}$	0.234	1.405*	0.151	-0.228	0.237	-0.544
	[0.303]	[0.823]	[0.605]	[0.691]	[0.468]	[0.443]
$Tariff_g \times T_{2018}$	0.189	1.054	0.337	0.038	0.653	-0.598
	[0.303]	[0.822]	[0.626]	[0.691]	[0.454]	[0.443]
$Tariff_g \times T_{2019}$	-0.167	-0.191	0.590	-1.382*	0.834*	-0.812*
	[0.303]	[0.821]	[0.626]	[0.728]	[0.454]	[0.443]
$Tariff_g \times T_{2020}$	-0.551*	-0.430	0.686	-1.790**	1.076**	-0.897**
	[0.303]	[0.821]	[0.626]	[0.729]	[0.454]	[0.443]
$Tariff_g \times T_{2021}$	-0.768**	0.026	0.382	-0.407	0.370	-0.548
	[0.303]	[0.866]	[0.605]	[0.691]	[0.454]	[0.443]
$Tariff_g \times T_{2022}$	-0.814**	-0.267	0.078	-1.243*	0.065	-1.392***
	[0.318]	[0.867]	[0.638]	[0.728]	[0.476]	[0.465]
# of obs.	1378	933	1178	1091	1312	1286
# of HS codes	162	138	153	150	160	159
R^2	0.184	0.263	0.104	0.118	0.141	0.029

Source: UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

Table A1. Impact of U.S. tariff increase against China (cont.)

	U.S. import amount					
	Singapore	Mexico	India	Germany	Netherlands	Japan
T_{2015}	0.104	-0.031	-0.507	-0.192	-0.644*	-0.216
	[0.487]	[0.481]	[0.570]	[0.214]	[0.375]	[0.268]
T_{2016}	-0.325	0.359	-0.578	-0.089	-0.115	-0.098
	[0.487]	[0.481]	[0.570]	[0.214]	[0.360]	[0.268]
T_{2017}	-0.127	-0.008	-0.644	-0.079	-0.535	0.016
	[0.522]	[0.544]	[0.642]	[0.258]	[0.420]	[0.322]
T_{2018}	-0.254	-0.306	-0.515	-0.203	-0.429	0.387
	[0.522]	[0.544]	[0.612]	[0.258]	[0.420]	[0.322]
T_{2019}	-0.667	-0.237	-0.398	-0.263	-0.190	0.391
	[0.540]	[0.544]	[0.642]	[0.258]	[0.420]	[0.322]
T_{2020}	-0.586	-0.497	-0.430	-0.216	-0.551	0.114
	[0.522]	[0.544]	[0.642]	[0.258]	[0.420]	[0.322]
T_{2021}	-0.348	-0.676	-0.147	-0.546**	-0.363	0.174
	[0.540]	[0.544]	[0.612]	[0.258]	[0.441]	[0.322]
T_{2022}	-0.011	-0.227	-0.177	0.001	0.384	-0.081
	[0.571]	[0.540]	[0.640]	[0.271]	[0.470]	[0.339]
$Tariff_g \times T_{2015}$	-0.018	0.041	0.534	0.252	0.684*	0.041
	[0.502]	[0.496]	[0.587]	[0.223]	[0.388]	[0.278]
$Tariff_g \times T_{2016}$	0.210	-0.201	0.625	0.007	0.095	-0.055
	[0.502]	[0.496]	[0.587]	[0.223]	[0.374]	[0.278]
$Tariff_g \times T_{2017}$	0.056	0.236	0.609	0.083	0.553	-0.143
	[0.536]	[0.558]	[0.657]	[0.265]	[0.431]	[0.331]
$Tariff_g \times T_{2018}$	0.177	0.721	0.834	0.274	0.730*	-0.569*
	[0.536]	[0.558]	[0.628]	[0.265]	[0.431]	[0.331]
$Tariff_g \times T_{2019}$	0.685	0.663	0.577	0.333	0.413	-0.590*
	[0.553]	[0.558]	[0.657]	[0.265]	[0.431]	[0.331]
$Tariff_g \times T_{2020}$	0.506	0.867	0.653	0.121	0.628	-0.425
	[0.536]	[0.558]	[0.657]	[0.265]	[0.431]	[0.331]
$Tariff_g \times T_{2021}$	0.282	1.176**	0.528	0.617**	0.578	-0.277
	[0.553]	[0.558]	[0.628]	[0.265]	[0.453]	[0.331]
$Tariff_g \times T_{2022}$	0.129	0.877	0.800	0.177	-0.046	0.029
	[0.584]	[0.554]	[0.656]	[0.278]	[0.480]	[0.347]
# of obs.	1134	1215	1198	1368	1257	1374
# of HS codes	155	160	156	161	158	162
R^2	0.011	0.051	0.037	0.031	0.034	0.024

Source: UN Comtrade.

Note: Standard errors are shown in brackets. ***, **, * indicate 10%, 5%, and 1% significance, respectively.

Appendix.B List of semiconductor-related products

Table B1. List of semiconductor-related products

Upstreamness	HS code	Description
4.0	280461	Silicon; containing by weight not less than 99.99% of silicon
4.0	282560	Germanium oxides and zirconium dioxide
4.0	284920	Carbides; of silicon, whether or not chemically defined
4.0	370130	Photographic plates and film; in the flat, sensitised, unexposed, with any side exceeding 225mm, of any materials other than paper, paperboard or textiles
4.0	370199	Photographic plates and film; (for other than color photography), in the flat, sensitised, unexposed, with no side exceeding 255mm, of any material other than paper, paperboard or textiles
4.0	370790	Photographic goods; chemical preparations other than sensitised emulsions, put up in measured portions or put up for retail sale in a form ready for use
4.0	811299	Gallium, germanium, indium, niobium (columbium) and vanadium; articles thereof, other than unwrought including waste and scrap and powders
4.0	848610	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers
4.0	848690	Machines and apparatus of heading 8486; parts and accessories
4.0	903082	Instruments and apparatus; for measuring or checking semiconductor wafers or devices (including integrated circuits)
4.0	903141	Optical instruments and appliances; for inspecting semiconductor wafers or devices or for inspecting photomasks or reticles used in manufacturing semiconductor devices, n.e.c. in chapter 90
3.5	381800	Chemical elements; doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics
3.0	841459	Fans; n.e.c. in item no. 8414.51
3.0	841950	Heat exchange units; not used for domestic purposes
3.0	842129	Machinery; for filtering or purifying liquids, n.e.c. in item no. 8421.2
3.0	842139	Machinery; for filtering or purifying gases, other than intake air filters, catalytic converters or particulate filters for internal combustion engines
3.0	842199	Machinery; parts for filtering or purifying liquids or gases
3.0	848620	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
3.0	848640	Machines and apparatus of a kind used solely or principally for the manufacture or repair of masks and reticles, assembling semiconductor devices or electronic integrated circuits, or for lifting, handling, loading or unloading items of heading 8486
3.0	900120	Optical elements; polarising material, sheets and plates thereof
3.0	900190	Optical elements; lenses n.e.c. in heading no. 9001, prisms, mirrors and other optical elements, unmounted, of any material (excluding elements of glass not optically worked)
3.0	900219	Lenses; objective, (other than for cameras, projectors or photographic enlargers or reducers), mounted, of any material (excluding elements of glass not optically worked)
3.0	900220	Filters; mounted as parts or fittings for instruments or apparatus, of any material (excluding elements of glass not optically worked)
3.0	900290	Optical elements; n.e.c. in heading no. 9002 (e.g. prisms and mirrors), mounted, being parts or fittings for instruments or apparatus, of any material (excluding elements of glass not optically worked)
3.0	901210	Microscopes (excluding optical microscopes); diffraction apparatus
3.0	901290	Microscopes (excluding optical microscopes); diffraction apparatus; parts and accessories
2.5	852351	Semiconductor media; solid-state non-volatile storage devices, whether or not recorded, excluding products of Chapter 37
2.5	852352	Semiconductor media; smart cards, whether or not recorded, excluding products of Chapter 37
2.5	852359	Semiconductor media; other than smart cards, whether or not recorded, excluding products of Chapter 37
2.5	853290	Electrical capacitors; parts of the capacitors of heading no. 8532
2.5	853310	Electrical resistors; fixed carbon resistors, composition or film types (including rheostats and potentiometers but excluding heating resistors)
2.5	853321	Electrical resistors; fixed, for a power handling capacity not exceeding 20W (including rheostats and potentiometers but excluding heating resistors and carbon resistors)
2.5	853329	Electrical resistors; fixed, for a power handling capacity exceeding 20W (including rheostats and potentiometers but excluding heating resistors and carbon resistors)
2.5	853331	Electrical resistors; wirewound variable, including rheostats and potentiometers, for a power handling capacity not exceeding 20W (excluding heating)
2.5	853339	Electrical resistors; wirewound variable, including rheostats and potentiometers, for a power handling capacity exceeding 20W (excluding heating)

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
2.5	853340	Electrical resistors; variable, including rheostats and potentiometers (excluding heating)
2.5	853390	Resistors; parts of the resistors of heading no. 8533
2.5	853400	Circuits; printed
2.5	854210	Cards incorp. an electronic integrated circuit (smart cards)
2.5	854211	Monolithic integrated circuits, digital
2.5	854212	Cards incorp elect integ
2.5	854213	Metal oxide semiconducto
2.5	854214	Circuits obtained by bip
2.5	854219	Monolithic integrated circuits, except digital
2.5	854220	Hybrid integrated circuits
2.5	854221	Monolithic integrated circuits, digital
2.5	854229	Monolithic integrated circuits, other than digital
2.5	854230	Monolithic integrated ci
2.5	854231	Electronic integrated circuits; processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
2.5	854232	Electronic integrated circuits; memories
2.5	854233	Electronic integrated circuits; amplifiers
2.5	854239	Electronic integrated circuits; n.e.c. in heading no. 8542
2.5	854240	Hybrid integrated circui
2.5	854250	Electronic microassembli
2.5	854260	Hybrid integrated circuits
2.5	854270	Electronic microassemblies
2.5	854280	Electronic integrated circuits/microassemblies, nes
2.5	854290	Parts of electronic integrated circuits
2.0	854011	Tubes; cathode-ray television picture tubes, including video monitor cathode-ray tubes, color
2.0	854012	Tubes; cathode-ray television picture tubes, including video monitor cathode-ray tubes, monochrome
2.0	854020	Tubes; television camera tubes, image converters and intensifiers, other photo-cathode tubes
2.0	854030	Cathode-ray tubes, except for television
2.0	854040	Tubes; data/graphic display tubes, monochrome; data/-graphic display tubes, color, with a phosphor dot screen pitch smaller than 0.4mm
2.0	854041	Magnetron tubes
2.0	854042	Klystron tubes
2.0	854049	Microwave tubes, except magnetron/klystron
2.0	854050	Data/graphic display tubes, black & white/other monochrome
2.0	854060	Tubes; cathode ray, n.e.c. in heading no. 8540
2.0	854071	Tubes; microwave, magnetrons, excluding grid-controlled tubes
2.0	854072	Klystrons
2.0	854079	Tubes; microwave (for example klystrons, travelling wave tubes, carlinotrons), excluding magnetrons and grid-controlled tubes
2.0	854081	Valves and tubes; receiver or amplifier
2.0	854089	Valves and tubes; n.e.c. in heading no. 8540
2.0	854091	Tubes; parts of cathode-ray tubes

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
2.0	854099	Valves and tubes; parts of the valves and tubes of heading no. 8540, excluding parts of cathode-ray tubes
2.0	854110	Electrical apparatus; diodes, other than photosensitive or light-emitting diodes (LED)
2.0	854121	Electrical apparatus; transistors, (other than photosensitive), with a dissipation rate of less than 1W
2.0	854129	Electrical apparatus; transistors, (other than photosensitive), with a dissipation rate of 1W or more
1.5	847310	Typewriters and word-processing machines; parts and accessories of the machines of heading 84.69 (other than covers, carrying cases and the like)
1.5	847321	Calculating machines; parts and accessories of the electronic calculating machines of item no. 8470.10, 8470.21 or 8470.29 (other than covers, carrying cases and the like)
1.5	847329	Machinery; parts and accessories of the machines of item no. 8470.30. 8470.50 or 8470.90 (other than covers, carrying cases and the like)
1.5	847330	Machinery; parts and accessories (other than covers, carrying cases and the like) of the machines of heading no. 8471
1.5	847340	Machinery; parts and accessories (other than covers, carrying cases and the like) of the machines of heading no. 8472
1.5	847350	Machines; parts and accessories (other than covers, carrying cases and the like) equally suitable for use with machines of two or more of the headings 8470 to 8472
1.5	851190	Ignition or starting equipment; parts of the equipment of heading no. 8511, for use in spark-ignition or compression-ignition internal combustion engines
1.5	851761	Base stations
1.5	851762	Communication apparatus (excluding telephone sets or base stations); machines for the reception, conversion and transmission or regeneration of voice, images or other data, including switching and routing apparatus
1.5	851769	Communication apparatus (excluding telephone sets or base stations); machines for the transmission or reception of voice, images or other data (including wired/wireless networks), n.e.c. in item no. 8517.6
1.5	851890	Microphones, headphones, earphones, amplifier equipment; parts of the equipment of heading no. 8518
1.5	852290	Sound or video recording or reproducing apparatus; parts and accessories thereof, other than pick-up cartridges
1.5	852729	Radio-broadcast receivers not capable of operating without an external source of power, of a kind used in motor vehicles; not combined with sound recording or reproducing apparatus
1.5	852990	Reception and transmission apparatus; for use with the apparatus of heading no. 8524 to 8528, excluding aerials and aerial reflectors
1.5	854430	Insulated electric conductors; ignition wiring sets and other wiring sets of a kind used in vehicles, aircraft or ships
1.5	900661	Photographic flashlight apparatus; discharge lamp (electronic)

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
1.5	901490	Navigational instruments and appliances; parts and accessories
1.5	902490	Machines and appliances; parts and accessories for those testing hardness, strength, compressibility, elasticity or other mechanical properties of materials (e.g. metal, wood, textiles, paper, plastics)
1.5	902790	Microtomes and parts and accessories thereof
1.5	902890	Meters; parts and accessories of gas, liquid, electricity supply or production meters, including calibrating meters thereof
1.5	902990	Meters and counters; parts and accessories for revolution and production counters, taximeters, mileometers, pedometers and the like; speed indicators, tachometers (excluding heading no. 9015), stroboscopes
1.5	903090	Instruments, apparatus for measuring, checking electrical quantities, not meters of heading no. 9028; parts and accessories, for measuring or detecting alpha, beta, gamma, x-ray, cosmic and other radiations
1.5	903190	Instruments, appliances and machines; parts and accessories for those measuring or checking devices of heading no. 9031
1.5	903290	Regulating or controlling instruments and apparatus; automatic, parts and accessories
1.5	903300	Machines and appliances, instruments or apparatus of chapter 90; parts and accessories n.e.c. in chapter 90
1.0	847010	Calculating machines; electronic calculators capable of operation without an external source of electric power and pocket-size data recording, reproducing and displaying machines with calculating functions
1.0	847021	Calculating machines; electronic, incorporating a printing device, needing an external source of power
1.0	847029	Calculating machines; electronic, (not incorporating a printing device), needing an external power source
1.0	847030	Calculating machines; non-electronic
1.0	847040	Accounting machines
1.0	847050	Cash registers
1.0	847090	Machines incorporating a calculating device; n.e.c. in heading no. 8470
1.0	847110	Analogue or hybrid computers
1.0	847120	Digital computers with cpu and input-output units
1.0	847130	Automatic data processing machines; portable, weighing not more than 10kg, consisting of at least a central processing unit, a keyboard and a display
1.0	847141	Automatic data processing machines; comprising in the same housing at least a central processing unit and an input and output unit, whether or not combined, n.e.c. in item no. 8471.30
1.0	847149	Automatic data processing machines; presented in the form of systems, n.e.c. in item no. 8471.30 or 8471.41
1.0	847150	Units of automatic data processing machines; processing units other than those of item no. 8471.41 or 8471.49, whether or not containing in the same housing one or two of the following types of unit: storage units, input units or output units

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
1.0	847160	Units of automatic data processing machines; input or output units, whether or not containing storage units in the same housing
1.0	847170	Units of automatic data processing machines; storage units
1.0	847180	Units of automatic data processing machines; n.e.c. in item no. 8471.50, 8471.60 or 8471.70
1.0	847190	Magnetic or optical readers, machines for transcribing data onto data media in coded form and machines for processing such data, not elsewhere specified or included
1.0	847191	Digital computer cpu with some of storage/input/outpu
1.0	847192	Computer input or output units
1.0	847193	Computer data storage units
1.0	847199	Automatic data processing machines and units, nes
1.0	847210	Office machines; duplicating machines
1.0	847220	Addressing machines, address plate embossing machines
1.0	847230	Office machines; for sorting or folding mail or for inserting mail in envelopes or bands, machines for opening, closing or sealing mail and machines for affixing or cancelling postage stamps
1.0	847290	Office machines; not elsewhere classified
1.0	851712	Telephones for cellular networks or for other wireless networks
1.0	851718	Telephone sets n.e.c. in item no. 8517.1
1.0	851770	Telephone sets and other apparatus for the transmission or reception of voice, images or other data, via a wired or wireless network; parts
1.0	851810	Microphones and stands therefor
1.0	852580	Television cameras, digital cameras and video camera recorders
1.0	852610	Radar apparatus
1.0	852691	Radio navigational aid apparatus
1.0	852692	Radio remote control apparatus
1.0	852810	Color television receivers/monitors/projectors
1.0	852812	Color television receive
1.0	852813	B & W television receive
1.0	852820	Monochrome television receivers/monitors/projectors
1.0	852821	Color video monitors
1.0	852822	B & w video monitors
1.0	852830	Video projectors
1.0	852841	Cathode-ray tube monitors; of a kind solely or principally used in an automatic data processing system of heading 84.71
1.0	852842	Monitors; cathode-ray tube, capable of directly connecting to and designed for use with an automatic data processing machine of heading 84.71
1.0	852849	Monitors; cathode-ray tube, n.e.c. in subheading 8528.42, whether or not color
1.0	852851	Monitors other than cathode-ray tube; of a kind solely or principally used in an automatic data processing system of heading 84.71
1.0	852852	Monitors; other than cathode-ray tube; capable of directly connecting to and designed for use with an automatic data processing machine of heading 84.71

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
1.0	852859	Monitors other than cathode-ray tube; n.e.c. in subheading 8528.52, whether or not color
1.0	852861	Projectors; of a kind solely or principally used in an automatic data processing system of heading 84.71
1.0	852862	Projectors; capable of directly connecting to and designed for use with an automatic data processing machine of heading 84.71
1.0	852869	Projectors; n.e.c. in subheading 8528.62, whether or not color
1.0	852871	Reception apparatus for television, whether or not incorporating radio-broadcast receivers or sound or video recording or reproducing apparatus; not designed to incorporate a video display or screen
1.0	852872	Reception apparatus for television, whether or not incorporating radio-broadcast receivers or sound or video recording or reproducing apparatus; incorporating a color video display or screen
1.0	900610	Cameras, photographic (excluding cinematographic); of a kind used for preparing printing plates or cylinders
1.0	900620	Cameras for recording microfilm etc
1.0	900630	Cameras, photographic (excluding cinematographic); specially designed for underwater use, aerial survey, medical or surgical examination of internal organs; comparison cameras for forensic or criminological use
1.0	900640	Cameras, photographic (excluding cinematographic); instant print cameras
1.0	900651	Cameras, photographic (excluding cinematographic); with a through-the-lens viewfinder, single lens reflex (SLR), for a roll film of a width not exceeding 35mm
1.0	900652	Cameras, photographic (excluding cinematographic); of a kind (not SLR) for roll film of a width less than 35mm
1.0	900653	Cameras, photographic (excluding cinematographic), for roll film of a width of 35mm
1.0	900659	Cameras, photographic (excluding cinematographic); n.e.c. in heading no 9006
1.0	900661	Photographic flashlight apparatus; discharge lamp (electronic)
1.0	900662	Flashbulbs, flashcubes and the like
1.0	900669	Photographic flashlight apparatus; n.e.c. in heading no. 9006
1.0	900691	Cameras, photographic (excluding cinematographic); parts and accessories
1.0	900699	Photographic flashlight apparatus; parts and accessories, for other than cameras
1.0	901410	Navigational instruments and appliances; direction finding compasses
1.0	901420	Navigational instruments and appliances; for aeronautical or space navigation (excluding compasses)
1.0	901480	Navigational instruments and appliances; for navigation other than aeronautical or space navigation (excluding direction finding compasses)

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
1.0	901490	Navigational instruments and appliances; parts and accessories
1.0	902211	Medical X-ray apparatus
1.0	902212	Apparatus based on the use of x-rays; including radiography or radiotherapy apparatus, whether or not for medical, surgical, dental or veterinary uses, computed tomography apparatus
1.0	902213	Apparatus based on the use of x-rays; including radiography or radiotherapy apparatus, for dental uses, excluding computed tomography apparatus
1.0	902214	Apparatus based on the use of x-rays; including radiography or radiotherapy apparatus, for medical, surgical or veterinary uses, not dental uses, excluding computed tomography apparatus
1.0	902219	Apparatus based on the use of x-rays, including radiography or radiotherapy apparatus; for other than medical, surgical, dental or veterinary uses
1.0	902221	Apparatus based on the use of alpha, beta, gamma or other ionising radiations, including radiography or radiotherapy apparatus; for medical, surgical, dental or veterinary uses
1.0	902229	Apparatus based on the use of alpha, beta, gamma or other ionising radiations, including radiography or radiotherapy apparatus; (for other than medical, surgical, dental or veterinary uses)
1.0	902230	X-ray tubes
1.0	902290	Apparatus based on use of x-rays and similar; parts and accessories (x-ray generators, tubes, high tension generators, control panels and desks, screens, examination or treatment tables, chairs and like
1.0	902710	Instruments and apparatus; gas or smoke analysis apparatus, for physical or chemical analysis
1.0	902720	Chromatographs and electrophoresis instruments
1.0	902730	Spectrometers, spectrophotometers and spectrographs; using optical radiations (UV, visible, IR)
1.0	902740	Exposure meters
1.0	902750	Instruments and apparatus; using optical radiations (UV, visible, IR), (other than spectrometers, spectrophotometers and spectrographs)
1.0	902780	Instruments and apparatus; for physical or chemical analysis, for measuring or checking viscosity, porosity, expansion, surface tension or quantities of heat, sound or light, n.e.c. in heading no. 9027
1.0	902781	Instruments and apparatus; for physical or chemical analysis, for measuring or checking viscosity, porosity, expansion, surface tension or quantities of heat, sound or light, mass spectrometers
1.0	902789	Instruments and apparatus; for physical or chemical analysis, for measuring or checking viscosity, porosity, expansion, surface tension or quantities of heat, sound or light, exposure meters

Sources: OECD 2019; UN Comtrade.

Table B1. List of semiconductor-related products (cont.)

Upstreamness	HS code	Description
1.0	902790	Microtomes and parts and accessories thereof
1.0	902810	Meters; gas, supply or production meters, including calibrating meters thereof
1.0	902820	Meters; liquid supply or production meters, including calibrating meters thereof
1.0	902830	Meters; electricity supply or production meters, including calibrating meters thereof
1.0	902890	Meters; parts and accessories of gas, liquid, electricity supply or production meters, including calibrating meters thereof
1.0	902910	Meters and counters; revolution counters, production counters, taximeters, mileometers, pedometers and the like
1.0	902920	Meters; speed indicators and tachometers; stroboscopes
1.0	902990	Meters and counters; parts and accessories for revolution and production counters, taximeters, mileometers, pedometers and the like; speed indicators, tachometers (excluding heading no. 9015), stroboscopes
1.0	903010	Instruments and apparatus; for measuring or detecting ionising radiations
1.0	903020	Oscilloscopes and oscillographs
1.0	903031	Multimeters; for measuring or checking voltage, current, resistance or power (other than those for measuring or checking semiconductor wafer or devices), without a recording device
1.0	903032	Multimeters; for measuring or checking voltage, current, resistance or power, with a recording device
1.0	903033	Instruments and apparatus; for measuring or checking voltage, current, resistance or power, without a recording device (excluding multimeters)
1.0	903039	Instruments and apparatus; for measuring or checking voltage, current, resistance or power, with a recording device (excluding multimeters)
1.0	903040	Instruments and apparatus; specially designed for telecommunications (e.g. cross-talk meters, gain measuring instruments, distortion factor meters, psophometers)
1.0	903081	Electrical measurement recording instruments
1.0	903082	Instruments and apparatus; for measuring or checking semiconductor wafers or devices (including integrated circuits)
1.0	903083	Instr f/radiat mes,recor
1.0	903084	Instruments and apparatus; n.e.c. in heading no. 9030, with a recording device
1.0	903089	Instruments and apparatus; n.e.c. in heading no. 9030, without a recording device
1.0	903090	Instruments, apparatus for measuring, checking electrical quantities, not meters of heading no. 9028; parts and accessories, for measuring or detecting alpha, beta, gamma, x-ray, cosmic and other radiations
1.0	950430	Games; operated by coins, banknotes, bank cards, tokens or by other means of payment, other than billiard articles and accesssories, and automatic bowling alley equipment
1.0	950450	Games; video game consoles and machines, other than those of subheading 9504.30

Sources: OECD 2019; UN Comtrade.