(Un)intended spillovers of export controls: evidence on the semiconductor production chain.

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Abstract

Export controls play a strategic role in the ongoing technological race between the United States and China. We collect information on unilateral US export control measures targeting China on semiconductors, and their related products, and merge it with trade data on exports from several countries operating in the semiconductor supply chain. First, we find a negative, significant, effect on US exports of chips. Second, results show positive and significant effects on the exports of equipment for the manufacturing of semiconductors from the EU, Japan, and Singapore. The only third country that reports a reduction in exports to China due to US measures is Taiwan. This evidence is suggestive of a lack of indirect enforcement of US policies on foreign jurisdictions, but also indicates temporary stockpiling of Chinese companies in anticipation of more stringent restrictions applied consistently by the major players in the value chain.

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1 Introduction

Export controls are among the preferred trade policy tools in the ongoing technological race between the United States and China (Bown and Wang, 2024). This type of trade restriction regulates and, in some cases, prevents the flow of sensitive technologies and materials to protect national security interests. Since governments are increasingly committed to maintaining a leading edge in strategic sectors to sustain their economic and geopolitical leadership, trade policy has recently become a key tool in achieving this objective (Fajgelbaum and Khandelwal, 2022; Amiti et al., 2019). Starting with the US Export Control Reform Act adopted in August 2018, the US Department of Commerce has implemented a series of unilateral measures targeting the semiconductor value chain, thus bypassing the multilateral regime on export controls primarily established by the Wassenaar Arrangement on dual-use items.[1] Despite the increasing adoption of unilateral export control measures by governments around the globe, little is known about their effects on trade flows of semiconductors, and semiconductor manufacturing equipment.

The strategic role of semiconductors has increased exponentially in recent years given their role for the functioning of advanced economies. In mid-December 2024, the combined market capitalization of the top 10 global chip companies reached a stunning 6.5 trillion US Dollars.[2] The semiconductor production chain is dominated by a handful of countries (Ciani and Nardo, 2022). However, given the high specialization of companies, no country is autonomous over the entire chain and different economies retain a leading position in specific segments of the chain. This might lead to the presence of choke-points in the production chain that can be leveraged to weaponize trade policy.

This paper investigates the causal effects of US export controls targeting China on the exports of countries playing a leading role in this production chain. We consider four waves of US export controls measures introducing additional restrictions to export flows of semiconductors, and related products, between 2020 and 2023. Our findings show that US exports decrease after the introduction of export controls, while there are significant adjustments, which are heterogeneous across the third exporting countries in the value chain.

We expect US export controls to have a *direct impact* on the exports of US companies. In addition, US measures can also have intended and unintended *spillover effects* on the exports of other countries operating along the production chain. Different mechanisms are in place behind these spillovers effects on third countries. First, one potential mechanism concerns the role played by the US Foreign Direct Product Rule (FDPR) and the *de minimis* rule, which oblige non-US companies relying on

[1]Since 1996, the Wassenaar Arrangement regulates trade flows in dual-use items.

[2]Refer to this Report prepared by Deloitte.

US technology, components, or personnel to be subject to US restrictions even if they are not directly under US jurisdiction. The second channel through which US policies might affect other countries' exports is the reorganization and adjustment of trade flows induced by the trade restrictions. For example, customers of companies potentially affected by restrictions might switch suppliers or strengthen relationships with those not subject to the policy to ensure continued access to the targeted products. Third, trade circumvention may also occur. Even without a substantial shift in suppliers, companies constrained by these rules might attempt to bypass them by exporting to China through third countries or intermediaries. Fourth, we expect an indirect effect through lobbying actions by the US government, which aim to align like-minded countries playing a determinant role in the supply chain, such as Japan or the Netherlands, to also impose such type of measures.

To perform our empirical investigation, we create a unique database merging information on US export control policies targeting China for specific products in the semiconductors' chain with export flows of these same items. Monthly-level trade data, spanning from January 2017 to August 2024, is retrieved from UN Comtrade for selected geographical jurisdictions (US, EU, Taiwan, Japan, Malaysia, Singapore, and South Korea). We focus on a set of 33 HS 6-digit products belonging to the semiconductor production chain.[3] To obtain information on semiconductors products targeted by the US export controls measures, we collect data from the Global Trade Alert (GTA) database.[4] The GTA database reports information on unilateral state interventions that are likely to affect international trade, such as subsidies, export-related measures, tariffs, or protective measures. As our focus is on export control measures imposed by the US on China, we specifically choose policies where the US is the implementing jurisdiction and China is listed as one of the affected countries. Finally, we select only interventions that impact at least one semiconductor or semiconductor-related product.

To estimate the effects of these policies on trade flows, we adopt a difference-in-differences approach. We run separate regressions for the US to examine the direct effects of export controls on US export dynamics and for other key exporting countries to investigate potential spillover effects. Given the high-dimensionality of our data, we include origin-destination-month, origin-product-month, and origin-destination-product fixed effects to control for changes in exports driven by unobserved factors other than export controls. Moreover, we adopt four specifications that allow us to account for extensive versus intensive margin effects, either by using different definitions of the dependent variable or by implementing the PPML

[3] In their studies on the EU semiconductor value chain, Ciani and Nardo (2022) and Bonnet and Ciani (2023) provide a list of trade codes at the HS-6-digit level related to chips and integrated circuits, as well as machines for the manufacturing of chips, wafers, raw materials and other inputs.

[4] Refer to the GTA website for more detailed information.

estimator. Finally, given the sequential nature of policy implementation, we rely on a staggered difference-in-differences approach, comparing the evolution of exports over time for products subject to US export control measures on China with those of products and destinations unaffected throughout the sample period.[5]

First, we find a negative, significant, effect on US exports of chips. The introduction of US export control measures led to decreases of US exports to China between 21.6 percent and 36 percent during the period under investigation. Secondly, there are positive and significant effects on the exports of equipment from the EU, Japan, and Singapore, hinting to a lack of (indirect) enforcement in non-US jurisdictions, but also indicating temporary stockpiling of Chinese companies in anticipation of more stringent restrictions.[6] The EU and Japan report an increase in the export of semiconductor manufacturing equipment to China equal to 139 and 65 percent, respectively. The significant, positive, impact on exports from Singapore supports the presence of trade circumvention, given the limited production capacity of Singapore in this segment. Importantly, the only third country reporting a reduction of exports to China due to US export controls is Taiwan.

We also observe a, mild, positive effect for chips exported by third countries at the extensive margin. These countries might have started to export chips previously supplied by US companies, in line with the negative impact on US chip exports at the intensive margin and suggesting a substitution effect in the sourcing preferences of Chinese firms. When accounting for the heterogeneity in the adoption of the four export control policies, effects seem to be driven by the latest measures introduced in October 2022 and November 2023. The staggered DiD estimates suggest that the positive effect on exports of equipment for third countries starts to be effective after 8 months and remains consistently positive. Meanwhile, we observe a negative and significant effect on chips' exports from third countries 6 months after the introduction of the policy.

Overall, our findings suggest that unilateral trade restrictions, such as the recent wave of US export controls on semiconductors, can have unintended spillover effects on exporters operating in the various segments of the production chain, thereby influencing the trade performance of other countries. This, in turn, could imply that a multilaterally coordinated set of policies should be preferred to achieve the desired policy target, especially in the case of a highly dispersed and segmented production chains, such as the one of semiconductors.

[5]More precisely, we use the estimator proposed by Nagengast and Yotov (2025), which accounts for heterogeneous treatment effects in a PPML setting with high-dimensional fixed effects.

[6]The interested reader can refer to this column, which appeared on the Financial Times in August, 2023.

Literature review. Our study contributes to different strands of the literature. First, it builds on the extensive body of work examining the impact of protectionist measures and economic sanctions on trade. A wide stream of research investigates the impact of protectionist measures on trade and domestic economies, focusing mainly on tariffs (Fajgelbaum and Khandelwal, 2022; Amiti et al., 2019; Bown, 2020). Recent studies focus on the trade effects of economic sanctions (Afesorgbor, 2019), with a particular emphasis on the sanctions imposed on Iran, in 2010, (Haidar, 2017) and Russia, in 2014 (Crozet and Hinz, 2020). Several papers have investigated the trade effects of political tensions with China, including those written by Fuchs and Klann (2013), Heilmann (2016), and Du et al. (2017)). We contribute to this literature by providing evidence on the effects of unilateral US export control measures in the semiconductor industry with the aim of quantifying the direct and indirect effects on trade flows of such measures.

A second stream of the literature to which we contribute to is related to the effectiveness of non-tariff policy tools and, more precisely, in the context of a high-tech industry, such as semiconductors. Ando et al. (2024) analyze the effect of US export controls, and specifically the entry of the Chinese company Huawei into the US Entity List[7], on Japanese exports. Hayakawa et al. (2023) study the effects of the Japanese export control regulation, and the US restrictions affecting Huawei, on Japanese exports, finding that it is more costly for exporters to obtain export permission from the US government than from the Japanese government. Makioka and Zhang (2023) focus on the Japan-Korea trade dispute in the semiconductor industry, while Anwar et al. (2024) look at the effects of US export controls on the innovation strategies of Chinese firms. Our study contributes to this stream of the literature by providing evidence on a heterogeneous group of jurisdictions indirectly affected by US export controls, with the aim of assessing whether adjustments differ across segments of the value chain.

This manuscript unfolds as follows. In Section 2, we describe the database and the policy context, Section 3 illustrates the empirical specification. Estimation results are reported in Section 4, while additional mechanisms and robustness checks are discussed in Section 5. Section 6 concludes.

[7]This refers to the decision made by the US Department of Commerce in 2019 to add the Chinese company Huawei, together with its affiliates, to a list of entities deemed to pose a national security risk to the United States. This listing imposes significant restrictions on Huawei's ability to do business with American companies and access certain technologies, particularly those related to semiconductors and telecommunications equipment

2 Data and Background

2.1 Data

Our dataset is built using data on US export control policies and monthly level data on export values for the United States, European Union, Japan, Malaysia, Singapore, South Korea, and Taiwan in the period January, 2017 - August, 2024, available from Comext.[8] Concerning the policy component of the database, we collected information related to the introduction of US export control measures on semiconductor-related products from the Global Trade Alert (GTA) database.[9] The GTA database tracks information on unilateral state interventions since 2008 that are likely to affect international trade, such as subsidies, export-related measures, tariffs, or protective measures. Each GTA database entry reports key information on the policy, including the timing of the intervention (announcement, publication, and implementation date), a short title describing the policy, the implementing and affected jurisdictions, the intervention type, the affected products (HS-six-digit level), as well as relevant links to the official document and official websites used to build this database.

We selected interventions categorized under the UN Mast Chapter P3.[10] Under this chapter, we are interested in GTA intervention types labelled as "Export bans," which prohibit the exports of certain products, and "Export Licensing Requirements," which encompass all measures related to requirements by the governments of the exporting country to obtain a license before exporting products.[11] Additionally, as our focus is on export control measures imposed by the US on China, we specifically chose policies where the US is the implementing jurisdiction and China is listed as one of the affected countries.

Finally, we selected only interventions that impact at least one semiconductor-related product, exploiting the information on the affected products provided by GTA. In their studies on the EU semiconductor value chain, Bonnet and Ciani (2023) and Bonnet et al. (2025) provide a list of trade codes (HS-six-digit or CN-eight-digit) related to chips and integrated circuits, as well as machines for the manufacturing of wafers and semiconductors, together with raw materials and inputs. For example, the majority of chips and ICs fall under headings 8541 and 8542 of the HS custom classification, while machines are categorized under heading 8486.

[8] Data on exports from Taiwan is available thanks to a specific agreement between Eurostat and the Taiwan Customs Office.

[9] The GTA database is available here.

[10] Chapter P3 includes "export licences, export quotas, export prohibition and other restrictions other than sanitary and phytosanitary or technical barriers to trade measures".

[11] This types of measures corresponds to the Non-Tariff measures "P31 Export prohibitions" and "P33 Licensing, permit or registration requirements to export" of the UNCTAD UN MAST classification, which can be found here.

We utilized these mappings of trade codes related to the semiconductor value chain and the GTA information on each intervention's affected products to define our set of semiconductor-related export control policies.Given the scope of our empirical investigation, we focus on products belonging to three different segments of the semiconductor value chain: semiconductor manufacturing equipment, wafers, and the final products of the production chain, i.e. analog, discrete, logic, micro chips, and memories.

2.2 Background on US Export Control Policies

Before the recent wave of export controls issued by the US government, trade flows of a limited set of products pertaining to the semiconductor production chain were regulated by multilateral agreements. These agreements had the objective to limit exports of items that could be employed for both civil and military applications (i.e. dual use items). In fact, mostly the final products of the production chain, the integrated circuits, were subject to multilateral measures aimed at restricting trade to specific destinations.

Since 1996, the Wassenaar arrangement regulates trade flows in dual-use items.[12] This multilateral export control regime governs the export of goods with civil and military applications, including also integrated circuits. Participating countries agree to implement controls on their exports by implementing a licence system and ensure that their exports are not used for malicious purposes. During the last decades, parties involved in the Wassenaar arrangement started to experience disagreement on the implementation of additional export controls measures. As a consequence, some of its members introduced unilateral measures to control trade flows of products in the semiconductor value chain. In the recent years, the US Government started to use export controls measures more aggressively to hamper the efforts of the Chinese leadership aiming at reducing the technological gap with the US in the manufacturing of high-performance computers.[13]

During the first Trump administration, in 2019, the US introduced measures aiming at reducing exports of chips to China to address national security concerns related to critical infrastructure and telecommunications. At the time, the Chinese

[12]Countries participating to the Wassenaar Arrangement are: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India (since 2017), Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Republic of Korea, Romania, Russian Federation, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Türkiye, Ukraine, United Kingdom and United States. In addition to the participating countries, the Wassenaar Arrangement also has associate members that are not full members but participate in the regime's activities and implement its control lists: Israel, Singapore, Taiwan. The Wassenaar Arrangement also has guest countries that participate in its meetings and activities but are not full members or associate members: Brazil, Chile, China, Egypt, Indonesia, Kazakhstan, Malaysia, Pakistan, Philippines, Saudi Arabia, Thailand, United Arab Emirates.

[13]The interested reader can refer to this column.

company Huawei was set to become a world leader in the production and installation of 5G networks, thus holding control on strategic information wherever these networks were installed. US export controls targeting Huawei followed a US Department of Justice (2019) charge on Huawei for wire fraud, obstruction of justice, conspiracy and attempted theft of trade secrets. This first wave of controls aimed therefore at limiting exports to China of advanced semiconductors essential to set-up 5G networks. Nevertheless, these policies were subject to a crucial weakness: chips sold to China were mostly manufactured outside the US. For this reason, the US administration announced that also foreign manufacturers could not employ US technology to produce chips for Huawei. The US government implemented then the foreign direct product rule (FDPR) which forbids foreign chips manufacturers to supply chips to Huawei if they want to continue using US-made equipment in their production chains.[14]

The purpose of the present study is to assess the effect of unilateral measures recently issued by the US administration to control exports to China. When selecting unilateral policies under consideration, a balance has to be struck between the novelty of the policy under analysis and the amount of data points available after their introduction. The first policy we take into consideration is the restriction on exports of specific high-technology goods intended for military end-use to China, Russia, and Venezuela, introduced by the US Bureau of Industry and Security (BIS) in June, 2020. This measure mostly targeted integrated circuits which could be employed also in military applications. This policy expanded licensing requirements for China to include military end-users. It also increased the list of items for which the licensing requirements and review policy apply, and broadened the definition of military end use.

The second policy we consider, issued by the US administration in August, 2022. This policy, was mostly aimed at reducing exports of chips produced by the US Company Nvidia to China and Russia with the aim of preventing their use for military end-use or by military end-users. In particular, the US government imposed a system of additional license requirements on exports to China, Hong Kong, and Russia of the Nvidia's A100 and H100 integrated circuits, or any system incorporating them. This regulation also implied that licenses were implicitly needed for any future Nvidia chip achieving a performance equal or greater than the A100 and H100 chips, or any system including these circuits. Finally, licences were introduced for the export of technology supporting the targeted products as well as to further develop and enhance their performance.

[14]US companies like Applied Materials, Lam Research, and KLA-Tencor together with the EU company ASML are leaders in the equipment segment. The FDPR was created in 1959 and tailored during the Cold War to inhibit the trade of items subject to national security controls in the event they were produced overseas either as a product of US technology or in a plant using US technology.

The third policy concerns the introduction of controls on the most sophisticated chips and on advanced semiconductor equipment to China, issued in October 2022. This new set of controls were an additional policy designed by the US administration to influence the organization of the global semiconductor production chain. In this policy, the Export Administration Regulations (EAR) was modified by the BIS to introduce additional controls on specific equipment employed in the production of semiconductors, on integrated circuits for advanced computing, and on computer devices containing these circuits. By focusing on equipment, the US government started to exploit a choke-point in the value chain resulting from the leadership of US companies in the equipment segment. Moreover, controls on the targeted products were increased by expanding the scope of foreign-produced items subject to licenses according the foreign-direct product rule (FDPR). Under this new regulation, activities of US citizens supporting the technological development and manufacturing of certain types of integrated circuits became conditional on a licence issued by the US Administration. To minimize the negative short-term impact on the semiconductor value chain of this intervention, the BIS established a temporary general license scheme to enable the manufacturing in China of specific products to be exported to the Western markets.

The fourth policy under our scrutiny is the one introduced by the BIS in November, 2023, targeting semiconductors, semiconductor manufacturing equipment, and super-computing items with the aim of further reinforcing controls imposed on exports to China in October 2022. The final goal of this measure was to further restrain China's capability to manufacture advanced semiconductors with possible applications in the military sector, AI applications, and advanced computing which can have military use.[15] This policy introduced controls on high-bandwidth memory circuits (HBM), while 140 new Chinese companies were added to the entity list. Regulatory changes to improve the cogency of previous controls were also introduced. Figure 1 displays a timeline with the implementation date of the four semiconductor-related policies potentially impacting exports to China.

[15]Another factor explaining this tightening of rules could have been the announcement by the Chinese company SMIC that it was capable of manufacturing advanced semiconductors despite US export controls directly targeting the company introduced by the first Trump administration.

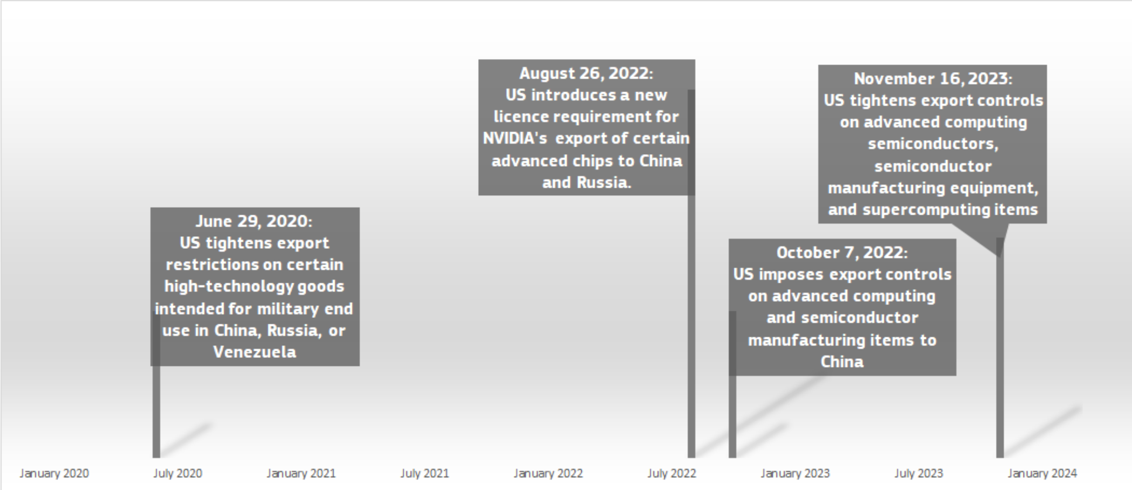


Figure 1: Timeline of Semiconductor-Related Policies Affecting Exports to Chinese Companies (with Implementation Dates). Data on US export controls policies are retrieved from the Global Trade Alert database.

2.3 Motivating Evidence

We now report, as motivating evidence of our paper, the trend of aggregate export flows for the two segments of the value chain, chips and equipment, both for the jurisdiction imposing the export controls (the US) and for one of the jurisdictions indirectly affected by the US measures (the European Union).[16] Figure 2 displays data for exports (excluding China) of semiconductor manufacturing equipment from the US and EU. While showing an increasing trend after the Covid-19 pandemic, we observe that after the implementation of US export controls in October 2022, EU and US world exports experienced a reduction. In contrast, when looking at exports of semiconductor manufacturing equipment to China, reported in Figure 3, we observe a striking increase in EU exports starting in the early months of year 2023. On the contrary, US exports of equipment to China experience a reduction followed by a mild increase in the second half of 2023 and early 2024.

Looking at US and EU exports of chips to the world (excluding China), reported in Figure 4, we observe that export control measures introduced in 2020 were not associated with a reduction in chips exports from the EU and US. On the contrary, starting from the second half of 2020 and during 2021, we observe a sharp increase in chips' exports due to higher world demand fueled by the pandemic and the reorganization of production chains following the chip shortage experienced by large manufacturing sectors, such as the automotive. In contrast, export control measures introduced in the second half of 2022 seem to be associated with a reduction in exports from both jurisdictions, more pronounced for the US, milder for the EU.

[16] Data on export flows for other affected jurisdictions is reported in the Appendix.

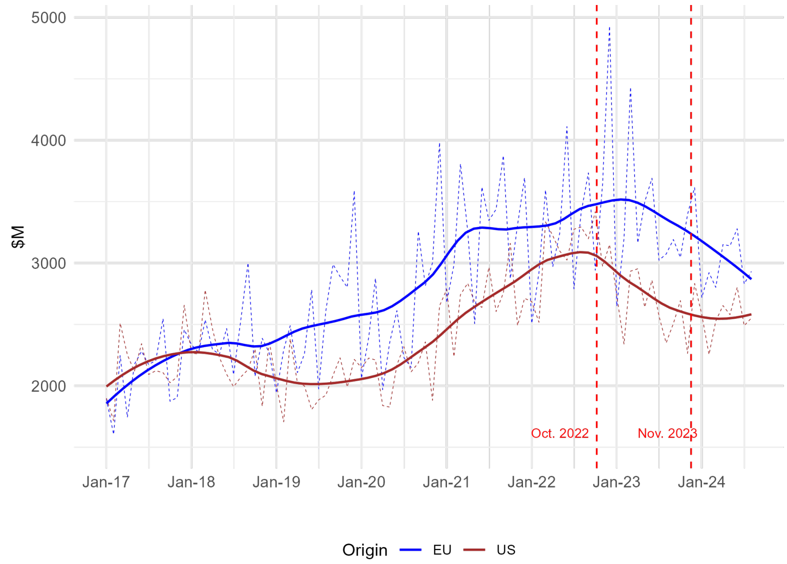


Figure 2: Export values ($M) to the world (ex China), equipment segment.

Notes: Dashed lines show the monthly trade flows, the bold ones show the loess smoother using local regressions (smoothing parameter = 0.4). The vertical red line shows the implementation date of the US export controls on advanced computing and semiconductor manufacturing items to the People's Republic of China (PRC) (Oct.2022). EU represents data for EU27 countries. Data on monthly trade flows are retrieved from UN Comtrade; data on US export controls policies are retrieved from the Global Trade Alert database.

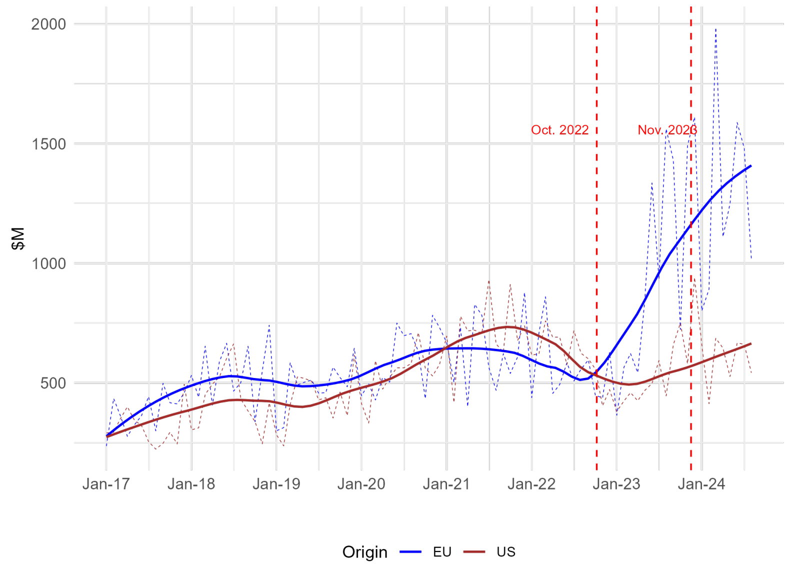


Figure 3: Export values ($M) to China, equipment segment.

Notes: Dashed lines show the monthly trade flows, the bold ones show the loess smoother using local regressions (smoothing parameter = 0.4). The vertical red line shows the implementation date of the US export controls on advanced computing and semiconductor manufacturing items to the People's Republic of China (PRC) (Oct.2022). EU includes EU27 countries. China includes Hong Kong and Macao. Data on monthly trade flows are retrieved from UN Comtrade; data on US export controls policies are retrieved from the Global Trade Alert database.

Focusing on chips' exports to China, in Figure 5, we observe a more pronounced reduction in flows from both jurisdictions starting from the second half 2021 and continuing for the following 20 months. A rebound in exports to China is observable starting from the second half of 2023. In the coming sections of this paper we develop an empirical strategy which should enable us to assess and quantify the causal impact of US export controls on export flows from the US and from the geographical

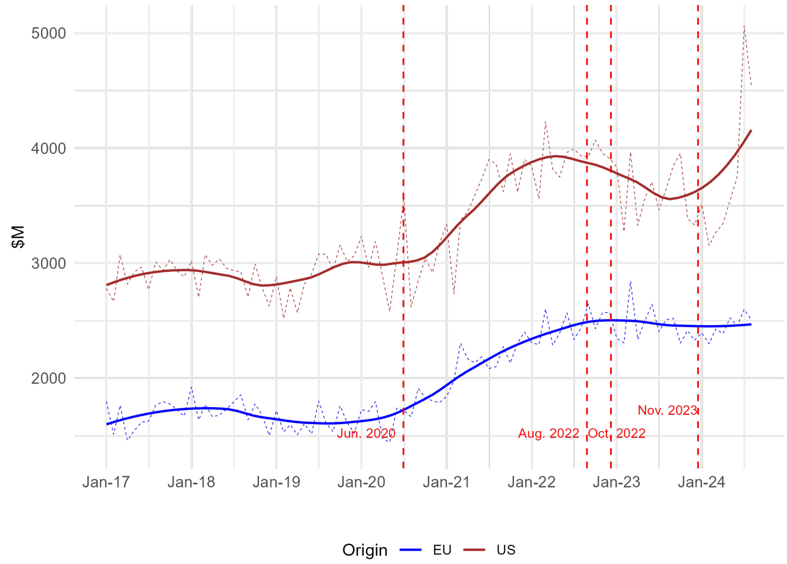


Figure 4: Export values ($M) to the world (ex China), final products segment

Notes: Dashed lines show the monthly trade flows, the bold ones show the loess smoother using local regressions (smoothing parameter = 0.4). The vertical red line shows the implementation date of exports restrictions of certain high-technology goods intended for military end use in China, Russia, or Venezuela (June 2020), US restrictions on the exports of NVIDIA chips to China and Russia (Aug. 2022), and of the US export controls on advanced computing and semiconductor manufacturing items to the People's Republic of China (PRC) (Oct.2022). EU includes EU27 countries. Data on monthly trade flows are retrieved from UN Comtrade; data on US export controls policies are retrieved from the Global Trade Alert database.

jurisdictions indirectly affected by these policies (i.e. spillover countries).[17]

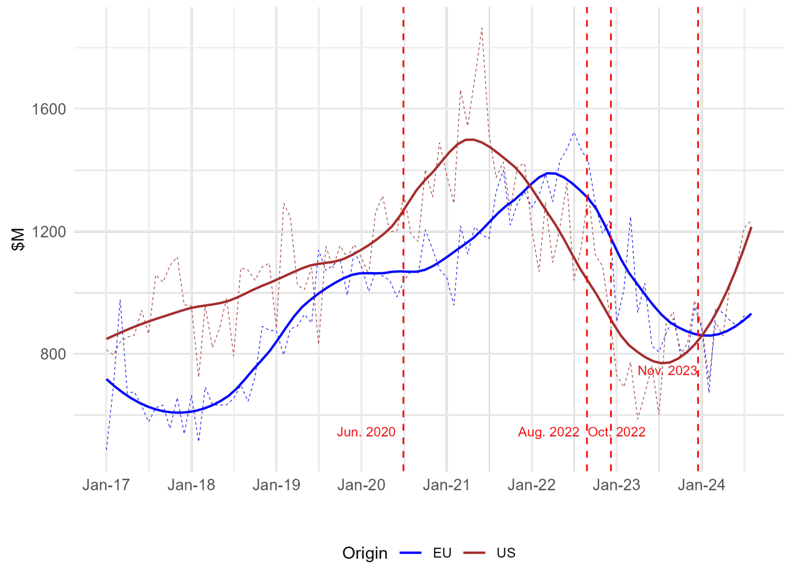


Figure 5: Export values ($M) to China, final products segment

Notes: The dashed lines show the monthly trade flows, the bold ones show the loess smoother using local regressions (smoothing parameter = 0.4). The vertical red line shows the implementation date of exports restrictions of certain high-technology goods intended for military end use in China, Russia, or Venezuela (June 2020), US restrictions on the exports of NVIDIA chips to China and Russia (Aug. 2022), and of the US export controls on advanced computing and semiconductor manufacturing items to the People's Republic of China (PRC) (Oct.2022). EU includes EU27 countries. China includes Hong Kong and Macao. Data on monthly trade flows are retrieved from UN Comtrade; data on US export controls policies are retrieved from the Global Trade Alert database.

[17] As confirmed by industry data, demand for chips largely increased during the pandemic and then decreased when production capacity of new production facilities became available.

2.4 Descriptive Statistics

In Table 1, we report statistics on the number of HS 6-digit products exported, on average, by each exporting jurisdiction together with the average number of destination countries reached, by product. Statistics show that, on average, the different origin countries under analysis export 22 products in the semiconductor value chain across 110 destinations. Data show that China, together with the US, and the EU are the geographical entities exporting the largest amount of products in the chain, and whose exports reach the highest number of destinations, on average. On the opposite extreme, Malaysia is the country exporting, on average, the lowest number of products, 19, to the smallest number of destinations across the globe, 57. Taiwan and South Korea seem to have a similar export structure as they export 20 products across 75 and 76 destinations, respectively.

Table 1: Number of Exported Products and Destinations reached by product

	CN	EU	JP	KR	MY	SG	TW	US	Total
N. of 6-digit Products	23	24	20	19	19	21	20	24	22
N. of Destinations	137	135	84	75	58	76	76	128	107

Summary statistics on the estimation sample for the period January, 2017 - August, 2024.

Table 2 shows the amount of HS 6-digit products under analysis in the different segments of the value chain, as well as the number of products affected by the four US export control policies under analysis. It is evident that policies adopted in October 2022 and in November 2023 imposed controls on a higher number of products both in the equipment segment and in the final products segment. Interestingly, wafers were not affected by US export controls.

Table 2: Number of Products affected by US export controls

Segment of Value Chain	N. of 6-digit Products	N. of 6-digit Products affected by the policy			
		Jun. 2020	Aug. 2022	Oct. 2022	Nov. 2023
Wafers	2	0	0	0	0
Equipment	17	0	0	5	5
Final Products	13	1	5	11	11

Summary statistics on the estimation sample for the period January, 2017 - August, 2024.

Figure 6 reports data on aggregate export flows, across the different segments, for the different jurisdictions taken under consideration in our empirical exercise, in year 2023. Data show that trade in final products, accounts for the largest amount of flows in the three segments, while trade in wafers and equipment represents a relatively smaller share of trade in this production chain. From the histogram, we can also observe that China and Taiwan are the leading exporters of final products in the chain. China has a leading position due to its exports of analog and discrete devices, while Taiwan has a leading role in the export of logic chips and memories. Korea and Singapore follow in the ranking. The EU, together with the US, is the leader in the export of semiconductor manufacturing equipment, while China is the leader in wafer exports, followed by the EU, Japan, and the US.

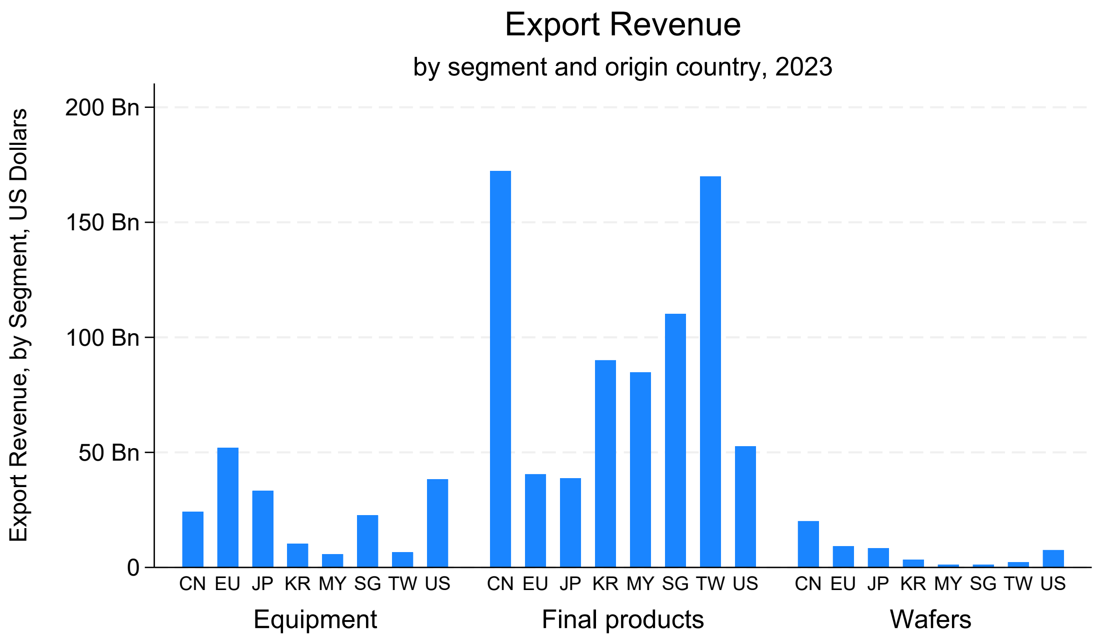


Figure 6: Export Revenue across segments of the value chain.

3 Empirical Model

Throughout our analysis, we will estimate a standard difference-in-difference specification and conduct an event study exercise comparing exports from *spillover countries* to China with exports from *spillover countries* to the rest of the world. Our baseline regressions will include only semiconductors and semiconductor-related products, while we extend the analysis to all products in Section 5 where we perform several robustness checks. We estimate the following baseline specification:

$$Y_{odpt} = \beta Post_t \times CHN_d \times TargetSEMIC_p + \alpha_{odp} + \alpha_{opt} + \alpha_{odt} + \varepsilon_{odpt} \qquad (1)$$

Our coefficient of interest is β, which captures the effect of the triple interaction between (i) the binary variable for the introduction of the policy ($Post_t$) (ii) another binary variable indicating China as target of the export controls (CHN_d) among destination countries and (iii) a third dummy equal to one when the product is a semiconductor, object of the policy. We saturate the specification with a rich set of fixed effects to consider different sets of factors which may hamper our identification due to the omitted variable bias. We include origin-destination-product fixed effects (α_{odp}) to control for any time invariant characteristic within cross-section units. Origin-product-month (α_{opt}) fixed effects absorb product-specific supply shocks, together with industry trends, that are common for all destination countries but can depend on the inherent features of the exporting country. Origin-destination-month (α_{odt}) fixed effects account for macroeconomic factors affecting all products traded between a given country pair. We estimate Equation 1 using both OLS and Poisson pseudo-likelihood (PPML), adoptinng different outocme variable to capture both the intensive and extensive margin of export, and we further split the policy variable to distinguish between different segments of the semiconductor supply chain actually affected, i.e. equipment and chips.

We also estimate an event study version of equation 1:

$$Y_{odpt} = \sum_{l=-T}^{T-1} \beta_l (USExportControl_{pt}) + \alpha_{odp} + \alpha_{opt} + \alpha_{odt} + \varepsilon_{odpt} \tag{2}$$

where $USExportControl^l_{pt}$ are now event time dummy variables equal to 1 for each period after the introduction of US export control policies on a given product p, and 0 in other time periods, and y_{opct} are the exports, or the export dummy, for the different origin countries o, to all destination countries c for a given product p. Here, each coefficient β_l captures the relative trends of the affected export flow to China in each period time after the policy shock compared to exports of never affected products and destinations and not-yet affected products. To estimate Equation 2, we rely on the methodology developed by Nagengast and Yotov (2025), who generalize the linear setting from Wooldridge (2021) proposing an extended two-way fixed effect estimator specifically for the estimation of nonlinear models.[18]

4 Results

All baseline specifications reported in Table 3, which focuses on the effects on US exports, include destination-product, product-month, and destination-month fixed effects to take into account confounding factors that may hamper the proper identification of the effects under investigation, as detailed in the previous Section. In Table 4, which focuses on the effects on other exporting countries, we include origin-destination-product, origin-product-month, and origin-destination-month fixed effects to account for origin-level factors affecting exports. In both Tables, Panel A reports estimates obtained without distinguishing between export control measures affecting chips or semiconductor manufacturing equipment, while Panel B reports estimates obtained distinguishing whether a given measure affects either one or both segments of the value chain. The first specification, displayed in column (1), reports estimates obtained employing *ln(exports + 1)* as a dependent variable to take into account both trade zeros and positive export values when running our estimations.

[18] The extended two-way fixed effect estimator maintains the general structure of the basic two-way fixed effect regression, but it also allows for treatment effect heterogeneity by additionally introducing suitable cohort (i.e., all units treated in a particular year) and year interactions.

This specification therefore assesses the effect of the policy measure on both the intensive and the extensive trade margin. The second specification, included in column (2), reports findings obtained using the Poisson Pseudo Maximum Likelihood (PPML) estimation method, proposed by Silva and Tenreyro (2006). PPML estimators provide an additional advantage, given to their robustness to heteroscedasticity in log-linear gravity equations and their capability to take into account trade zeros. As consequence, PPML estimation enables us to assess effects on both the intensive and the extensive trade margin. The third specification, displayed in column (3), estimates an OLS model using the logarithm of export value as dependent variable. Consequently, this specification reports on effects of export controls on the intensive margin of trade. The fourth specification, reported in column (4), relies on a linear probability model to determine effects on the extensive trade margin using a dummy variable equal to one for positive export flows and zero for zero trade flows between country pairs for a given product.

Direct Effects on US Exports In Table 2, we investigate direct effects of US export control interventions on US exports of targeted products. Coefficients reported in Panel (A) show that effects are mostly due to reductions in export flows. Indeed, looking at estimates reported in column (3), the introduction of US export control measures led to a reduction of US exports by 25.4 percent to China.[19] Estimates reported in columns (1), (2), and (3) of Panel (B) show that this decrease in export flows can be ascribed to a reduction in the exports of final products in the semiconductor production chain. The introduction of US export control measures led to decreases of US chips' exports to China between 21.6 percent, as reported in specification (2), and 36 percent, as in specification (1). Looking at results in column (4), do not find evidence of exit of US exports from destinations markets. Overall, results point to a reduction in US exports mainly due to adjustments at the intensive margin.

[19] The magnitude of estimated coefficients is obtained using the formula: $100 * (e^{\hat{\beta}} - 1)$.

Table 3: Direct Effects on US Exports

Dep. Var.:	OLS ln($Exports + 1$) (1)	PPML $Exports$ (2)	OLS ln($Exports$) (3)	OLS $ExportDummy$ (4)
Panel A:				
$Post_t \times CHN_d \times TargetSEMIC_p$	-0.218	-0.132	-0.293*	0.007
	(0.167)	(0.119)	(0.155)	(0.006)
Panel B:				
$Post_t \times CHN_d \times TargetSEMIC_p^{equip}$	0.223	0.174	0.093	0.003
	(0.246)	(0.116)	(0.239)	(0.011)
$Post_t \times CHN_d \times TargetSEMIC_p^{chips}$	-0.398**	-0.243*	-0.448***	0.009
	(0.174)	(0.125)	(0.166)	(0.007)
destination-product FE	Y	Y	Y	Y
product-month FE	Y	Y	Y	Y
destination-month FE	Y	Y	Y	Y
Observations	458,988	419,625	197,850	458,988
Adjusted R-squared	0.780		0.851	0.662
Pseudo R-squared		0.979		

Note: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Indirect Effects on other exporting countries. In Table 4, we investigate the effect of US export measures on the exports of other geographical entities to China. Coefficients reported in Panel (A) show that US export controls led to an increase in export flows to China for other countries whose companies operate in the semiconductor value chain. Findings reported in column (2) report a positive effect equal to 13 percent, significant at the 10 percent.

As shown by the findings reported in Panel (B) of the same Table, the increase in exports of geographies indirectly affected by US policies is mostly due to an increase in exports of equipment for semiconductor manufacturing. Findings reported in columns (1) and (2), report a positive effect ranging between 25.1 percent and 66.2 percent. The intensive margin contributes to this positive effect with a 22.7 percent increase, as reported in column (3). Notably, specification (4) of Panel (B) reports a positive effect on the extensive margin, suggesting that the introduction of US restrictions on the export of chips led to a 1.2 percent increase in the extensive export margin of other geographies. Reductions in US exports due to US export controls were then partly compensated by the entry of exporters of chips in the Chinese market.

Effects are heterogeneous across the various exporting countries indirectly affected by US export controls, as reported in Figure 7. The EU, Japan, and Singapore report increases in the export of equipment for the manufacturing of semiconductors to China. Singapore also reports an increase in chips' exports due to the introduction of US restrictions. On the opposite side, Taiwan exports of chips and equipment to China have significantly decreased after the introduction of US export controls.

The EU and Japan report an increase in the export of semiconductor manufacturing equipment to China equal to 139 and 65 percent, respectively. This increase can be explained by the rise of orders from Chinese chip manufacturers which, since the beginning of 2023, started stockpiling manufacturing equipment fearing that European and Japanese restrictions would have soon prevented to acquire also those products.[20] Results for Singapore show that exports to China from this country increase both for chips, by 36.7 percent, and semiconductor manufacturing equipment, by 94 percent. Since the Asian country is a major trade-hub and not a relevant manufacturing site for products in the two segments, we conclude that this finding is mostly supportive of a reorganization of trade flows taking place via the Republic of Singapore after the introduction of US export controls. US export control measures seem to have the intended indirect effect on Taiwan exports. Indeed, we find that Taiwanese exports of semiconductor manufacturing equipment decrease by 37.7 percent, while exports of chips decrease by 25.8 percent.

Table 4: Indirect Effects on Other Countries

	OLS	PPML	OLS	OLS
Dep. Var.:	$\ln(Exports+1)$	$Exports$	$\ln(Exports)$	$ExportDummy$
	(1)	(2)	(3)	(4)
Panel A:				
$Post_t \times CHN_d \times TargetSEMIC_p$	0.139	0.127*	0.087	0.005
	(0.099)	(0.075)	(0.062)	(0.006)
Panel B:				
$Post_t \times CHN_d \times TargetSEMIC_p^{equip}$	0.224*	0.508***	0.205**	-0.012
	(0.122)	(0.094)	(0.102)	(0.008)
$Post_t \times CHN_d \times TargetSEMIC_p^{chips}$	0.105	0.002	0.041	0.012*
	(0.110)	(0.065)	(0.067)	(0.007)
origin-destination-product FE	Y	Y	Y	Y
origin-product-month FE	Y	Y	Y	Y
origin-destination-month FE	Y	Y	Y	Y
Observations	1,690,526	1,461,494	658,104	1,690,526
Adjusted R-squared	0.792		0.858	0.675
Pseudo R-squared		0.989		

Note: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

[20] Anedoctal evidence on this stockpiling strategy is also confirmed by industry experts; see for example: https://www.ft.com/content/6a1a88ff-a122-41a0-8e16-d062f603f81c. Interestingly, the FT article mentions a surge in Chinese imports of chips equipment tools Chinese imports, with a magnitude around 70% over the period.

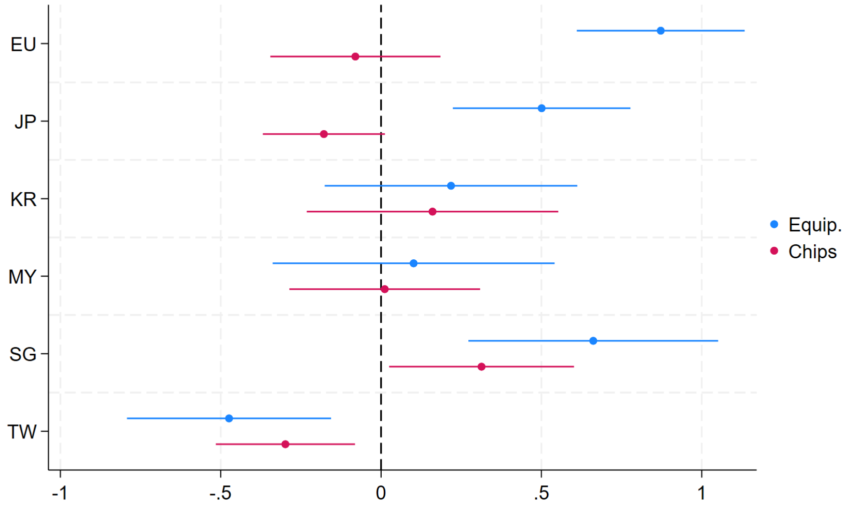


Figure 7: Heterogeneous Effects Across Spillover Countries
Notes: Coefficients obtained using PPML estimation.

Heterogeneity by policy. We now turn the attention to disentangling the effect of the four US export control policies on the exports of chips and semiconductor manufacturing equipment. In this section we report evidence on the exports of countries indirectly affected by US policies. We rely here on estimates obtained using PPML estimation as they take in consideration effects at the extensive and intensive margin while treating properly the presence on trade zeros. Findings obtained using PPML estimation, reported in Figure 8 show that policies had a similar effect on the export of chips by the geographies indirectly affected by US policies. On the contrary, policies introduced in October 2022, and November 2023 had a relevant effect on the export of semiconductor manufacturing equipment. The first policy led to an increase in the export of equipment by the all exporting geographies equal to 28 percent while the policy introduced in November, 2023 led to an increase in the exports of equipment equal to 74.2 percent. These findings further support the evidence discussed above, and confirm the positive indirect effects on the exports of equipment. On the other side, it is not possible to claim that any the four policies taken under consideration had either a positive or negative effect on the exports of chips of the countries under analysis.

In Figure A.1 we report PPML estimates for direct effects across policies on US exports. Coefficients confirm a negative, and significant, direct effect of the export control policy introduced in October 2022, while policies introduced in June 2020 and in November 2023 are associated with a positive effect on US exports of chips. Nevertheless, this is consistent with the average negative direct effect reported in Table 3, as the policy introduced in June 2020 affected only one product code in the group representing semiconductor chips, while the policy introduced in November 2023 has a limited impact on trade flows, given the time frame analyzed in our investigation.

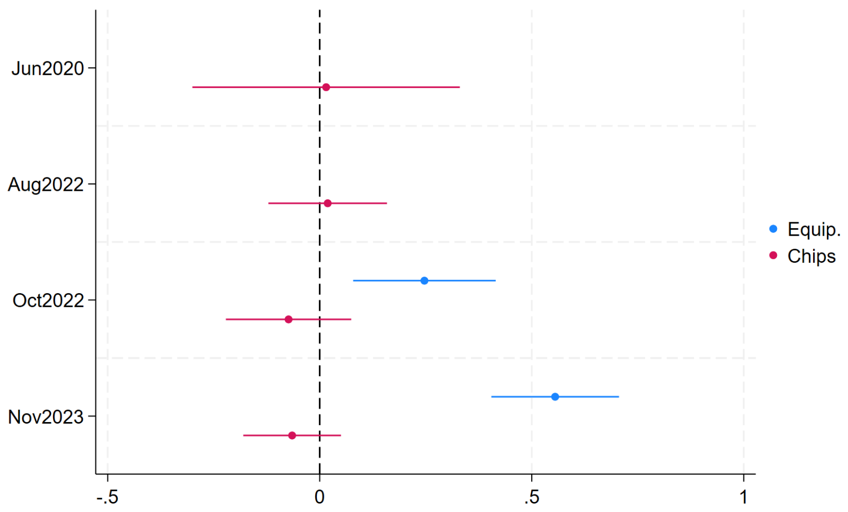


Figure 8: Heterogeneous Effects Across Policies for Spillover Countries

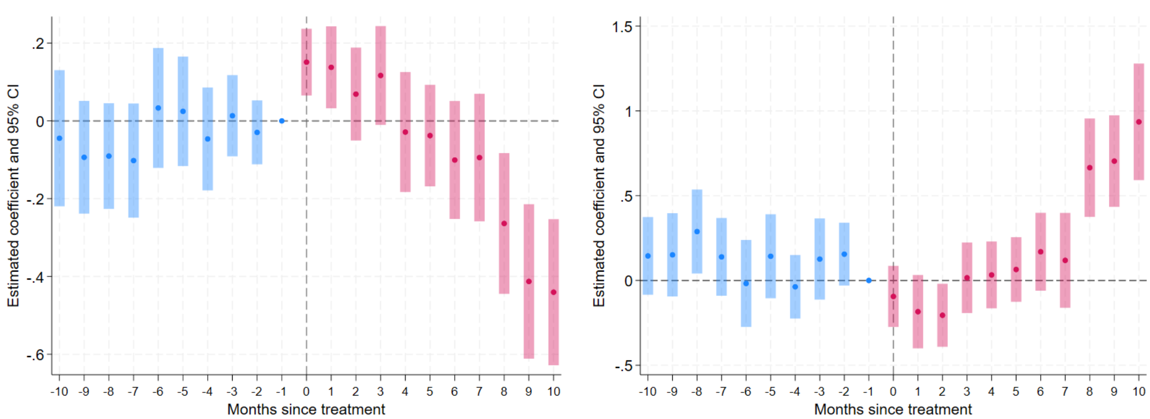
Notes: Coefficients obtained using PPML estimation.

Staggered difference-in-differences. Given the sequential implementation of US export policies between 2021 and 2023, in this Section we account for potential drawbacks of the standard two-way fixed-effects estimator and incorporate recent advances in the literature on heterogeneity-robust staggered difference-in-differences (DiD) estimators. We compare the evolution of exports over time for products subject to US export control measures targeting China with those of products and destinations unaffected throughout the sample period. More precisely, we use the estimator proposed by Nagengast and Yotov (2025), which accounts for heterogeneous treatment effects in a PPML setting with high-dimensional fixed effects.

Figure 9: Staggered Difference-in-Differences: Spillover Effects

Panel (a): Chips

Panel (b): Equipment



Notes: The figure plots the estimates from a PPML estimation of equation (X). Panel (a) shows results for export controls targeting chips, while panel (b) focuses in equipment. 95% confidence intervals are based on standard errors clustered at the origin-destination-product level.

Estimates reported in Figure 9 confirm that the pre-trend assumption is not violated for products in both segments of the value chain. More importantly, baseline results displayed in Table 4 on the indirect effects of US policies on exports of chips and manufacturing equipment are largely confirmed. The effect on exports of equipment is relatively small in the months right after the introduction of the policy but it builds up stronger after eight months. Exports of chips do not report significant reductions in the first eight months after the introduction of the policy, but suffer seizable reductions afterwards. Direct effects of the policy on US exports in a staggered treatment setting are illustarted in the Appendix, Figure A.2.

5 Additional Mechanisms and Robustness Checks

The imposition of US export controls on China may have triggered even more complex dynamics in global trade patterns of semiconductors, with effects propagating to countries with geographic proximity to China. To this end, we explore whether there are signals of trade diversion, triggered by US export controls, to ASEAN countries such as Vietnam or Singapore. A shift in the destination markets of products subject to US export controls might indicate more structural adjustments to the policy in terms of trade reallocation, but also potential violations of export controls, such as trade circumvention practices, where goods affected by export controls are re-shipped to China via third countries.[21] We conduct a preliminary investigation into whether there are concurrent changes in exports of semiconductor-related products to the ASEAN group of countries[22], potentially acting as a trade hub due to their geographic proximity to China. Indeed, the ASEAN community is among the top trade partner for China both on the import and the export side.

Table 5 reports diff-in-diff PPML estimates investigating exports from the US to ASEAN countries. In columns 1 and 2, we replace, in our baseline equation, the destination interaction term of the policy treatment status with a binary indicator for ASEAN countries as the destination, instead of China, excluding exports to China from the sample. In columns 3 and 4, we estimate separate coefficients for treatment effects on ASEAN and China as destination markets. Findings from all regressions confirm that US exports to ASEAN countries did not experience significant changes after the export control policies, relative to exports to other destination markets, regardless of whether we distinguish between equipment products or chips. [23] This suggests that there was no clear sign of trade diversion or circumvention of US

[21]For example, a FT article reports that US authorities have been investigating whether intermediate entities located in countries such as Singapore could have accumulated US Nvidia chips to re-sell to China: https://www.ft.com/content/65e9c766-9ff7-4ff8-bff1-2c1c05c9d802

[22]This group includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam

[23]Given the anecdotal evidence on potential trade circumvention via Singapore, we also explored effects using only Singapore as the destination market and did not find any significant effect.

exports of equipment and chips affected by the US export control measures via ASEAN countries, at least not visible at the aggregate level of export data.

On the other hand, when looking at estimates for the other exporting countries in Table 6, we find that exports of equipment products to ASEAN countries (columns 2 and 4) experienced an increase, although with a magnitude of about half the effect found for China. This concomitant increase in the exports of semiconductor manufacturing machines to ASEAN countries could even indicate that the positive spillover effects found for equipment exports to China might be even larger than those suggested by the diff-in-diff econometric analysis focusing only China as the affected destination market. This is particularly true if there are trade circumvention practices of export controls through third countries at play. However, these results should not be read as indicating obvious violations, since we are not yet taking into account trade flows between third-country trade hubs and China, or methods to detect illicit shipments. Instead, they underscore other potential channels of unintended spillovers, and, more generally, the difficulty of policing global trade in semiconductors, given how dispersed and decentralized is the global production chain for these goods.

Table 5: Effects on Exports of the US to ASEAN Countries:

Dep. Var.:	PPML *Exports*			
	excl. China		incl. China	
	(1)	(2)	(3)	(4)
$Post_t \times ASEAN_d \times TargetSEMIC_p$	-0.083		-0.097	
	(0.092)		(0.098)	
$Post_t \times ASEAN_d \times TargetSEMIC_p^{equip}$		0.105		0.111
		(0.174)		(0.174)
$Post_t \times ASEAN_d \times TargetSEMIC_p^{chips}$		-0.155		-0.174
		(0.111)		(0.116)
$Post_t \times CHN_d \times TargetSEMIC_p$			-0.143	
			(0.121)	
$Post_t \times CHN_d \times TargetSEMIC_p^{equip}$				0.197*
				(0.116)
$Post_t \times CHN_d \times TargetSEMIC_p^{chips}$				-0.266**
				(0.127)
destination-product FE	Y	Y	Y	Y
product-month FE	Y	Y	Y	Y
destination-month FE	Y	Y	Y	Y
Observations	416,681	416,681	419,625	419,625
Pseudo R-squared	0.975	0.975	0.978	0.979

Note: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 6: Effects on Exports of Other Countries to ASEAN Countries:

Dep. Var.:	PPML *Exports*			
	excl. China		incl. China	
	(1)	(2)	(3)	(4)
$Post_t \times ASEAN_d \times TargetSEMIC_p$	0.068		0.100	
	(0.058)		(0.063)	
$Post_t \times ASEAN_d \times TargetSEMIC_p^{equip}$		0.192**		0.306***
		(0.085)		(0.096)
$Post_t \times ASEAN_d \times TargetSEMIC_p^{chips}$		0.052		0.022
		(0.061)		(0.065)
$Post_t \times CHN_d \times TargetSEMIC_p$			0.150*	
			(0.080)	
$Post_t \times CHN_d \times TargetSEMIC_p^{equip}$				0.550***
				(0.094)
$Post_t \times CHN_d \times TargetSEMIC_p^{chips}$				0.001
				(0.070)
origin-destination-product FE	Y	Y	Y	Y
origin-product-month FE	Y	Y	Y	Y
origin-destination-month FE	Y	Y	Y	Y
Observations	1,444,559	1,444,559	1,461,494	1,461,494
Pseudo R-squared	0.981	0.981	0.989	0.989

Note: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

As a robustness check, we also run our baseline regressions on all Harmonized System (HS) products, without restricting the sample to semiconductor-related products. Tables Table 7 and Table 8 show that the results are very similar to those obtained in our baseline regressions, confirming the magnitude and significance of the positive effect on exports to China of equipment products from other countries (i.e., the indirect effects of export controls). In all these specifications shown in panel B, we estimate separate effects for product categories related to semiconductors (i.e., equipment and chips) and other products (e.g., radars, advanced electronics) that have also been affected by the different US regulations on export controls and are flagged in the GTA dataset. Results further support conclusions drawn from Tables 3 and 4.

Table 7: Direct Effects on US Exports - All HS products in sample

Dep. Var.:	OLS ln($Exports+1$) (1)	PPML $Exports$ (2)	OLS ln($Exports$) (3)	OLS $ExportDummy$ (4)
Panel A:				
$Post_t \times CHN_d \times TargetProducts_p$	0.416***	-0.098	0.038	0.037***
	(0.148)	(0.107)	(0.060)	(0.011)
Panel B:				
$Post_t \times CHN_d \times TargetSEMIC_p^{equip}$	0.616***	0.139	0.173	0.034***
	(0.222)	(0.101)	(0.217)	(0.009)
$Post_t \times CHN_d \times TargetSEMIC_p^{chips}$	0.015	-0.298**	-0.341**	0.040***
	(0.173)	(0.143)	(0.167)	(0.006)
$Post_t \times CHN_d \times TargetOther_p$	0.482***	0.057	0.119**	0.037***
	(0.184)	(0.081)	(0.059)	(0.014)
destination-product FE	Y	Y	Y	Y
product-month FE	Y	Y	Y	Y
destination-month FE	Y	Y	Y	Y
Observations	41,224,740	40,760,024	11,113,514	41,224,740
Adjusted R-squared	0.666		0.777	0.574
Pseudo R-squared		0.954		

Note: Robust standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.

Table 8: Indirect Effects on Other Countries - All HS products in sample

Dep. Var.:	OLS ln($Exports+1$) (1)	PPML $Exports$ (2)	OLS ln($Exports$) (3)	OLS $ExportDummy$ (4)
Panel A:				
$Post_t \times CHN_d \times TargetProducts_p$	0.174***	0.062	0.088***	0.012**
	(0.056)	(0.052)	(0.029)	(0.005)
Panel B:				
$Post_t \times CHN_d \times TargetSEMIC_p^{equip}$	0.304***	0.564***	0.225**	-0.005
	(0.110)	(0.105)	(0.093)	(0.008)
$Post_t \times CHN_d \times TargetSEMIC_p^{chips}$	0.208**	-0.025	0.076	0.018***
	(0.083)	(0.048)	(0.054)	(0.006)
$Post_t \times CHN_d \times TargetOther_p$	0.153**	-0.015	0.074**	0.012**
	(0.071)	(0.051)	(0.035)	(0.006)
origin-destination-product FE	Y	Y	Y	Y
origin-product-month FE	Y	Y	Y	Y
origin-destination-month FE	Y	Y	Y	Y
Observations	125,258,879	120,929,055	37,708,858	125,258,879
Adjusted R-squared	0.699		0.796	0.607
Pseudo R-squared		0.960		

Note: Robust standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.

6 Conclusion

This study provides novel insights into the effects of unilateral export control policies on trade flows along the semiconductor supply chain, a critical sector for advanced economics. Our findings suggest that the recent wave of US export controls targeting China has had significant and far-reaching consequences, not only for US companies but also for other countries operating in the production chain. The negative impact on US and Taiwan exports of chips to China is consistent with the expected direct effect of these policies, while the positive effects on the exports to China of equipment from the EU, Japan, and Singapore hint at a lack of indirect enforcement in non-US jurisdictions and potential stockpiling by Chinese companies.

The significant impact on exports from Singapore also suggests the existence of potential trade circumvention, highlighting the complexities and challenges of enforcing unilateral export controls in a globally interconnected supply chain. Furthermore, the positive effect on chip exports from third countries at the extensive margin implies a substitution effect in the sourcing preferences of Chinese firms, as they seek alternative suppliers to replace US companies. The heterogeneity in the adoption of the four export control policies and the staggered DiD estimates provide additional nuance, suggesting that the effects of these policies are driven by the latest measures introduced in October 2022 and November 2023.

The findings of this study have important implications for policymakers and highlight the need for a coordinated approach to export controls, particularly in sectors with highly dispersed and segmented production chains. The unintended spillover effects of unilateral trade restrictions can influence the trade performance of other countries, potentially undermining the desired policy targets. A multilaterally coordinated set of policies, such as those established by the Wassenaar arrangement on dual-use items, may be more effective in achieving national security objectives while minimizing the risks of trade circumvention and unintended consequences.

Ultimately, this research contributes to a deeper understanding of the complex interactions between trade policy, national security, and the global semiconductor supply chain. As the technological race between the United States and China continues to evolve, it is essential to consider the potential consequences of unilateral export control policies and to explore alternative approaches that balance national security interests with the need for cooperation and coordination in the global economy. By doing so, policymakers can work towards creating a more stable and secure trade environment that supports the growth and development of critical sectors like semiconductors.

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A List of HS product codes in the semiconductors' supply chain

HS17 code	HS2017 description	Segment
381800	Chemical elements; doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics	Wafers
382499	Chemical products, mixtures and preparations; n.e.c. heading 3824	Wafers
841410	Pumps; vacuum	Equipment
841459	Fans; n.e.c. in item no. 8414.51	Equipment
841490	Pumps and compressors; parts, of air or vacuum pumps, air or other gas compressors and fans, ventilating or recycling hoods incorporating a fan	Equipment
841950	Heat exchange units; not used for domestic purposes	Equipment
842129	Machinery; for filtering or purifying liquids, n.e.c. in item no. 8421.2	Equipment
842139	Machinery; for filtering or purifying gases, other than intake air filters for internal combustion engines	Equipment
842199	Machinery; parts for filtering or purifying liquids or gases	Equipment
844319	Printing machinery; used for printing by means of plates, cylinders and other printing components of heading 84.42, n.e.c. in item no. 8443.1	Equipment
848610	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers	Equipment
848620	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits	Equipment
848640	Machines and apparatus of a kind used solely or principally for the manufacture	Equipment

Continued on next page

HS17 code	HS2017 description	Segment
	or repair of masks and reticles, assembling semiconductor devices or electronic integrated circuits, or for lifting, handling, loading or unloading items of heading 8486	
848690	Machines and apparatus of heading 8486; parts and accessories	Equipment
901120	Microscopes, compound optical; for photomicrography, cinephotomicrography or microprojection	Equipment
903082	Instruments and apparatus; for measuring or checking semiconductor wafers or devices	Equipment
903084	Instruments and apparatus; n.e.c. in heading no. 9030, with a recording device	Equipment
903089	Instruments and apparatus; n.e.c. in heading no. 9030, without a recording device	Equipment
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	Equipment
853650	Electrical apparatus; switches n.e.c. in heading no. 8536, for a voltage not exceeding 1000 volts	Final products
854110	Electrical apparatus; diodes, other than photosensitive or light-emitting diodes (LED)	Final products
854121	Electrical apparatus; transistors, (other than photosensitive), with a dissipation rate of less than 1W	Final products
854129	Electrical apparatus; transistors, (other than photosensitive), with a dissipation rate of 1W or more	Final products
854130	Electrical apparatus; thyristors, diacs and triacs, other than photosensitive devices	Final products
854140	Electrical apparatus; photosensitive, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes (LED)	Final products

Continued on next page

HS17 code	HS2017 description	Segment
854190	Electrical apparatus; parts for diodes, transistors and similar semiconductor devices and photosensitive semiconductor devices	Final products
854231	Electronic integrated circuits; processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits	Final products
854232	Electronic integrated circuits; memories	Final products
854233	Electronic integrated circuits; amplifiers	Final products
854239	Electronic integrated circuits; n.e.c. in heading no. 8542	Final products
854290	Parts of electronic integrated circuits	Final products
903300	Machines and appliances, instruments or apparatus of chapter 90; parts and accessories n.e.c. in chapter 90	Final products

B Direct effects on US exports

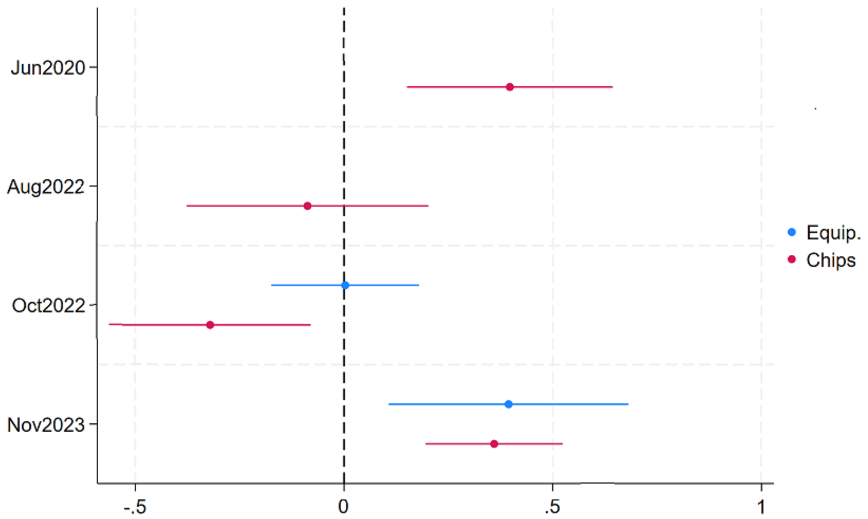
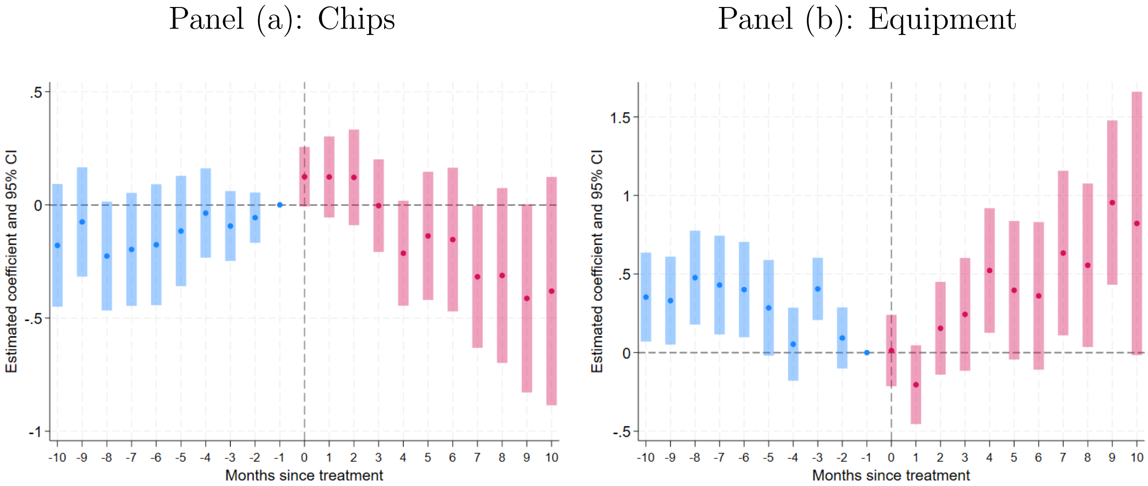


Figure A.1: Heterogeneous Effects Across Policies for US

Notes: Coefficients obtained using PPML estimation.

Figure A.2: Staggered Difference-in-Differences: Direct Effects on US exports



Notes: The figure plots reswults from a PPML estimation of equation 2. Panel (a) shows results for export controls targeting chips, while panel (b) focuses in equipment. 95% confidence intervals are based on standard errors clustered at the origin-destination-product level.