RIETI Discussion Paper Series 23-E-017

The Impact of Export Controls on International Trade: Evidence from the Japan–Korea trade dispute in the semiconductor industry

MAKIOKA, Ryo
RIETI

ZHANG, Hongyong
RIETI

RIETI
Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
https://www.rieti.go.jp/en/

RIETI Discussion Paper Series 23-E-017
March 2023

The Impact of Export Controls on International Trade: Evidence from the Japan–Korea Trade Dispute in the Semiconductor Industry[*]

Ryo Makioka Hongyong Zhang[†]

Abstract

In July 2019, the Japanese government announced export controls to South Korea of three chemical inputs essential in semiconductor production. The paper investigates the short- to middle-run effect of these Japan–Korea export controls on trade patterns (i.e., Japanese export and production and Korean import, export, and production) along the global value chain of the semiconductor industry. The results show that the export controls caused a large decline in Japanese exports to South Korea of one of the three restricted inputs, hydrogen fluoride, but not in the other two restricted inputs, photoresist and fluorinated polyimide. Second, the restrictions increased Japanese exports of hydrogen fluoride to the U.S., and thus did not cause a decrease in the Japanese production of semiconductor-related products. Third, South Korea reallocated input sourcing from Japan to economies such as Belgium, the U.S., and Taiwan. Fourth, South Korea increased the export of semiconductor manufacturing equipment to China, possibly because of its semiconductor production relocation to China. Fifth, Korean firms' domestic production and Japanese affiliates' local production in South Korea increased after the export controls. These results suggest a potential role of export controls in sourcing patterns and production relocation in the semiconductor industry.

Keywords: Trade, Export controls, Semiconductors, Japan–Korea trade disputes
JEL classification: F12, F13, F51, F52

[*] This study is conducted as a part of the Project "Empirical Studies on Crises and Issues in Global Supply Chains," undertaken at the Research Institute of Economy, Trade and Industry (RIETI). We thank Keisuke Kondo, Masayuki Morikawa, Masataka Saburi, Yoichi Sekizawa, Eiichi Tomiura, Makoto Yano, and Discussion Paper seminar participants at RIETI for their helpful comments. Makioka acknowledges financial support from JSPS KAKENHI (grant no. 21K13308). Zhang acknowledges financial support from JSPS KAKENHI (grant no. 22K01451). All remaining errors are ours.

[†] Makioka: Hokkaido University and RIETI, rxm425@gmail.com; Zhang: RIETI, zhang-hong-yong@rieti.go.jp

1 Introduction

Trade policy has played a main role in economic and national-security policy discussions in recent years. Notable examples are the U.S. trade restrictions against China in 2018, the U.S. trade sanction against Russia following its invasion of Ukraine in 2022, and the U.S. export controls on the Chinese semiconductor industry in 2019 in the name of national security. A recent body of work has studied the impact of these policies on trade and domestic economies, focusing mostly on import tariffs as policy instruments (e.g., Fajgelbaum et al., 2020; Bown 2021; Fajgelbaum et al., 2021; Latipov et al., 2022). Another remarkable feature in recent international trade is the expansion of the global value chain (GVC). Production process is fragmented across countries, and firms participate it by specializing in a specific task rather than producing the entire product. For instance, about 50% of world trade crosses at least two national borders, thus being related to GVCs (World Bank, 2020).

While research on trade policy and GVCs have been prevalent, the trade-policy effect on GVCs is under-studied (Antras and Chor, 2022). Furthermore, the effect of non-tariff barriers on GVCs is rarely studied, primarily because the effect of non-tariff barriers is difficult to measure. What is the effect of a protectionist trade policy on trade in GVCs? How does non-tariff trade policy affect domestic production in the countries engaging in GVCs? How does an importing country change its sourcing strategy for intermediate inputs in the face of non-tariff trade barriers? To answer such questions on the non-tariff barrier effect on GVCs, moving away from an economy-wide analysis to an industry-specific one can be useful, because it allows us to capture institutional and regulatory details as well as industry-specific market conditions (Goldberg and Pavcnik, 2016).

With this motivation, this study investigates the effect of non-tariff trade policy on GVCs using a recent Japan–Korea trade disputes in the semiconductor industry. In July 2019, the Japanese government announced export controls to South Korea of three chemical inputs essential in semiconductor production[1]. As a result, the Japanese firms that supply these three chemical products to South Korea are required to have an individual export license rather than a bulk export license, thus facing a larger policy-induced administrative cost. We use a difference-in-differences approach, the event study approach, and the synthetic control method to estimate the effect of the Japanese export controls on Japanese exports and production and Korean imports, exports, and production in the semiconductor industry.

Recent Japanese trade policy against South Korea in the semiconductor industry provides a good case study concerning the trade-policy effect on GVCs because the semiconductor production process is fragmented globally. For instance, one U.S. semiconductor company has over 16,000 suppliers worldwide. More than 7,300 of its suppliers are based in 46 different American states, and more than 8,500 of its suppliers are located outside of the United States (Semiconductor Industry Association [SIA], 2016). In addition, GVCs in the semiconductor industry are intriguing because some materials and equipment are essential to produce high-quality chips and are supplied by only a small number of firms around the world. Therefore, the GVCs in the semiconductor industry are *relational* and the final goods producers may not easily resort to alternative suppliers, making the potential effects long-lasting.

Our findings are the following. First, the export controls caused a large decline in Japanese ex-

[1]The export control was due to the South Korean government non-compliance with export controls and regulations to prevent resale of strategic goods. It was also reportedly tied to long-lasting policy concerns between Japan and South Korea about wartime labor during the World War II and its compensation liability to them.

ports to South Korea of one of three restricted inputs, hydrogen fluoride, by 87.9% but not in two other restricted inputs, photoresist and fluorinated polyimide. Second, the restrictions increased the Japanese exports of hydrogen fluoride to the U.S. by 94.6%, thus did not cause a decrease in Japanese production of semiconductor-related products. Third, South Korea reallocated input sourcing from Japan to economies such as Belgium, the U.S., and Taiwan. Fourth, South Korea increased its export of semiconductor manufacturing equipment to China, possibly because of its semiconductor production relocation to China. Fifth, Korean firms' domestic production and Japanese affiliates' local production in South Korea increased after the export controls. These results suggest a potential role of export controls in sourcing patterns and production relocation in the semiconductor industry.

This paper is related to recent studies on the effect of protectionist measures in the late 2010s on trade and domestic prices (Amiti et al., 2019; Benguria and Saffie, 2019; Fajgelbaum et al., 2020; Handley et al. 2020; Bown, 2021; Fajgelbaum et al., 2021; Hayakawa et al., 2022). Most of them investigate the effects of tariff but not non-tariff trade policies. Among them, the closest paper to ours is Hayakawa et al. (2022), which analyzes the effect of tightening U.S. and Japanese export controls, including the same policy change studied here, on Japanese exports. However, their focus is mostly on Japanese exports, not South Korean imports, of intermediate inputs, and not on how South Korea change its imports and exports because of the export control. Our paper instead analyzes the effect on Japanese production, South Korean imports, exports, and their production as well as on Japanese exports in the semiconductor industry, thus suggesting a potential propagation effect of export controls via GVCs.

This paper is also more broadly related to the studies on the effect of trade policy in GVCs (Vandenbusschea and Viegelahn, 2018; Flaaen et al. 2020; Chen et al, 2021; Bown et al., 2021). Compared to them, however, our study uses a non-tariff trade policy measure introduced by the Japanese export controls against South Korea and analyzes the effect on the semiconductor industry[2].

The reminder of this paper is organized as follows. Section 2 explains the backgrounds of the semiconductor industry and Japan–Korea trade disputes and provides a data summary. After introducing our empirical framework in Section 3, Section 4 presents the estimation results and their robustness checks. Finally, Section 5 offers some concluding thoughts.

2 Background

2.1 Semiconductor industry

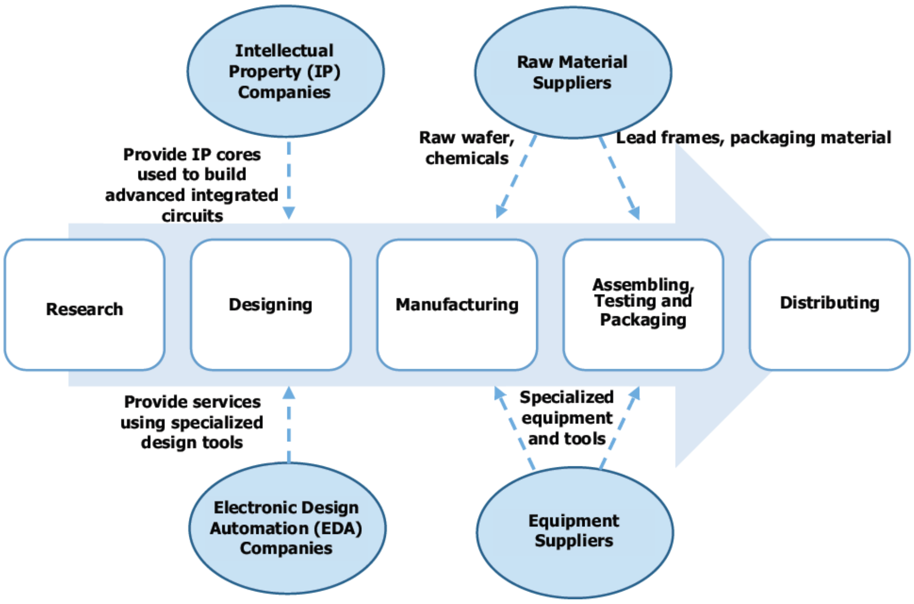
Semiconductors, also know as integrated circuits (ICs), microchips, or simply "chips," are used in many modern products, such as cellphones, computer products, automobiles, weapons systems, data centers, and many others. The industry's global sales are $335.2 billion USD in 2015. Its main final products are logic and memory chips in ICs, which account for more than 80% of the industry's sales (Bown, 2020).

The production steps in the semiconductor industry are composed of the following: R&D, design, manufacturing, assembly, testing, packaging, and distribution (Figure 1). First, R&D is a preproduction stage where researchers try to increase the processing capability and speed of devices

[2]The paper is also related to theoretical studies on the effect of trade policy on relational GVCs, such as Ornelas and Turner (2008), Antras and Staiger (2012), Chor and Ma (2020), and Grossman and Helpman (2020), and provides a reduced-form empirical evident to them.

and to reduce the costs. The semiconductor industry is so R&D intensive that its R&D expenditure ranges from 15% to 20% of their sales. Second, the design stage is a step where highly skilled engineers construct prototypes and specifications of chips using computer-aided design (CAD) and other design services provided by electronic design automation (EDA) companies. The design stage also tends to use pre-designed blocks of circuits provided by intellectual property (IP) companies, to utilize them as a subset of their own chip design.

Figure 1. Value chain in semiconductor production



Note: The figure shows the production steps and supporting activities in the semiconductor industry. It is originally from SIA (2016).

Third, the constructed designs are then used in the manufacturing stage of the designed chips. This stage requires a large fixed capital investment and constant facility improvement to catch up on technological developments. It also uses semiconductor manufacturing equipment and specialized chemicals and materials as inputs. For instance, photoresists are used together with lithography equipment to print an image of a circuit pattern on a wafer. Similarly, hydrogen fluoride is used together with etching and cleaning equipment in etching (i.e., removing unnecessary patterns besides circuit patterns) and cleaning (i.e., removing impurities from wafers) steps of the semiconductor manufacturing process [3]. Fourth, the final stage in the production of semiconductors is to assemble, test, and package the wafers into semiconductors, and requires larger material and labor costs than other production stages. Finally, the finished semiconductor devices are distributed to distributors or end-users.

Historically, the design, manufacturing, and assembling-testing-packaging stages are integrated within a firm, which is called integrated devise manufactures (IDMs) (or is called "captive" production when firms produce semiconductors for their own usage, as IBM, Hewlett-Packard, and AT&T do). Examples of IDM firms are Intel, Micron, and Samsung. However, due to technological developments and market competition, the production process has shifted from vertical integration to vertical specialization. The design stage is outsourced to design firms, which is also called fabless firm, such as Spreadtrum and Qualcomm. The manufacturing stage is contracted out to foundry

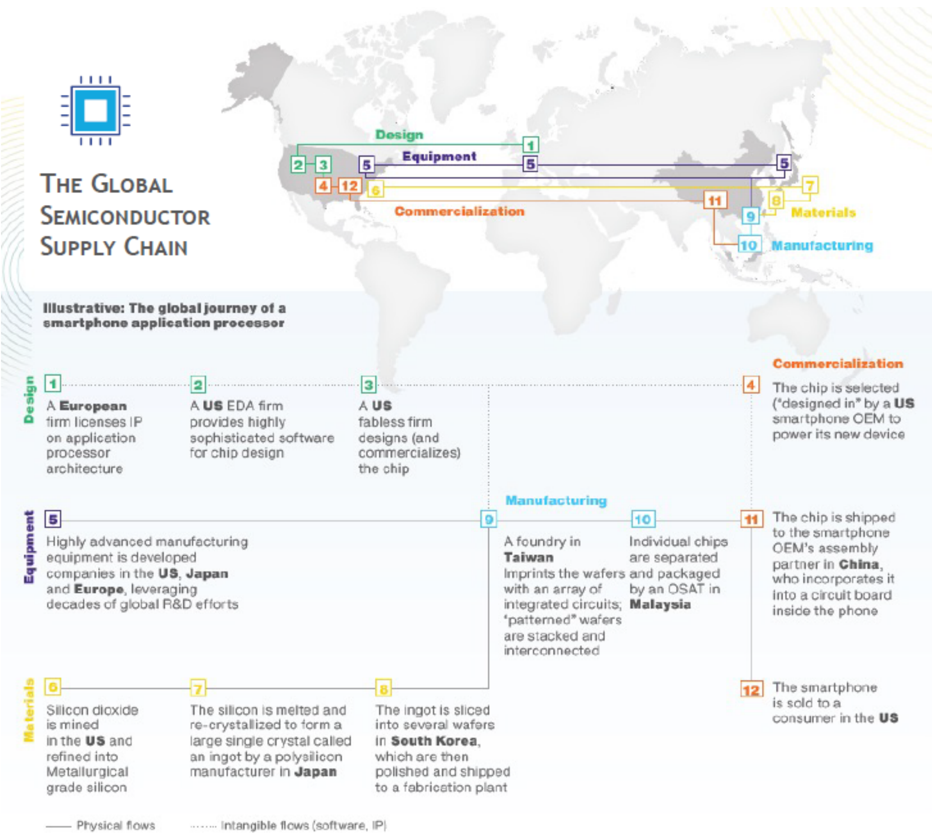
[3] See Samsung (2020) https://semiconductor.samsung.com/support/tools-resources/dictionary.

firms, such as TSMC and SMIC. The assembly is also outsourced to outsourced semiconductor assembly and test (OSAT) firms.

In sum, the modern semiconductor industry is shaped mainly through these two models, i.e., IDM and fabless-foundry models. The sales in the semiconductor industry in 2015 come 51.7% from IDM firms, 22.9% from fabless firms, 11.1% from foundry firms, and 6% from OSAT firms (SIA, 2016). While IDM firms still produce more than half of the sales in the industry, firms using the fabless-foundry model have a higher compound growth rate, and thus the industry structure is shifting dramatically toward fragmentation.

Another feature of semiconductor production is its globally dispersed production stages (Figure 2). This is primarily due to factors such as differences in factor requirements across stages and countries' different comparative advantages, trade-facilitating and policy environments, proximity to demand, and tougher market competition. For instance, in the IDM models, Micron locates its research and design stages in the U.S. and Japan, its manufacturing stage in the U.S., China, Taiwan, and other locations, and its assembly and testing stages in China and countries in South-East Asia (SIA, 2016). In the fabless-foundry model, the U.S., Taiwan, and China have dominant sales shares in all design, manufacturing, and OSAT stages, while the design stage tends to be located in Europe and Japan, the foundry stage in Israel and South Korea, and the OSAT stage in Singapore and Japan.

Figure 2. Global value chain in semiconductor production



Note: The figure shows a distribution of production stages across countries in the semiconductor industry. It is originally from SIA (2021).

Not only the production process, but activities supporting the semiconductor production chain are also spread globally. For instance, 85% of the global EDA is provided by U.S. firms (e.g., Synopsus, Cadence Design Systems, and Mentor Graphics). ARM, a UK-based firm, is a dominant player in IP. In addition, 40% of semiconductor manufacturing equipments are provided by three U.S.-

based firms: Applied Materials, Lam Research, and KLA-Tencor. ASML, a Dutch firm, and Tokyo Electron, a Japanese firm, together account for another 30% of the market. Furthermore, specialized chemicals and materials are mostly supplied by Japanese firms, such as Tokyo Ohka Kogyo, JSR, and Shin-Etsu Chemical.

Given that each stage of the semiconductor supply chain is distributed globally, natural disasters and protectionist trade measures can potentially affect the entire production process and input-sourcing patterns. Indeed, one of the key subjects in the U.S.-China trade war is export controls in the semiconductor industry in the name of national security. The U.S. government has applied a series of export controls against China, such as including Huawei and SMIC in the Entity List (i.e., the official list of foreign companies for which Americans are prohibited to provide a good or service without a license) in May 2019 and December 2020, respectively.

2.2 Japan–Korea trade disputes

In July 2019, the Japanese government announced potential export controls to South Korea of three chemical inputs, namely hydrogen fluoride, photoresist, and fluorinated polyimide, all essential in semiconductor production. This is due to the South Korean government's non-compliance with export regulations to prevent resale of strategic goods, while is also reportedly related to long-lasting political concerns between Japan and South Korea after World War II. As a result, Japanese exporters of these three chemical materials are required to apply for individual export licences, rather than bulk export licences. Thus, they need to report information on end-user, product specifications, technology, and so on for each export contract.

Before the export controls, the semiconductor industry in South Korea was heavily dependent on these three chemical materials imported from Japan. For instance, the Korean International Trade Administration estimated that its imports of these three materials from Japan account for 12.6% of their total imports (Bown, 2020). In addition, Japanese firms supply more than 90% of South Korean imports of two out of three key materials, crucially used for production in the industry, which consists of 20% of South Korean total exports. In response to the export controls, the Korean government has increased domestic subsidies to encourage domestic production of these materials, though they are reportedly difficult to promptly shift to self-production or sourcing from other countries.

In sum, given that the restricted materials (in combination with semiconductor manufacturing equipment) are crucial in the production of advanced semiconductor products, whether such export controls affect South Korea's domestic production and sourcing strategy for these materials is important questions. Furthermore, from the perspective of Japan, it is necessary to evaluate if the export controls have backfire effects on Japan, which is analyzed in the next section.

2.3 Data

We use the Global Trade Atlas by IHS Markit to investigate South Korean exports and imports at the level of HS 6-digit products. We also obtain the monthly Japanese exports data from Trade Statistics of Japan, by the Ministry of Finance. Furthermore, Japanese product-level production data are taken from the Current Survey of Production, by the Ministry of Economy, Trade and Industry (METI).

Finally, the Korean production data are from financial reports collected from the firm website and Reuters.

The following tables and figures in this subsection show summary statistics and raw-data patterns. Tables 1 to 3 show the top ten countries from which South Korea imported each of the restricted chemical materials in 2018. Table 1 shows that the imports of hydrogen fluoride by South Korea were mostly from China (63%), Japan (32%), and Taiwan (4%). Table 2 shows that more than 85% of the South Korean imports of photoresist is from Japan, followed by the U.S. (7%) and China (3%). It also indicates that the unit values are different between imports from the top two sourcing countries and those from others, thus suggesting that substitution may be difficult. Finally, Table 3 makes it clear that South Korea imports fluorinated polyimide almost equally from the U.S. (26%), China (25%), and Japan (21%). These statistics suggest that Japanese export controls on these three materials could significantly affect the South Korean sourcing strategy and that South Korea may face difficulty in substituting some products from other countries for Japanese-controlled sources.

Table 1: Ranking of imports in Hydrogen fluoride in 2018

Country	Value ($ 100 thousand)	Unit value (value/KG)	Share
China	1445.75	1.86	63.34
Japan	731.41	1.77	32.04
Taiwan	90.62	1.96	3.97
Singapore	6.56	0.847	0.29
United States	6.04	84.25	0.26
India	1.62	1.685	0.07
Belgium	0.19	143.698	0.009
Germany	0.14	215.55	0.006
Canada	0.13	397.91	0.006
Spain	0.07	81.18	0.003

Note: The table shows the top 10 countries from which South Korea imports hydrogen fluoride in 2018. Unit values are calculated as import values divided by import quantities in kilograms. ”Share” denotes the share of hydrogen fluoride import values from each country out of the total imports of the product.

The Japanese export controls of these chemical materials may also affect South Korean imports of other semiconductor products and equipment used in the semiconductor production process. Tables 4 and 5 show the top ten countries from which South Korea imported semiconductor products

Table 2: Ranking of imports in Photoresist products in 2018

Country	Value ($ 100 thousand)	Unit value (value/KG)	Share
Japan	3981.92	150.33	87.99
United States	297.21	115.72	6.57
China	121.74	5.45	2.69
Belgium	38.66	5.52	0.85
Singapore	21.66	1.83	0.48
Netherlands	15.43	22.71	0.34
Germany	15.41	28.89	0.34
Taiwan	9.47	14.38	0.21
Hong Kong	8.00	31.05	0.17
Spain	5.54	21.14	0.12

Note: The table shows the top 10 countries from which South Korea imports photoresist in 2018. Unit values are calculated as import values divided by import quantities in kilograms. ”Share” denotes the share of photoresist import values from each country out of the total imports of the product.

Table 3: Ranking of imports in fluorinated polyimide products in 2018

Country	Value ($ 100 thousand)	Unit value (value/KG)	Share
United States	462.63	7.43	26.02
China	452.50	3.57	25.45
Japan	373.32	7.12	21.00
Germany	225.34	8.43	12.68
Thailand	63.44	5.06	3.57
India	53.37	56.62	3.00
Malaysia	42.03	6.45	2.36
France	32.72	4.07	1.84
Belgium	20.38	130.09	1.15
Netherlands	12.06	3.32	0.68

Note: The table shows the top 10 countries from which South Korea imports fluorinated polyimide in 2018. Unit values are calculated as import values divided by import quantities in kilograms. "Share" denotes the share of fluorinated polyimide import values from each country out of the total imports of the product.

and semiconductor manufacturing equipment in 2018. Both imports are concentrated on several sourcing countries, thus again suggesting a difficulty finding substitutes for these products from other countries.

Table 4: Ranking of imports in semiconductor products in 2018

Country	Value ($ 100 thousand)	Unit value (value/KG)	Share
China	138598.68	1797.80	35.37
Taiwan	101123.36	2287.37	25.81
Japan	36164.43	3445.48	9.23
United States	35105.87	4189.53	8.96
Singapore	19668.51	4427.81	5.02
Malaysia	16962.66	1980.10	4.33
Hong Kong	8448.36	2582.27	2.16
Unidentified Country	8027.97	23111.85	2.05
Philippines	6505.15	1134.18	1.66
Germany	4851.97	2489.87	1.24

Note: The table shows the top 10 countries from which South Korea imports semiconductor products in 2018. Unit values are calculated as import values divided by import quantities in kilograms. "Share" denotes the share of semiconductor product import values from each country out of the total imports of the product.

The following figures show preliminary data patterns for the effect of the Japanese export controls. Figure 3 shows the South Korean import and unit values of hydrogen fluoride from major sourcing countries from January 2015 to May 2021. While the imports from China increase throughout the period, those from Japan suddenly drop after July 2019 and stay low. This seems to be due to the Japanese export controls to South Korea.

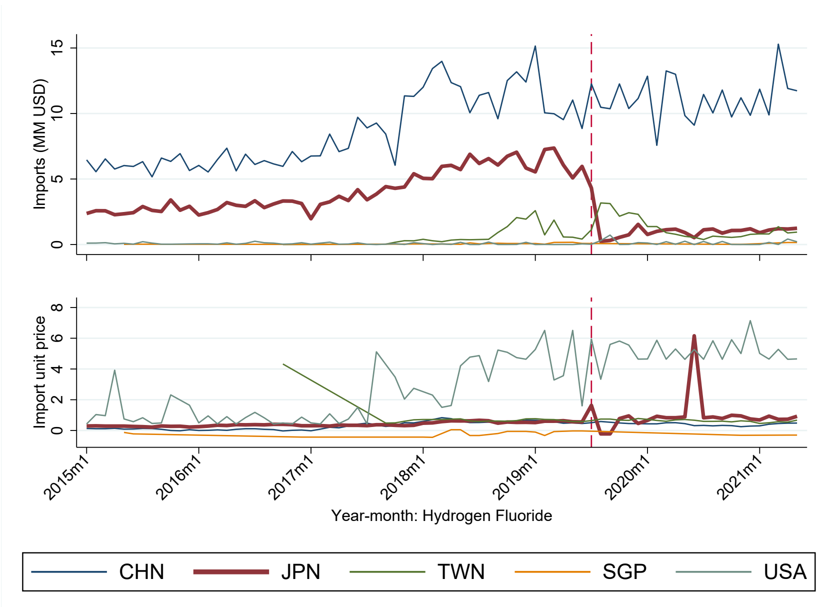
Figure 4 shows the South Korean import and unit values of photoresist from major sourcing countries. It reveals a sharp spike in import values from Japan at July 2019, probably due to last-minute demand, and then a small decrease in the value afterward for several months. However, its recovery was quick, and the entire trend did not change that much. This may be because the METI announced on December 20, 2019 that they allowed 3-year bulk export licences for some photoresist transactions. The quick recovery is also because the export controls targeted only photoresists used for extreme-ultraviolet lithography, while those used for mass-produced semiconductors were not restricted (Hayakawa et al., 2022). Another thing to notice from the figure is that the photoresist

Table 5: Ranking of imports in semiconductor manufacturing equipment in 2018

Country	Value ($ 100 thousand)	Unit value (value/number)	Share
Japan	38421.84	282105.69	31.99
Netherlands	37955.70	16818430	31.60
United States	29961.60	620434.88	24.94
Singapore	11743.52	1611998.38	9.78
Germany	459.17	682561.75	0.38
Unidentified Country	330.31	2136771.25	0.27
Taiwan	273.34	234493.77	0.23
China	268.76	5694.26	0.22
Austria	239.20	3598711	0.20
United Kingdom	131.44	171741.80	0.11

Note: The table shows the top 10 countries from which South Korea imports semiconductor making equipment in 2018. Unit values are calculated as import values divided by import quantities per machine. "Share" denotes the share of the import values of semiconductor manufacturing equipment from each country out of the total imports of the product.

Figure 3. Korean Import of hydrogen fluoride



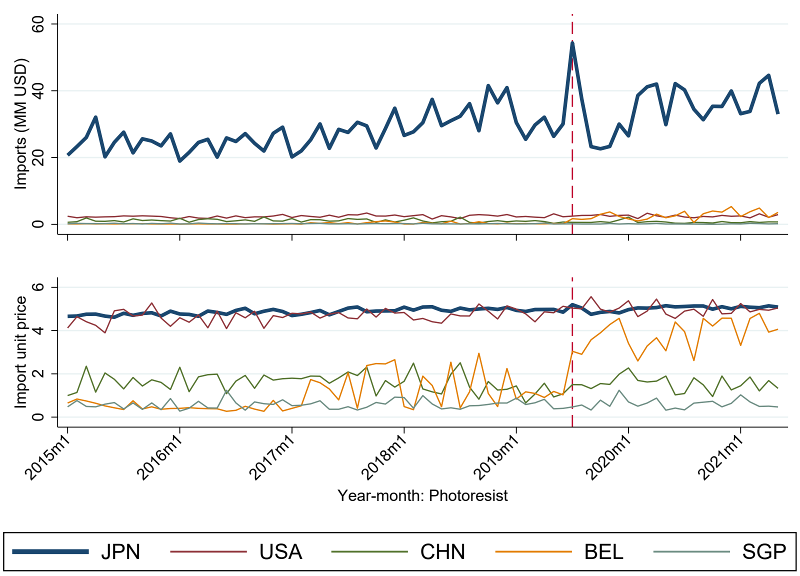
Note: The figure plots raw data on South Korean import value and import unit value of hydrogen fluoride from major sourcing countries.

import and unit values from Belgium started to increase just after the Japanese export controls. This may suggest the South Korean substitution of photoresist from Japan by that from Belgium.

Figure 5 presents the South Korean import and unit values of fluorinated polyimide from January 2015 to May 2021. It does not show any noticeable patterns around the introduction of the export control, probably due to the fact that only a subset of fluorinated polyimide is restricted. Finally, Figures 6 and 7 present the South Korean import and unit values of semiconductor products and semiconductor manufacturing equipment, respectively, from major sourcing countries. While showing some sectoral trends and cyclical patterns, they do not give us any noticeable patterns on the effect of the Japanese export controls.

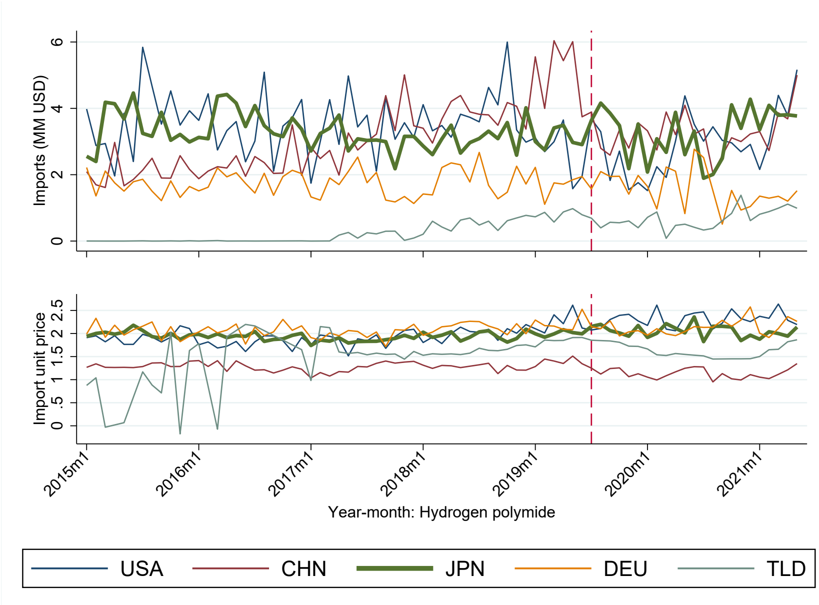
While the summary statistics and raw-data patterns show some suggestive evidence of the effect of the export controls, this may simply reflect the effect of some unrelated shocks (e.g., COVID-19). This motivates us to use a more formal regression analysis in the following sections.

Figure 4. Korean Import of photoresist



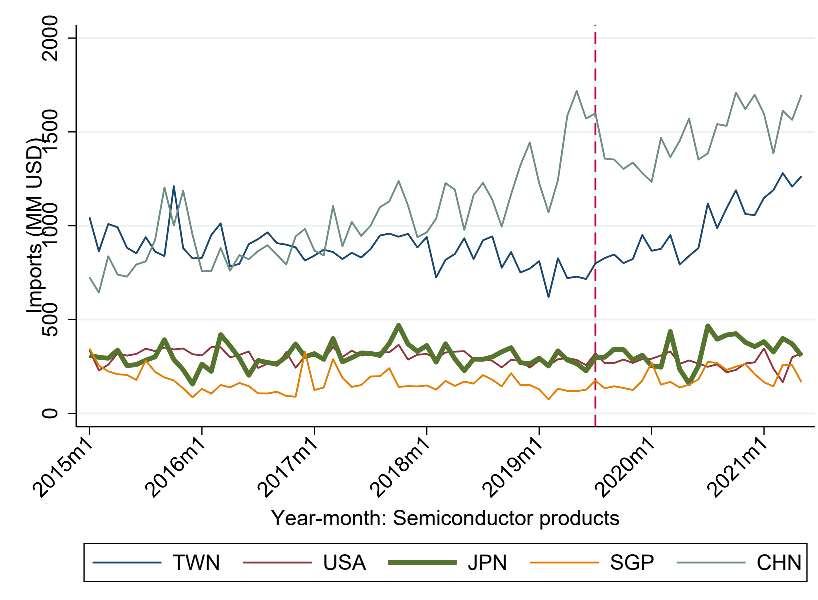
Note: The figure plots raw data on South Korean import value and import unit value of photoresist from major sourcing countries.

Figure 5. Korean import of fluorinated polyimide



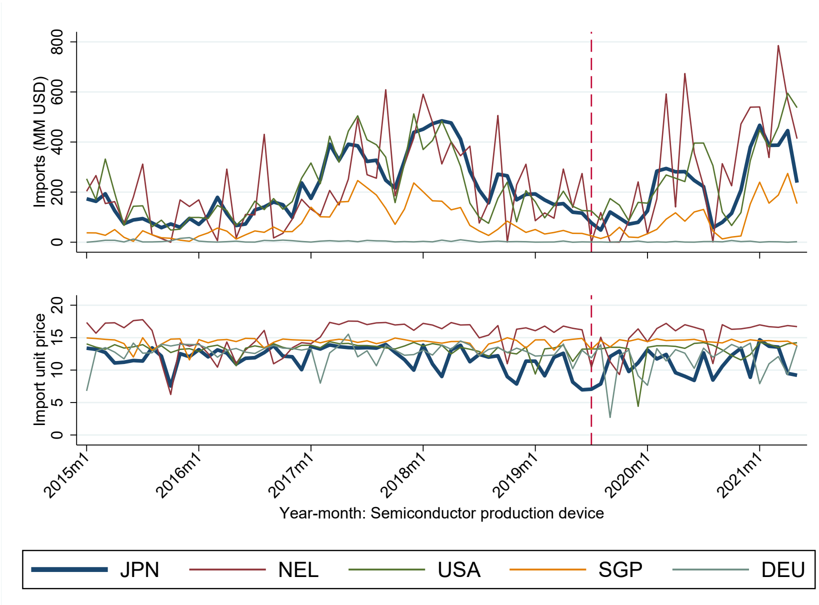
Note: The figure plots raw data on South Korean import value and import unit value of fluorinated polyimide from major sourcing countries.

Figure 6. Korean import of semiconductor products



Note: The figure plots raw data on South Korean import value and import unit value of semiconductor products from major sourcing countries.

Figure 7. Korean import of semiconductor making equipment



Note: The figure plots raw data on South Korean import value and import unit value of semiconductor manufacturing equipment from major sourcing countries.

3 Empirical framework

3.1 Specification

To investigate the effect of the export controls formally, we take a difference-in-differences (DID) approach. Specifically, the estimation equation for the impact of export control on Japanese exports is the following.

$$\ln \text{export}_{kht} = \beta_1 \text{KOR}_k \times \text{hydrogen}_h \times \text{after}_t + \beta_2 \text{KOR}_k \times \text{other}_h \times \text{after}_t + \alpha_{kt} + \alpha_{ht} + \alpha_{kh} + \epsilon_{kht}, \tag{1}$$

where $\ln \text{export}_{kht}$ is the log of export values of product h to country k in year-month t, KOR_k is a dummy variable for South Korea, and hydrogen_h is a dummy variable equal to one if the observation is the export of hydrogen fluoride (HS 281111). other_{kt} is a dummy variable equal to one if the observation is the export of photoresist (HS 370790) or fluorinated polyimide (HS 391190). α_{kt}, α_{ht}, and α_{kh} are country-year-month, product-year-month, and country-product fixed effects, absorbing those observable and unobservable factors affecting export values. α_{kt} controls for some aggregate shocks in destination country k (e.g., aggregate COVID-19 shocks in destination country k). α_{ht} accounts, for example, for supply and demand shocks to products that are common for all importing countries. The sample period in our regression is from January 2017 to May 2021.

β_1 and β_2 are our key coefficients, representing how the Japanese exports of restricted chemical materials to South Korea changed after the export controls relative to Japanese exports of those products to other destination countries and to Japanese exports of other products. Similar DID frameworks are used for analyzing (a) the effect on Japanese exports to other countries to see the substitution effect, (b) the effect on Korean imports and Korean exports to see the GVC effect, and (c) the effect on semiconductor manufacturing equipment and semiconductor products to see spillover effects. In (a), we replace the dummy variable on exports to South Korea, KOR_k, with those on other countries, such as China_k or USA_k. In (b), we use the dataset of South Korean exports and imports rather than that of Japanese exports (and use $\ln \text{import}_{kht}$ as a dependent variable in the latter case). In (c), hydrogen_h and other_h are replaced with a dummy variable for semiconductor manufacturing equipment (HS 848620) or one for semiconductor products (HS 8541, HS 8542).

The coefficients β_1 and β_2 are expected to be negative because putting the export controls on the three chemical materials should reduce their Japanese exports. We also expect a larger negative coefficient on hydrogen fluoride than on photoresist and fluorinated polyimide ($\beta_1 < \beta_2 < 0$) because, as we discussed in Section 2, the former is subject to a stricter restriction.

3.2 Identification

Our identification assumption is the (conditional) common trend assumption. This means that, after controlling for observable variables, the average Japanese exports of these restricted materials to South Korea would have changed in parallel with the equivalent exports by other countries and other products, if there were no policy change. To guarantee that the untestable assumption is likely to hold, we include destination-year-month, product-year-month, and product-destination fixed effects to control for the change in Japanese exports resulting from other sources.

To further check the validity of the common trend assumption, we provide results using the event study approach, where the trend of Japanese exports on the restricted chemical materials to South Korea is compared with those on other products and destination countries over the entire sample periods[4]. Specifically, the triple interaction terms with $after_t$ in equation (1) are replaced with those with the period dummy variables (i.e., 2018, the first half of 2019, the second half of 2019, 2020, and 2021) [5]. We also provide a sensitivity analysis as proposed by Rambachan and Roth (2022) if the "pre-tests" in the event-study design cast doubt on the parallel trend assumption.

Another assumption that is required is the Stable Unit Treatment Variable Assumption (SUTVA), meaning that the policy change should not affect the outcome for the control group. In the context of international trade, this is less likely to hold, because Japan can substitute its exports of these restricted products with those for other countries in the control group, such as the U.S. or China, thus violating SUTVA. In order to mitigate this concern, we provide the results of the same regressions, but exclude major destination countries of the products from the sample as robustness checks.

The final concern on the empirical framework is the statistical inference of the DID approach. Because the error terms are likely to be serially correlated and correlated across observations within the same products, we cluster standard errors by HS 6-digit product categories to allow for correlations within these categories, as many existing studies do. However, as MacKinnon et al. (2022) point out, when only a few clusters are categorized into the treatment groups, as in our case, there is a risk of over-rejection in the cluster-robust t-test. In order to confirm that our main results are not invalidated by this concern, we implement the synthetic control method as proposed by Abadie and Gardeazabal (2003) and Abadie et al. (2010).

4 Results

4.1 Japanese exports

Table 6 shows the effects of the export controls on the Japanese exports of three restricted products to South Korea. Columns 1, 3, and 5 provide the results of estimating export values, export quantities, and export unit values on the before–after policy dummy in equation (1), while columns 2, 4, and 6 show the results with the event-study design. First, we find a negative and significant estimate on the Japanese exports of hydrogen fluoride to South Korea, but not for photoresist and fluorinated polyimide (column 1). The magnitude of the coefficient suggests that the export value of hydrogen fluoride declined by 87.9%. Second, the decline in the export values comes from a decline mostly in export quantities, not a decline in export unit prices (columns 3 and 5). Based on the estimate, the export quantities of hydrogen fluoride declined by 97.5%. Third, the negative effect on Japanese hydrogen fluoride exists even in 2021, suggesting that South Korea replaced the Japanese chemical materials partly with domestic products or imports from other countries.

The event-study design shows a significant decline in the export values of hydrogen fluoride at the point of the export controls, but not for the other two restricted materials (columns 2, 4, and 6). It is true that there are some statistically significant differences between the restricted chemical material exports to South Korea and those of other products to other destination countries before

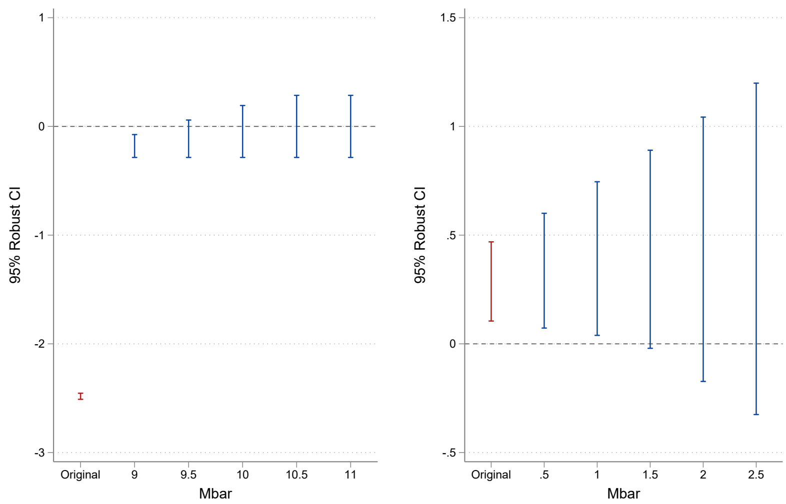
[4] In this case, if there are some significant differences before the timing of policy change, it would imply a violation of the common trend assumption.

[5] This event-study approach also allows us to see the dynamic medium-run effect of the export controls.

the export controls. However, they are in the opposite signs and/or smaller in magnitude, and the decline in the coefficients at the second half of 2019 is discontinuous. Furthermore, to see how much the difference in trends during the pre-treatment period affects our treatment effects, we use a methodology by Rambachan and Roth (2022), which provides a way to check the sensitivity of our results to violations of parallel trends.

Figure 8 shows confidence intervals for the estimates obtained in the event-study design (column 2 of Table 2) for different levels of parallel-trend "violations." The left window is the results for the Japanese exports of hydrogen fluoride to South Korea, and the right one is those for photoresist and fluorinated polyimide. $\bar{M}$ on the x-axis is a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. The left window suggests that a 95% robust confidence interval of the negative effect on hydrogen fluoride is $[-0.285, -0.07]$ and significantly different from zero even if the post-treatment violations of parallel trends are 9 times larger than the maximum pre-treatment violations[6]. Therefore, these results suggest that the causal negative effect of the export controls on the exports of these restricted products.

Figure 8. Sensitivity analysis on Japanese export of three chemical materials to South Korea



Note: This figure plots the results of Rambachan and Roth's (2022) methodology for the estimates on Japanese exports of hydrogen fluoride (left) and, photoresist and fluorinated polyimide (right) to South Korea. $\bar{M}$ on the x-axis denotes a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. For instance, the confidence intervals at $\bar{M} = 9$ is a 95% robust CIs of treatment effects when the post-treatment violation of parallel trends is restricted to be less than 9 times the maximum pre-treatment violation of parallel trends.

Figure 9 shows the results by plotting the coefficients on the triple interactions of the year-quarter, South Korea, and restricted chemical dummies, as in the even columns of Table 6, but using country-product-quarter fixed effects as the control variables. Because all quarters in 2017 are omitted from the regression, the coefficients represent the effect of the three restricted chemical

[6]On the other hand, the estimate for other two restricted materials becomes insignificant if there were some shocks to the treatment and control groups that create the post-treatment violations of parallel trends with the magnitude being 1.5 times larger than the maximum pre-treatment violations of parallel trends.

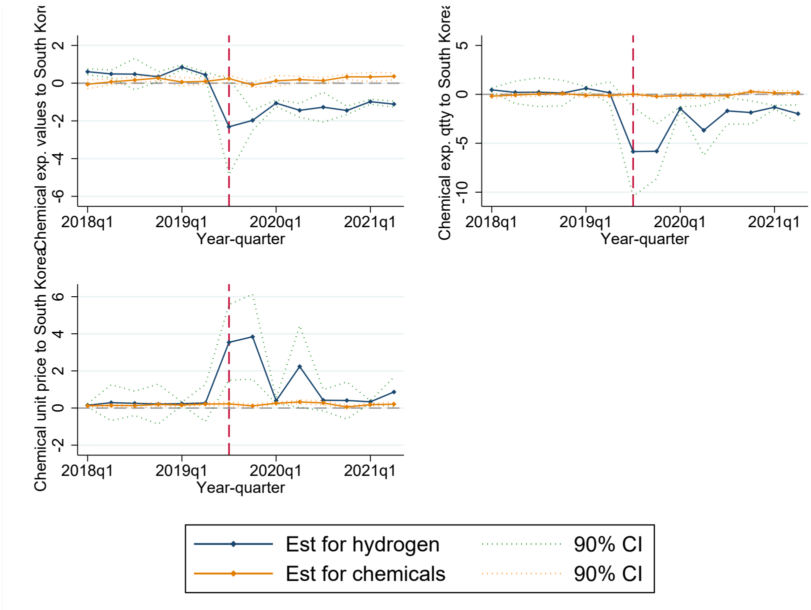
Table 6: Effect on Japanese exports of three restricted chemical materials to South Korea

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	Value	Value	Qtty	Qtty	Uval	Uval
after#KOR#hydrogen	-2.111***		-3.685***		1.573***	
	(0.0107)		(0.0132)		(0.00759)	
2018#KOR#hydrogen		0.317***		-0.364***		0.681***
		(0.00921		(0.0124)		(0.00772)
2019h1#KOR#hydrogen		0.0663***		-0.929***		0.992***
		(0.0126)		(0.0164		(0.0107
2019h2#KOR#hydrogen		-2.482***		-7.206**		4.722**
		(0.0143)		(0.0183)		(0.0113)
2020#KOR#hydrogen		-1.787***		-3.081***		1.293***
		(0.0140)		(0.0179)		(0.0106)
2021#KOR#hydrogen		-1.898**		-3.076***		1.176***
		(0.0161)		(0.0203)		(0.0120)
after#KOR#chemical	0.373**		0.345		0.0311	
	(0.149)		(0.237)		(0.0870)	
2018#KOR#chemical		0.131		0.0229		0.114***
		(0.123)		(0.116)		(0.0151)
2019h1#KOR#chemical		0.155*		0.0442		0.116***
		(0.0919)		(0.0972)		(0.0107)
2019h2#KOR#chemical		0.287***		0.152		0.141*
		(0.0928)		(0.172)		(0.0761)
2020#KOR#chemical		0.516**		0.41		0.109
		(0.251)		(0.335)		(0.0805)
2021#KOR#chemical		0.516*		0.494		0.027
		(0.282)		(0.379)		(0.0951)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961,097	2,961,097	2,940,135	2,940,135	2,940,135	2,940,135
R-squared	0.861	0.861	0.894	0.894	0.913	0.913

Note: The table reports the results from estimating equation (1) to investigate the effect of the Japanese export controls on Japanese exports of three chemical materials to South Korea. The dependent variable is log export values (columns 1 and 2), log export quantity (columns 3 and 4), and log unit values (columns 5 and 6). For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#KOR#hydrogen" denotes an interaction term of year-2018, South Korea, and hydrogen fluoride (HS 281111) dummy variables. Similarly, "2018#KOR#chemical" denotes a similar interaction term but for other two restricted materials (HS 370790, 391190) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

materials in a year-quarter, relative to its corresponding quarter in 2017. The figure shows that there was a sharp decline in the export values of hydrogen fluoride in the third quarter of 2019, but not for photoresist and fluorinated polyimide.

Figure 9. Coefficient on Japanese export of three chemical materials to South Korea



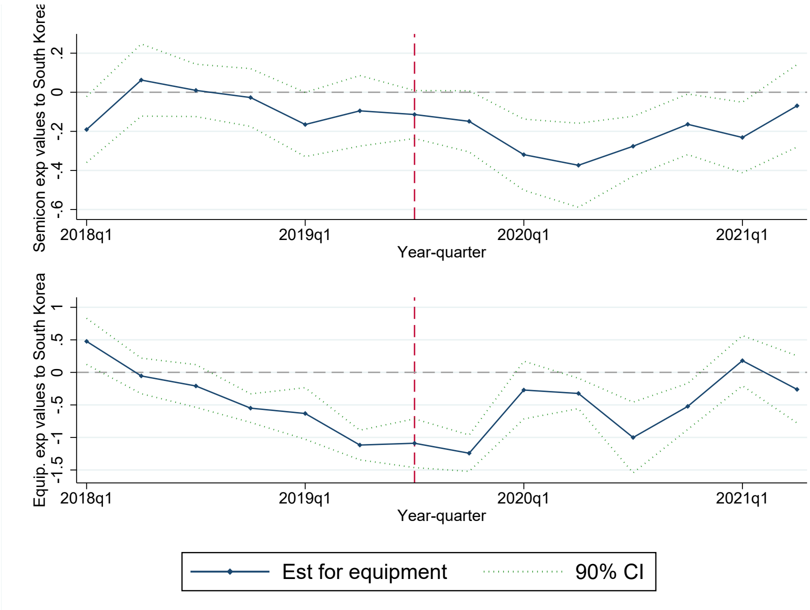
Note: This figure plots the coefficients on the interactions between year-quarter, South Korea, and product dummies as in even columns in Table 6, but using the year-quarter aggregated data and including HS 6-digit × country × month fixed effects. The coefficients are thus estimated with respect to their respective values in the year 2017 (all 12 months of 2017 are omitted). The vertical dashed line corresponds to the 3rd quarter in 2019 when the export control was placed.

The negative impact on the imports of the restricted chemical materials may have spillover effect on the Japanese exports to South Korea of semiconductor products and semiconductor manufacturing equipment, because they can be complement in the production process of semiconductor products. To investigate this, we implement the regression for semiconductor products and semiconductor manufacturing equipment. The results are reported in Table A1 of Appendix A2 and summarized graphically in Figure 10 using the year-quarter aggregated data. They do not show noticeable changes at around the introduction of the export controls, suggesting minimal spillover effects, if any.

While the export controls do not much affect the Japanese exports of semiconductor products and semiconductor manufacturing equipment to South Korea, they could have effects on the Japanese exports of the restricted materials to other destination countries. Table 7 shows the effect on the exports to the four major destination countries, the U.S., China, Taiwan, and the United Kingdom [7]. Japanese exports of hydrogen fluoride to the U.S. seem to increase discontinuously at the point of the export controls, while the results for exports to other countries and other restricted chemical materials show pre-trends or insignificant estimates. The coefficient for the U.S. suggests an increase in its export value by 94.6% after the Japanese export controls against South Korea. Furthermore, Figure A1 in Appendix A1 shows the robustness of the result against violations of parallel trends:

[7] Tables A2 and A3 of Appendix A2 provide the results on the Japanese exports of semiconductor products and semiconductor manufacturing equipments to other major export destination countries.

Figure 10. Coefficient on Japanese export of semiconductor products and semiconductor making equipments to South Korea



Note: This figure plots the coefficients on the interactions between year-quarter, South Korea, and product dummies as in even columns in Table A1 of Appendix A2, but using the year-quarter aggregated data and including HS 6-digit × country × quarter fixed effects. The coefficients are thus estimated with respect to their respective values in the year 2017 (all 12 months of 2017 are omitted). The vertical dashed line corresponds to the 3rd quarter in 2019 when the export control was placed. The dotted lines show the 90% confidence intervals.

the positive effect on the Japanese exports to the U.S. is significantly different from zero even if there is the post-treatment violation of parallel trends that is 3 times larger than the maximum pre-trend differences. These results suggest the possibility that Japan substitutes their exports of restricted chemical materials to the U.S. or exports the materials to South Korea through the U.S. (roundabout trade). The latter possibility is further investigated in the subsection of South Korean imports[8].

4.2 Japanese production

Given the decline in the Japanese exports of the restricted chemical materials to South Korea, one of the major buyers of the Japanese semiconductor-related materials, a natural question to ask is: What is the effect on the Japanese production of these chemical products, semiconductor products, and semiconductor manufacturing equipment? To investigate this, we use product-level monthly production data in the Current Survey of Production by METI and provide preliminary evidence. Figure 11 shows the profiles of the log of production quantities from January 2017 to March 2022 for semiconductor manufacturing equipments (top left), semiconductor products (top middle and right, and middle), and hydrofluoric acid (bottom). While they are preliminary results without any formal regressions, the figures suggest that there are no decline in the Japanese production of these products at the point and after the export controls on aggregate. The reason could be because, as we saw in the last subsection, Japan does not decrease its exports of semiconductor products and

[8]Appendix A3 provides the effect of the Japanese export controls on the Japanese exports to South Korea in other product categories.

Table 7: Effect on Japanese exports of three restricted chemical materials to other economies

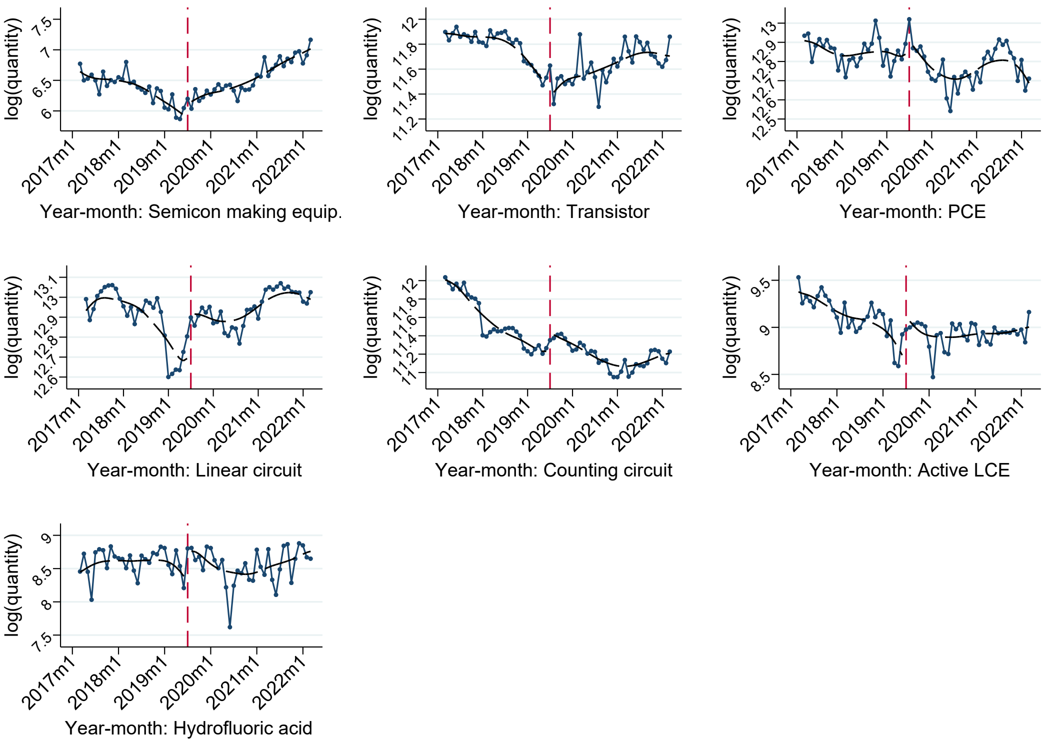
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ctry dummy:	USA		China		Taiwan		UK	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#hydrogen	0.666***		0.597***		0.550***		-0.149***	
	(0.0103)		(0.0111)		(0.00912)		(0.0214)	
2018#Ctry#hydrogen		-0.232***		-0.250***		1.160***		-0.147***
		(0.00961)		(0.00945)		(0.00902)		(0.0203)
2019h1#Ctry#hydrogen		-0.0359***		0.181***		1.478***		-0.923***
		(0.0133)		(0.0125)		(0.0121)		(0.0313)
2019h2#Ctry#hydrogen		0.657***		0.329***		1.613***		0.100***
		(0.0144)		(0.0138)		(0.0128)		(0.0317)
2020#Ctry#hydrogen		0.629***		0.495***		1.244***		-0.331***
		(0.0144)		(0.0154)		(0.0127)		(0.0290)
2021#Ctry#hydrogen		0.307***		0.866***		1.120***		-0.808***
		(0.0169)		(0.0176)		(0.0151)		(0.0369)
after#Ctry#chemical	-0.113***		0.213*		0.415***		-0.140	
	(0.0280)		(0.109)		(0.0170)		(0.162)	
2018#Ctry#chemical		0.0636		0.0453**		0.0610**		0.00270
		(0.0691)		(0.0207)		(0.0289)		(0.0621)
2019h1#Ctry#chemical		0.0788		0.0869***		0.206***		-0.0196
		(0.0927)		(0.0254)		(0.0682)		(0.156)
2019h2#Ctry#chemical		-0.0285		0.192***		0.167		-0.247***
		(0.0197)		(0.0133)		(0.128)		(0.0290)
2020#Ctry#chemical		-0.0780*		0.267**		0.573***		-0.197
		(0.0450)		(0.128)		(0.0127)		(0.268)
2021#Ctry#chemical		-0.109***		0.271		0.635***		0.109
		(0.0335)		(0.252)		(0.105)		(0.333)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097
R-squared	0.861	0.861	0.861	0.861	0.861	0.861	0.861	0.861

Note: The table reports the results from estimating equation (1) to investigate the effect of the Japanese export controls on Japanese exports of three chemical materials to other major destination economies. Columns 1 and 2 are the results for the Japanese exports to the U.S., columns 3 and 4 for China, columns 5 and 6 for Taiwan, and columns 7 and 8 for the UK. The dependent variable is log export values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#hydrogen" denotes an interaction term of year-2018, country under consideration, and hydrogen fluoride (HS 281111) dummy variables. Similarly, "2018#Ctry#chemical" denotes a similar interaction term but for other two restricted materials (HS 370790, 391190) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

semiconductor manufacturing equipment, and increases exports of the restricted chemical materials to third countries.

While the export controls do not have significant effects on the average Japanese producers, some firms (such as multinational semiconductor producers that have foreign affiliates in South Korea) may be affected differently. This possibility is further investigated in Section 4.5.3 using financial reports collected from the firm website and Reuters.

Figure 11. Japanese production of semiconductor related products



Note: The figure plots the transitions of production quantity of semiconductor-related products, reported in the Current Survey of Production by METI. From the left top, the windows show quantities for semiconductor making equipment, transistor, photoelectric conversion element (PCE), linear circuit, counting circuit, active liquid crystal element, and hydrofluoric acid. The vertical red dashed line denotes the timing of export controls in July 2019.

4.3 Korean imports

This subsection provides evidence on how South Korea reacts to Japanese export controls. Table 8 shows the effect on South Korean imports of the three restricted materials from other major source countries[9]. First, the South Korean imports of hydrogen fluoride from the U.S. and Taiwan seem to increase discontinuously at the time of the Japanese export controls. The coefficients on the U.S. and Taiwan suggest the increase in their export values by 281.5% and 144.2%, respectively[10]. This increase in hydrogen fluoride imports from the U.S. is consistent with a possibility of South Korea's roundabout trade via the U.S., as mentioned in the previous subsection. Second, the imports of

[9]Table A4 of Appendix A2 shows the effect of the Japanese export controls on the South Korean imports of the restricted materials from Japan as a robustness check for the results in Table 6.

[10]Figure A2 and A3 in Appendix A1 show the robustness of the result against violations of parallel trends.

other restricted materials from Belgium increases just after the introduction of the Japanese export controls, and even in 2021. The estimate for Belgian other chemical materials suggests a 445.2% increase in its export value[11]. This is consistent with what is reported in news media and suggests a substitution of the materials from Japan to other source countries[12].

[11] Figure A4 in Appendix A1 show the robustness of the result against violations of parallel trends.

[12] Samsung started sourcing photoresist from RMQC in Belgium, a joint venture of JSR from Japan and IMEC from Belgium (https://asia.nikkei.com/Spotlight/Japan-South-Korea-rift/Samsung-secures-key-chip-supply-in-Belgium-as-Tokyo-curbs-exports).

Table 8: Effect on South Korean imports of three restricted chemical materials from other economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ctry dummy:	China		USA		Germany		Taiwan		Singapore		Belgium	
	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value		
after#Ctry#hydrogen	0.0662***		1.339***		-0.422***		0.893***		0.413***		-0.650***	
	(0.0138)		(0.0146)		(0.0158)		(0.0216)		(0.0458)		(0.0340)	
2018#Ctry#hydrogen		0.448***		-1.541***		-0.0550***		1.367***		1.362***		0.649***
		(0.0139)		(0.0161)		(0.0175)		(0.0264)		(0.0311)		(0.0435)
2019h1#Ctry#hydrogen		0.141***		-2.608***		0.384***		1.786***		1.684***		-0.0484
		(0.0183)		(0.0198)		(0.0221)		(0.0332)		(0.0395)		(0.0439)
2019h2#Ctry#hydrogen		0.106***		0.618***		0.0688***		2.918***				-0.885***
		(0.0194)		(0.0213)		(0.0229)		(0.0341)				(0.0345)
2020#Ctry#hydrogen		0.496***		-0.167***		-0.627***		1.943***		0.865***		
		(0.0196)		(0.0206)		(0.0228)		(0.0345)		(0.0677)		
2021#Ctry#hydrogen		-0.0538**		0.342***		-0.257***		1.635***		1.434***		
		(0.0224)		(0.0241)		(0.0283)		(0.0398)		(0.0560)		
after#Ctry#chemical	-0.461***		-0.118		-0.108		0.523***		0.0787		1.696***	
	(0.0563)		(0.104)		(0.116)		(0.112)		(0.264)		(0.546)	
2018#Ctry#chemical		-0.0617		0.0900		0.408***		0.223		-0.357**		-0.175
		(0.234)		(0.147)		(0.0961)		(0.731)		(0.145)		(0.194)
2019h1#Ctry#chemical		-0.218		-0.341***		0.161***		0.972		0.131		0.00481
		(0.453)		(0.0595)		(0.0341)		(1.261)		(0.436)		(0.636)
2019h2#Ctry#chemical		-0.537***		-0.260**		0.225*		1.214		-0.622***		1.486***
		(0.196)		(0.130)		(0.132)		(1.122)		(0.101)		(0.323)
2020#Ctry#chemical		-0.496*		-0.112***		0.162		0.748**		0.0918		1.636***
		(0.298)		(0.0377)		(0.176)		(0.357)		(0.537)		(0.276)
2021#Ctry#chemical		-0.601***		-0.112		-0.253		0.568		0.374*		1.776***
		(0.154)		(0.0821)		(0.156)		(1.026)		(0.218)		(0.529)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes						
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157
R-squared	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808

Note: The table reports the results from estimating equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of three chemical materials from other major sourcing economies. Columns 1 and 2 are the results for the import values from China, columns 3 and 4 for those form the U.S., columns 5 and 6 for those from Germany, columns 7 and 8 for those from Taiwan, columns 9 and 10 for those from Singapore, and columns 11 and 12 for those from Belgium. The dependent variable is log import values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#hydrogen” denotes an interaction term of year-2018, country under consideration, and hydrogen fluoride (HS 281111) dummy variables. ”2018#Ctry#chemical” denotes a similar interaction term but for other two restricted materials (HS 370790, 391190). ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Turning to the imports of other inputs and outputs of semiconductor productions, Tables 9 and 10 show the effect on the South Korean imports of semiconductor products and semiconductor manufacturing equipment from other major source countries. While the effect on their imports of semiconductor products does not show any noticeable pattern in Table 9, Table 10 provides a sharp drop in the imports of semiconductor manufacturing equipment from the Netherlands and Germany. The estimates suggest that the imports from the Netherlands decline by 54.7%, and those from Germany by 72.6%. This could reflect the fact that semiconductor manufacturing equipment are no longer purchased due to the Japanese exports restrictions of the chemical materials[13].

Table 9: Effect on South Korean imports of semiconductor products from other economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ctry dummy:	China		Taiwan		USA		Singapore	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#semicon	0.0797		0.289***		0.0963		0.195	
	(0.130)		(0.0951)		(0.194)		(0.230)	
2018#Ctry#semicon		-0.179*		-0.0722		-0.00324		-0.0985
		(0.103)		(0.0971)		(0.105)		(0.117)
2019h1#Ctry#semicon		-0.0630		-0.0828		0.218		-0.0278
		(0.141)		(0.132)		(0.180)		(0.171)
2019h2#Ctry#semicon		-0.0641		0.179		0.0528		-0.313
		(0.192)		(0.114)		(0.210)		(0.286)
2020#Ctry#semicon		0.0528		0.265*		0.237		0.295
		(0.191)		(0.138)		(0.260)		(0.267)
2021#Ctry#semicon		-0.0709		0.266**		0.00471		0.360
		(0.169)		(0.114)		(0.312)		(0.249)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157
R-squared	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808

Note: The table reports the results from estimating equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of semiconductor products from other major sourcing economies. Columns 1 and 2 are the results for the import values from China, columns 3 and 4 for those from Taiwan, columns 5 and 6 for those from the U.S., and columns 7 and 8 for those from Singapore. The dependent variable is log import values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#semicon" denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 8541, 8542) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

4.4 Korean exports

The results for the South Korean exports are reported in Tables 11 and 12. Again, while their exports of semiconductor product do not provide any noticeable patterns, their exports of semiconductor

[13]Actually, a company in the Netherlands, the ASML, supplies 75% of lithography (one of the production steps in semiconductor products) equipment in the global market and is the only company supplying extreme-ultraviolet lithography equipment around the world, which is required to produce tiny-sized chips. On the other hand, the high-quality photoresist is also used in the extreme-ultraviolet lithography step, which is restricted due to the export control. Semiconductor manufacturing plants need to combine the material with the equipment to produce a slice of semiconductor (wafers). Hydrogen fluoride is also used together with etch equipment and therefore restricting the material can affect the demand for the equipment.

Table 10: Effect on South Korean imports of semiconductor manufacturing equipment from other economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ctry dummy:	Netherlands		USA		Singapore		Germany	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#equipment	-0.791***		0.0157		-0.275***		-1.295***	
	(0.0257)		(0.0150)		(0.0289)		(0.0162)	
2018#Ctry#equipment		-0.840***		-1.066***		-1.132***		-0.611***
		(0.0294)		(0.0153)		(0.0300)		(0.0173)
2019h1#Ctry#equipment		-0.573***		-1.021***		-1.450***		-1.697***
		(0.0347)		(0.0196)		(0.0385)		(0.0230)
2019h2#Ctry#equipment		-3.368***		-0.600***		-1.340***		-2.132***
		(0.0376)		(0.0215)		(0.0406)		(0.0230)
2020#Ctry#equipment		-0.713***		-0.760***		-1.191***		-1.355***
		(0.0364)		(0.0206)		(0.0409)		(0.0227)
2021#Ctry#equipment		0.0453		-0.291***		-0.223***		-2.662***
		(0.0431)		(0.0237)		(0.0466)		(0.0256)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157	2,568,157
R-squared	0.808	0.808	0.808	0.808	0.808	0.808	0.808	0.808

Note: The table reports the results from estimating equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of semiconductor manufacturing equipment from other major sourcing economies. Columns 1 and 2 are the results for the import values from Netherlands, columns 3 and 4 for those form the U.S., columns 5 and 6 for those from Singapore, and columns 7 and 8 for those from Germany. The dependent variable is log import values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#equipment" denotes an interaction term of year-2018, country under consideration, and semiconductor manufacturing equipment (HS 848620) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

manufacturing equipment to China seem to increase substantially at the time of the introduction of the Japanese export controls. The coefficient suggests a 506.2% increase in the South Korean export of semiconductor manufacturing equipment to China [14]. It is true that some of this increase could capture "Made in China 2025" plan, issued in 2015, where the Chinese government promotes the industry's self-sufficiency, especially in the semiconductor industry. However, most of the increase is a discontinuous jump at the introduction of the Japanese export controls (see also Figure 17). In addition, Samsung and SK Hynix have semiconductor production plants in China (Bown, 2020). It is thus consistent with the interpretation that these South Korean firms reallocate some of their production to China to securely source the necessary chemical materials under the export controls and require shipment of semiconductor manufacturing equipment to China[15].

[14]Figure A5 in Appendix A1 show the robustness of the result against violations of parallel trends.

[15]The increase in South Korean exports to China may be due to the fact that China actually decreased its MFN tariffs while increased tariffs against the U.S. under the US-China trade war (Bown et al., 2019). However, most of them happened in 2018. In addition, most of the semiconductor manufacturing equipment have already had zero MFN tariff rates in January 2018.

Table 11: Effect on South Korean exports of semiconductor products to other economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ctry dummy:	China		Hong Kong		Vietnam		Taiwan		Philippines		Japan	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#semicon	-0.155		0.0122		0.346		-0.138		-0.117		-0.141	
	(0.118)		(0.136)		(0.235)		(0.191)		(0.127)		(0.213)	
2018#Ctry#semicon		-0.161*		-0.0346		0.482**		-0.179*		-0.0378		-0.118
		(0.0955)		(0.103)		(0.216)		(0.102)		(0.103)		(0.0859)
2019h1#Ctry#semicon		-0.204		-0.142		0.709**		-0.397***		-0.0539		-0.360**
		(0.136)		(0.120)		(0.292)		(0.153)		(0.133)		(0.158)
2019h2#Ctry#semicon		-0.220		-0.0156		0.633*		-0.407*		-0.246*		-0.261
		(0.148)		(0.132)		(0.364)		(0.210)		(0.134)		(0.229)
2020#Ctry#semicon		-0.239		0.0169		0.726**		-0.266		-0.103		-0.211
		(0.165)		(0.141)		(0.349)		(0.222)		(0.138)		(0.219)
2021#Ctry#semicon		-0.363*		-0.161		0.636*		-0.193		-0.119		-0.388
		(0.188)		(0.164)		(0.346)		(0.341)		(0.215)		(0.243)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194
R-squared	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788

Note: The table reports the results from estimating equation (1) but using South Korean export data to investigate the effect of the Japanese export controls on South Korean exports of semiconductor products. Columns 1 and 2 are the results for the export values to China, columns 3 and 4 for those to Hong Kong, columns 5 and 6 for those to Vietnam, columns 7 and 8 for those to Taiwan, columns 9 and 10 for those to the Philippines, and columns 11 and 12 for those to Japan. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#semicon” denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 8541, 8542) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 12: Effect on South Korean exports of semiconductor manufacturing equipment to other economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ctry dummy:	China		USA		Taiwan		Japan		Vietnam	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#equipment	1.802***		-0.179***		0.324***		0.458***		-0.752***	
	(0.0164)		(0.0163)		(0.0193)		(0.0160)		(0.0169)	
2018#Ctry#equipment		0.563***		-0.362***		-0.291***		0.619***		0.909***
		(0.0154)		(0.0158)		(0.0186)		(0.0149)		(0.0168)
2019h1#Ctry#equipment		0.989***		-0.783***		-0.199***		0.238***		1.255***
		(0.0208)		(0.0207)		(0.0254)		(0.0203)		(0.0218)
2019h2#Ctry#equipment		2.176***		-0.919***		0.181***		0.848***		0.306***
		(0.0221)		(0.0222)		(0.0258)		(0.0215)		(0.0234)
2020#Ctry#equipment		2.056***		-0.198***		0.0408		0.791***		-0.491***
		(0.0223)		(0.0227)		(0.0262)		(0.0219)		(0.0235)
2021#Ctry#equipment		2.697***		-0.632***		0.456***		0.549***		0.185***
		(0.0259)		(0.0258)		(0.0312)		(0.0258)		(0.0276)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194	3,336,194
R-squared	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788

Note: The table reports the results from estimating equation (1) but using South Korean export data to investigate the effect of the Japanese export controls on South Korean exports of semiconductor manufacturing equipment. Columns 1 and 2 are the results for the export values to China, columns 3 and 4 for those to the U.S., columns 5 and 6 for those to Taiwan, columns 7 and 8 for those to Japan, and columns 9 and 10 for those to Vietnam. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#equipment” denotes an interaction term of year-2018, country under consideration, and semiconductor manufacturing equipment (HS 848620) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

4.5 Korean production

In this subsection, we show that the export control by the Japanese government has unexpected impacts on the production of three specified items in South Korea: (1) an increase in domestic production by Korean firms and (2) an increase in local production by Japanese multinational enterprises' (MNEs) affiliates in South Korea. To this end, we manually collect financial reports from the firm website and Reuters on several major manufactures of three specified items in South Korea, including Japanese affiliates. We show the time trend of sales and investment in South Korea from before to after the export controls in 2019, without conducting econometric analysis due to small sample size.

4.5.1 Domestic production by Korean firms

The escalation of Japan–Korea trade conflict and supply chain disruptions pushed the South Korean government to promote domestic production of semiconductor-related materials and equipment. After Japan's strengthening of export controls, in August 2019, the South Korean government specified 100 items (including three specified items under export control) as strategic products, and would invest 7.8 trillion won in 7 years to promote domestic production[16]. It aims at a secure supply of three specified items through domestic production and import from the third countries within one year. As a policy support, the South Korea government significantly increased its research and development (R&D) budget in 2019. In September 2020, Samsung Electronics announced that it has started the introduction of domestically produced hydrogen fluoride into part of the manufacturing process. The suppliers were South Korean chemical manufacturers, firm S1 and firm R[17]. Furthermore, on January 2, 2020, South Korea's Ministry of Trade, Industry and Energy announced that firm S1 has established a manufacturing technology that enables high-purity mass production of hydrogen fluoride. Firm S1 has built and expanded a manufacturing plant, and substantially reduced impurities in liquid hydrogen fluoride to a level that can be used in semiconductor manufacturing, which requires extremely high purity.

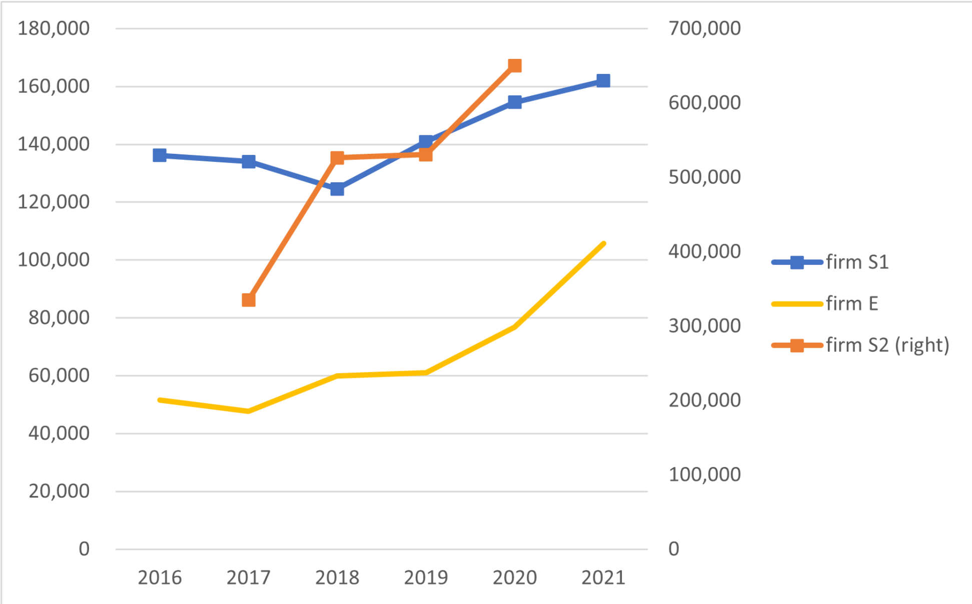
Figures 12 and 13 show the trend of four major Korean firms' net fixed assets and sales from 2016 to 2021. First, Korean firms significantly and persistently expanded their machine and equipment after Japan's export control in 2019. The investment is especially large for firm E, which is consistent with media report[18]. Interestingly, this Korean firm used to import hydrogen fluoride from Japanese supplier firm M. On average, the growth rates of net fixed assets were 5.3% during 2018–2019, 19.4% during 2019–2020, and 21.1% during 2020–2021. Second, the sales of Korean firms also increased during the period of 2016–2021, except firm S1 in 2020. On average, sales growth rates were 13.2% during 2018–2019, 2.9% during 2019–2020, and 33.1% during 2020–2021. It is worth noting that the all four Korean firms' sales were increasing before 2019, suggesting the increasing demand for semiconductor related materials and products and the possibility of promoting domestic production by Korean firms.

[16] In July 2020, the South Korea's Ministry of Trade, Industry and Energy laid out its Materials, Parts and Equipment 2.0 Strategy. The government will invest more than 5 trillion won by 2022 to develop new technologies in the materials, parts and equipment sectors in a bid to reduce dependence on Japan. It also expanded the number of strategic items from 100 to 338.

[17] The firm names are anonymized because of confidential reason.

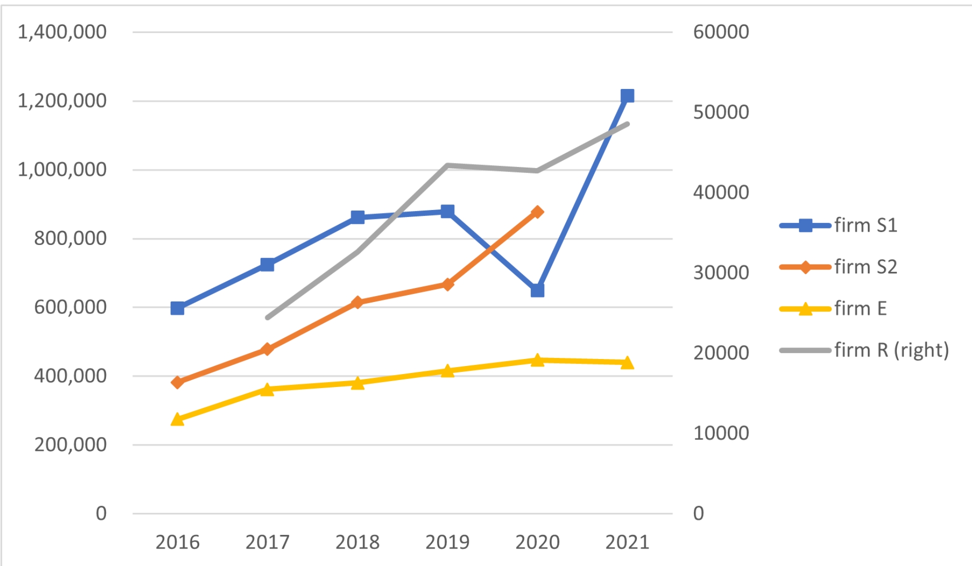
[18] https://news.mynavi.jp/techplus/article/20201211-1580067/ (in Japanese), accessed 25 October, 2022.

Figure 12. Trend of Korean firms' net fixed assets



Note: This figure shows the trend of net fixed assets of Korean firms producing semiconductor related materials. Information on firm R is not available.

Figure 13. Trend of Korean firms' sales

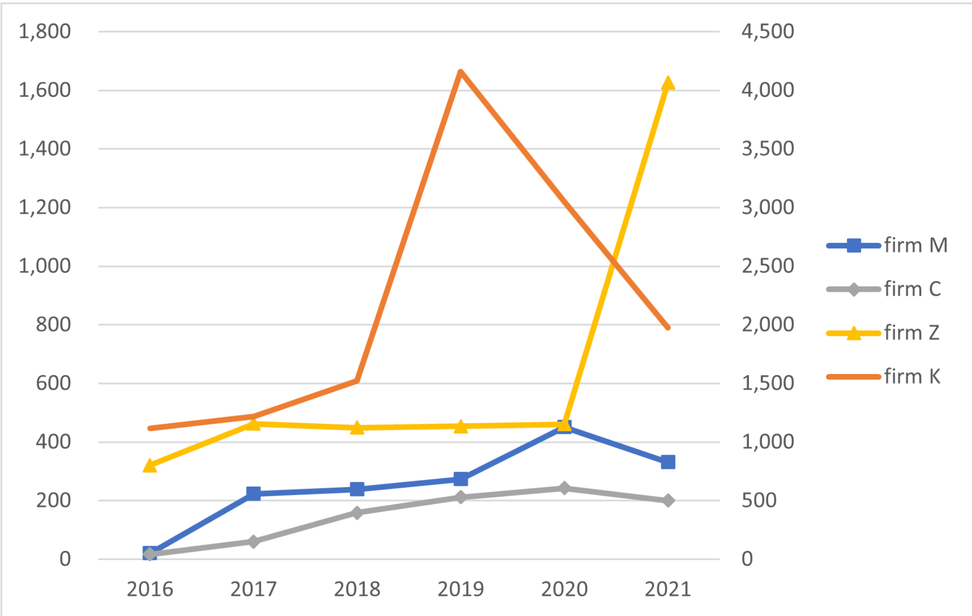


Note: This figure shows the trend of sales of Korean firms producing semiconductor related materials.

4.5.2 Local production by Japanese affiliates in South Korea

Japan's export control has also pushed Japanese MNEs to expand local production in South Korea. As Japanese firms have an overwhelmingly large market share in the three specified items, they will lose market share if Korean firms' domestic production advances. In addition, in expectation of government support policy and the development of the semiconductor industry in South Korea, Japanese firms might expand local production. In fact, it was reported that within one year after the export controls, several Japanese manufacturers of semiconductor-related materials were shifting their production to South Korea[19].

Figure 14. Trend of Japanese affiliates' capital investment



Note: This figure shows the trend of capital investment of Japanese foreign affiliates producing semiconductor related materials in South Korea.

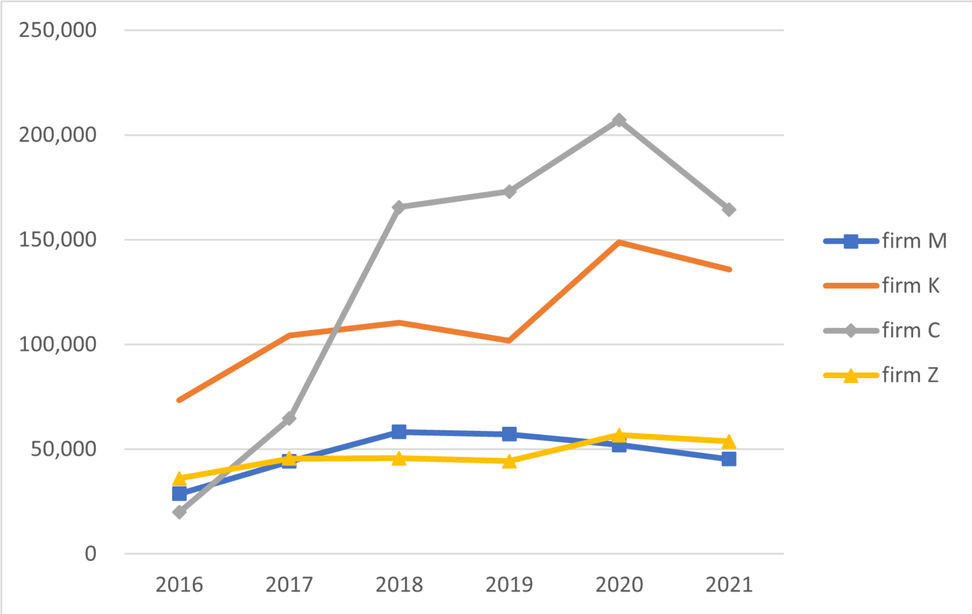
Figures 14 and 15 show the trend of four major Japanese affiliates' capital investment and sales in South Korea from 2016 to 2021. First, all Japanese affiliates increased their capital investment during 2018–2019 (firm Z is not obvious due to it relatively small scale). On average, the investment growth rates were 55.6% during 2018–2019 and 13.6% during 2019–2020. Second, the sales of Japanese affiliates significantly increased during 2019–2020 (except firm M), with an average growth rate at 21.2%. The sales growth rates declined during 2020–2021, probably because of the impact of the pandemic and market competition with Korean firms. However, total sales of Japanese affiliates in the post-2019 period was much larger than total sales in the pre-2019 period.

4.5.3 Domestic production of Japanese parent firms

It is worth noting that due to the export control, Japanese parent firms experienced a significant and persistent declines in sales after 2019 (Figure 16). Specifically, the average sales growth rate was 16.3% during 2017–2018, but it declined to -0.7% during 2018–2019, -7.9% during 2019–2020, and -4.8% during 2020–2021. Among four firms, firm M' sales dropped by 27.4% year-on-year in 2020.

[19]Nikkei Sangyo Shimbun (August 14, 2020) "Semiconductor materials shift to Korean production" TECH+ (December11,2020)"AseriesofinvestmentsinSouthKoreatoincreaseproductionofhydrogenfluorideforsemiconductors"h //www.nikkei.com/article/DGXMZO62914600R20C20A8X93000/ (in Japanese), accessed 25 October, 2022.

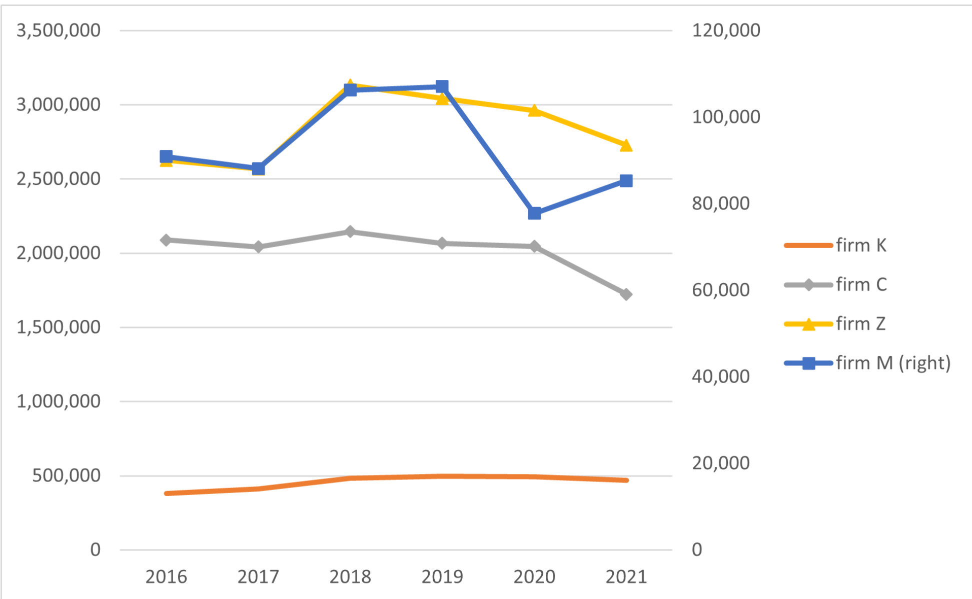
Figure 15. Trend of Japanese affiliates' sales



Note: This figure shows the trend of sales of Japanese foreign affiliates producing semiconductor related materials in South Korea.

This suggests that domestic production by Korean firms and local production by Japanese affiliates in South Korea are partly replacing domestic production by Japanese parent firms in Japan after the Japanese government's strengthening of export controls of three specified items.

Figure 16. Trend of Japanese parents' sales



Note: This figure shows the trend of sales of Japanese parent firms producing semiconductor related materials.

It should be mentioned that this negative pattern of Japanese parent firms with affiliates in South Korea is only suggestive evidence, without formal analysis. It should be further investigated using regression analysis with firm-level data in future studies.

4.6 Robustness

This subsection discusses several robustness checks to make sure that our identification assumptions are likely to be satisfied. First, our results may be vulnerable to the SUTVA, because the Japanese export controls against South Korea force South Korean firms to reallocate its exports and imports to other countries, thus affecting outcomes in the control groups. In order to mitigate the concern, we implement the same regressions as in equation (1), but focusing our control groups on countries less likely to be affected by our policy change. For instance, when analyzing the effect of the export controls on the Japanese exports of three restricted chemical materials to South Korea, we exclude the other major destination countries of the restricted Japanese chemical materials— the U.S., China, Taiwan, and the UK— and implement the regression. The odd columns in Tables A6 to A13 of Appendix A4 show that our main results do not change even if the analyses focus on the control groups without possible spillover effects.

Second, our main results are obtained using the entire sample of products. However, one may think that the control groups include products that have different trends than semiconductor-related products, thus providing biased estimates. To mitigate this concern, our next robustness checks focus on control groups with products within the same HS categories. For example, the effect of the Japanese export controls on exports of the restricted chemical materials to South Korea are analyzed by focusing on products with HS 2-digits of 37, 39, or 28. The results are reported in the even columns in Tables A6 to A13 of Appendix A4, thus confirming the robustness of our main estimates.

Third, there may be other concurrent events that affect the South Korean and Japanese trade in semiconductor-related products with other countries. The most relevant case should be the U.S. export controls against China. The U.S. announced its first export controls in May and August 2019, when the Department of Commerce added Huawei and its affiliates to the Entity List. Furthermore, they imposed additional export controls in May 2020 when it was recognized that the 2019 restrictions were ineffective. These controls were adopted with around the same timing as the Japanese export controls in July 2019 and therefore contaminate our results especially in their trades with third countries. However, these concerns are mitigated by (a) focusing our sample on products with the same HS 2-digit product categories as the treatment group and (b) using the exact timing of the introduction of the Japanese export controls (i.e., July 2019) in the event-study and the synthetic control approaches.

Fourth, our baseline analyses have only a few treatment units (e.g., hydrogen fluoride, photoresist, and fluorinated polyimide from Japan to South Korea) in each regression, and thus our inference based on asymptotic theory may be incorrect. According to MacKinnon et al. (2022), cluster-robust t-tests are at risk of over-rejecting when only a few clusters are treated. To check whether our main results are derived from this inference problem, we prefer to use the synthetic control method by Abadie and Gardeazabal (2003), Abadie et al. (2010), and Abadie (2021). The method can be used in the case of a single treatment unit, and provides a data-driven procedure to choose weights for control groups and construct a "synthetic" control group, which has a pre-treatment trend of the outcome variable comparable to the treatment group. In our robustness checks, the weights for each control unit are constructed so that pre-treatment outcome variables in all periods are as close as possible between the treatment and synthetic control groups, following Ferman et al. (2020).

One requirement in the synthetic control method is that the chosen weights should be non-negative and smaller than one, so that the synthetic control groups is constructed as a convex hull of all control group units. This is a potential problem in our setting because the outcome of our treatment unit may be an outlier, and therefore its synthetic control groups are not constructed as a convex combination (e.g., see Figure 4 for the Japanese exports of photoresist to South Korea). Therefore, following Ferman and Pinto (2021), we normalize each export and import value relative to its value in the corresponding month of 2017 and use the normalized value as an outcome variable. In addition, our donor pool of observations (control groups) is restricted to products having (a) the balanced panel and (b) the same HS 4-digits or 2-digits as our treatment group, in order to avoid the over-fitting problem.

The results are reported in Figure 17. They all show the same patterns found in the main DID analysis, thus supporting our main results[20]. In terms of their inference, Figure A8 in Appendix A6 shows the placebo tests for these synthetic control analyses. The gray dashed lines in each window are the estimates resulting from assigning treatment status to untreated units as if they were treated. The solid black lines in the South Korean imports of hydrogen fluoride from Japan (top left), those from the U.S. (middle middle) and Taiwan (middle right), South Korean photoresist imports from Belgium (middle left), and the South Korean exports of semiconductor manufacturing equipment to China (bottom right) show one of the most extreme treatment effects among the placebo groups, thus suggesting their statistical significance.

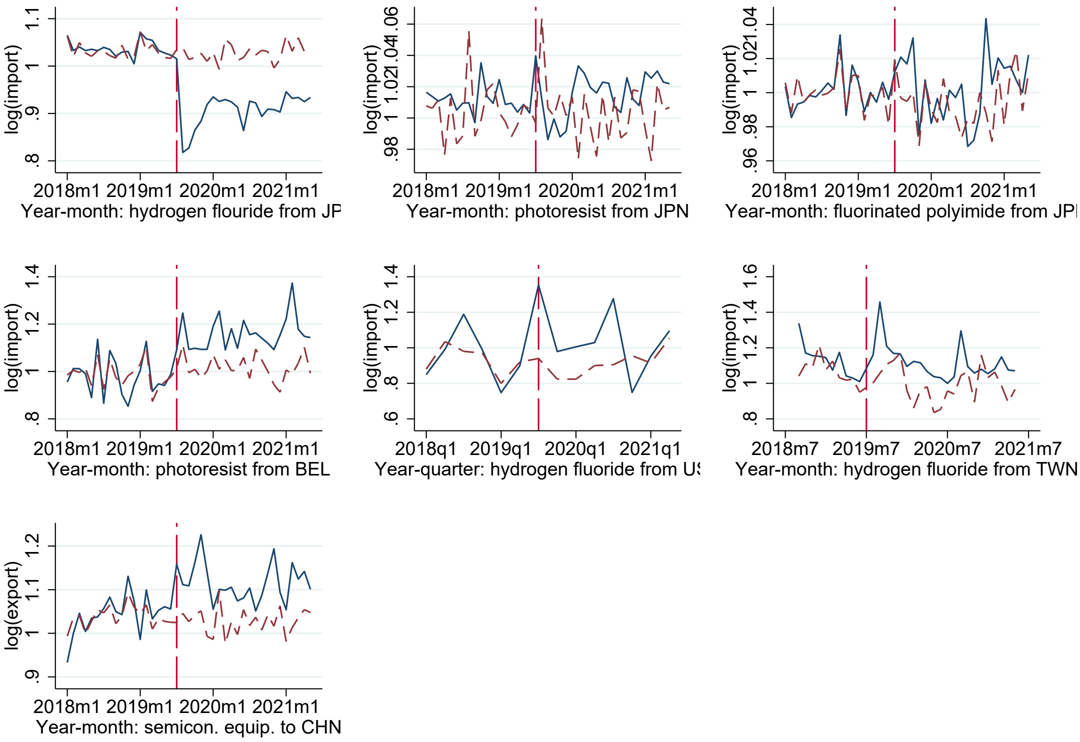
5 Conclusion

This paper analyzes the effects of Japanese export controls of three chemical materials necessary in semiconductor production against South Korea on their production, export, and import. The result shows first that the export controls caused a large decline in the Japanese exports of hydrogen fluoride to South Korea, but not those of photoresist or fluorinated polyimide. Second, they increased the Japanese exports of hydrogen fluoride to the U.S. as well as its South Korean import from the U.S., thus suggesting possible roundabout exports. Third, South Korea reallocated input sourcing of the restricted products from Japan to economies such as Belgium, the U.S., and Taiwan. Fourth, South Korea increased the export of semiconductor manufacturing equipment to China, implying that some of their semiconductor production was relocated to China. Fifth, Korean firms' domestic production and Japanese affiliates' local production in South Korea increased significantly after the export controls.

All the results suggest that the effectiveness of unilateral export controls is limited in the current global economy due to changes in firm's sourcing strategy, production locations, and MNEs' production decisions. Further research should be done especially by using more detailed firm-level data.

[20]The method allows us to approximate the characteristics of the treated unit by using a combination of units in the donor pool. For instance, the synthetic control group for the South Korean imports of hydrogen fluoride from Japan is comprised of 37.6% hydrogen fluoride imports from China, 4% inorganic acids imports from Germany, 7.9% inorganic acids imports from Israel, 4% silicon dioxide imports from France, 9.9% silicon dioxide imports from the United States, 37.8% inorganic oxygen compounds imports from Japan, and 2.3% inorganic oxygen imports from the United States (Table A14 in Appendix A5). The group is mostly constructed by the import of the same product (hydrogen fluoride) from the top source country (China, see Table 1) and the import of similar product (inorganic oxygen compounds) from the same country as the treatment group (Japan), and is able to track the trajectory of the outcome variable for the treatment group over the long pre-treatment periods (Table A15 in Appendix A5). Therefore, it should approximate well the counterfactual South Korean imports of hydrogen fluoride from Japan *in the absence of the dispute*.

Figure 17. Synthetic control method for the effect of the export controls



Note: The figure plots the results of the synthetic control method for South Korean imports of hydrogen fluoride from Japan (top left), their imports of photoresist from Japan (top middle), their imports of fluorinated polyimide from Japan (top right), their imports of photoresist from Belgium (middle left), their imports of hydrogen fluoride from the U.S. (middle middle), their imposts of hydrogen fluoride from Taiwan, and their exports of semiconductor manufacturing equipment to China (bottom left). Within each window, the blue line is log import values or log export values for each treatment group. The red dashed line is the corresponding values for the synthetic control group. The vertical red line denotes the timing of the Japanese export controls (July 2019 or third quarter in 2019).

References

[1] Abadie, Alberto. (2021). "Using Synthetic Controls: Feasibility, Data Requirements, and Methodological Aspects." *Journal of Economic Literatures*, 59(2): 391–425.

[2] Abadie, Alberto, Alexis Diamond, and Jens Hainmueller (2010). "Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program." *Journal of the American Statistical Association*, 105(490): 493-505.

[3] Abadie, Alberto. and Javier Gardeazabal. (2003). "The Economic Costs of Conflict: A Case Study of the Basque Country." *American Economic Review*, 93(1): 113-132.

[4] Amiti, Mary, Stephen Redding, and David Weinstein. (2019). "The Impact of the 2018 Tariffs on Prices and Welfare.", *Journal of Economic Perspectives*, 33(4): 187-210.

[5] Antras, Pol and Davin Chor. (2021). "Global Value Chains." in Gopinath, G., E. Helpman, and K. Rogoff, *Handbook of International Economics*, Vol. 5.

[6] Benguria, Felipe and Felipe Saffie. (2019) "Dissecting the Impact of the 2018-2019 Trade War on U.S. Exports." *Working Paper*.

[7] Bown, Chad P. (2020) "How the United States Marched the Semiconductor Industry into its Trade War with China." *East Asian Economic Review*, 24(4): 349-388.

[8] Bown, Chad P., Euijin Jung, and Eva Yiwen Zhang. (2019) "Trump Has Gotten China to Lower Its Tariffs. Just Toward Everyone Else." Peterson Institute for International Economics, https://www.piie.com/blogs/trade-and-investment-policy-watch/trump-has-gotten-china-lower-its-tariffs-just-toward.

[9] Chen, Zhe, Zhongzhong Hu and Kai Li. (2021) "The Spillover Effect of Trade Policy along the Value Chain: Evidence from China's Rare Earth-related Sectors." *The World Economy*, 44(12): 3550-3582.

[10] Fajgelbaum, Pablo, Pinelopi Goldberg, Patrick Kennedy, and Amit Khandelwal (2020) "The Return to Protectionism." *Quarterly Journal of Economics*, 135(1): 1-55.

[11] Fajgelbaum, Pablo, Pinelopi Goldberg, Patrick Kennedy, Amit Khandelwal, and Daria Taglioni (2021) "The US-China Trade War and Global Reallocations." *Working Paper*.

[12] Ferman, Bruno and Cristine Pinto (2021) "Synthetic Controls with Imperfect Pretreatment Fit." *Quantitative Economics*, 12: 1197-1221.

[13] Ferman, Bruno, Cristine Pinto, and Vitor Possebom (2020) "Cherry Picking with Synthetic Controls." *Journal of Policy Analysis and Management*, 39(2): 510-532.

[14] Flaaen, Aaron, Ali Hortacsu, and Felix Tintelnot (2020) "The Production Relocation and Price Effects of US Trade Policy: The Case of Washing Machines." *American Economic Review*, 110(7): 2103-2127.

[15] Goldberg, Pinelopi and Nina Pavcnik (2016) "The Effects of Trade Policy." *Handbook of Commercial Policy*, 1: 161-206.

[16] Handley, Kyle, Fariha Kamal, and Ryan Monarch (2020) "Rising Import Tariffs, Falling Export Growth: When Modern Supply Chains Meet Old-Style Protectionism." *Working Paper*.

[17] Hayakawa, Kazunobu, Keiko Ito, Kyoji Fukao, and Ivan Deseatnicov (2022) "The Impact of the U.S.-China Conflict and the Strengthening of Export Controls on Japanese Exports." *IDE Discussion Paper*, No. 852.

[18] Latipov, Olim, Christian Lau, Kornel Mahlstein, and Simon Schropp (2022) "Quantifying the impact of the latest U.S. tariff sanctions on Russia - a sectoral analysis." *IIEP Working Paper* 2022-08, The George Washington University, Institute for International Economic Policy.

[19] MacKinnon, James G., Morten Ørregaard Nielsen, and Matthew D. Webb. (2022) "Cluster-robust Inference: A Guide to Empirical Practice." *Journal of Econometrics*, In press.

[20] Rambachan, Ashesh and Jonathan Roth. (2022) " More Credible Approach to Parallel Trends." *Review of Economic Studies*, Forthcoming.

[21] Semiconductor Industry Association. (2016) *Beyond Borders the Global Semiconductor Value Chain*, SIA: Washington, DC, USA.

[22] Semiconductor Industry Association. (2021) *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, SIA: Washington, DC, USA.

[23] Vandenbussche, Hylke and Christian Viegelahn (2018) "Input Reallocation within Multi-Product Firms." *Journal of International Economics*, 114: 63-79.

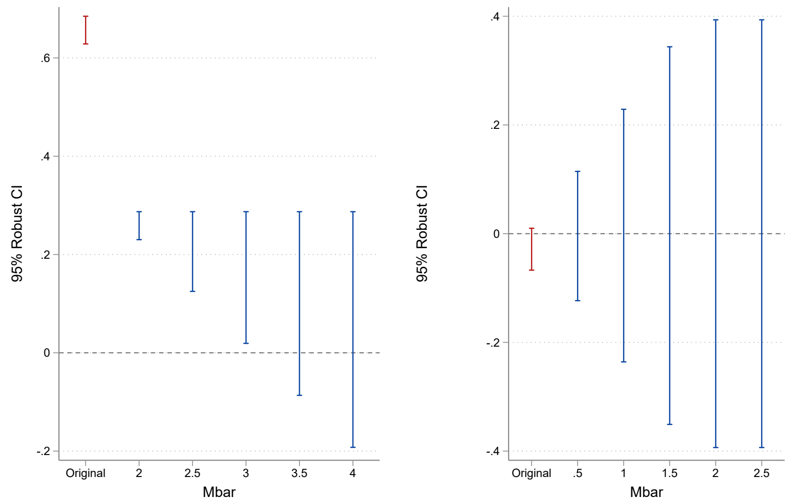
[24] World Bank (2020) *World Development Report 2020: Trading for Development in the Age of Global Value Chains*, World Bank Publications.

A1 Appendix: robustness to the violation of parallel trends

In Section 4, some results from the event-study approach show pre-treatment differences between treatment and control groups, thus implying violations of parallel trends, while the post-treatment estimates are large, statistically significant, and discontinuously jump after the export controls. To investigate how much the violation of parallel trends may affect our results, we use a methodology by Rambachan and Roth (2022). It allows violations of parallel trends and provides a way to set-identify treatment effects by restricting the post-treatment violations of parallel trends of untreated potential outcomes between treatment and control groups given the trends in pre-treatment periods.

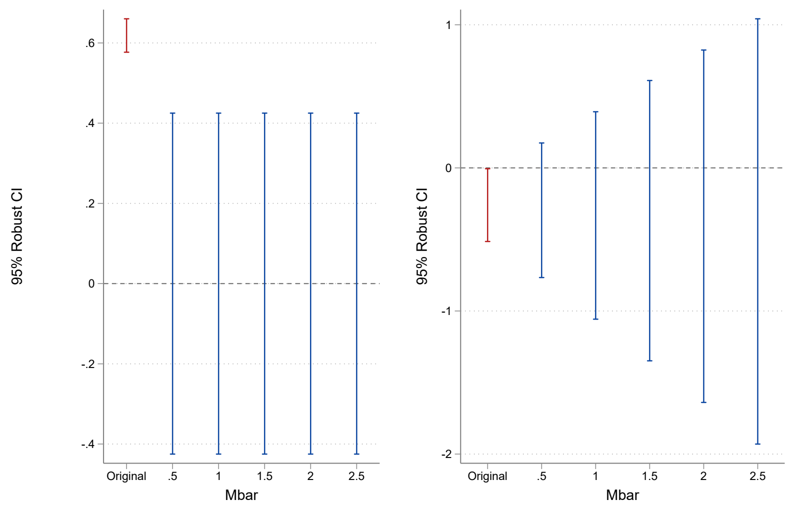
We report a sensitivity analysis by providing confidence intervals for different levels of the restriction, $\bar{M}$. $\bar{M}$ is a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. If, for example, $\bar{M} = 1$, its confidence interval is obtained by allowing the post-treatment violation of parallel trends to be no larger than the maximum pre-treatment violation of parallel trends.

Figure A1. Sensitivity analysis on Japanese export of three chemical materials to the United States



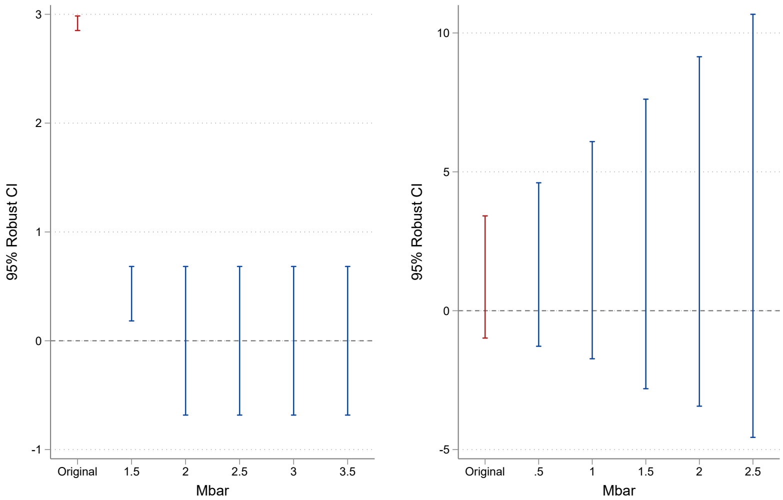
Note: This figure plots the results of Rambachan and Roth's (2022) methodology for the estimates on Japanese exports of hydrogen fluoride (left) and, photoresist and fluorinated polyimide (right) to the Unites States. $\bar{M}$ on the x-axis denotes a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. For instance, the confidence intervals at $\bar{M} = 2$ is a 95% robust CIs of treatment effects when the post-treatment violation of parallel trends is restricted to be less than 2 times the maximum pre-treatment violation of parallel trends.

Figure A2. Sensitivity analysis on South Korean imports of three chemical materials from the United States



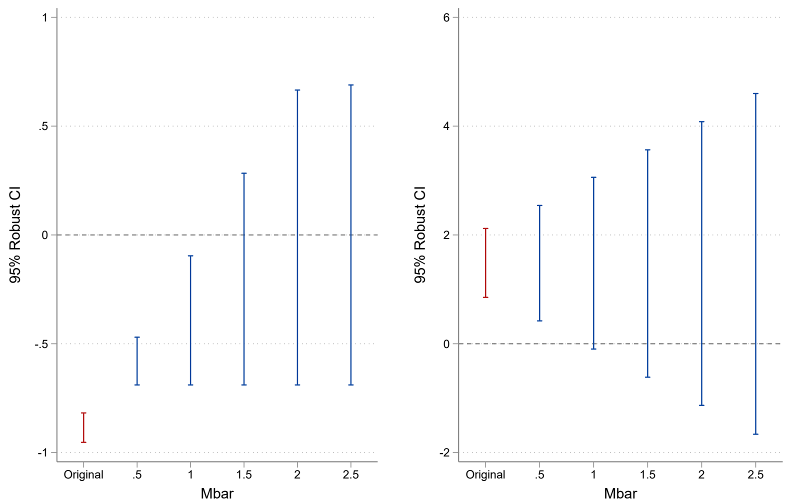
Note: This figure plots the results of Rambachan and Roth's (2022) methodology for the estimates on South Korean imports of hydrogen fluoride (left) and, photoresist and fluorinated polyimide (right) from the United States. $\bar{M}$ on the x-axis denotes a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. For instance, the confidence intervals at $\bar{M} = 0.5$ is a 95% robust CIs of treatment effects when the post-treatment violation of parallel trends is restricted to be less than half the maximum pre-treatment violation of parallel trends.

Figure A3. Sensitivity analysis on South Korean imports of three chemical materials from Taiwan



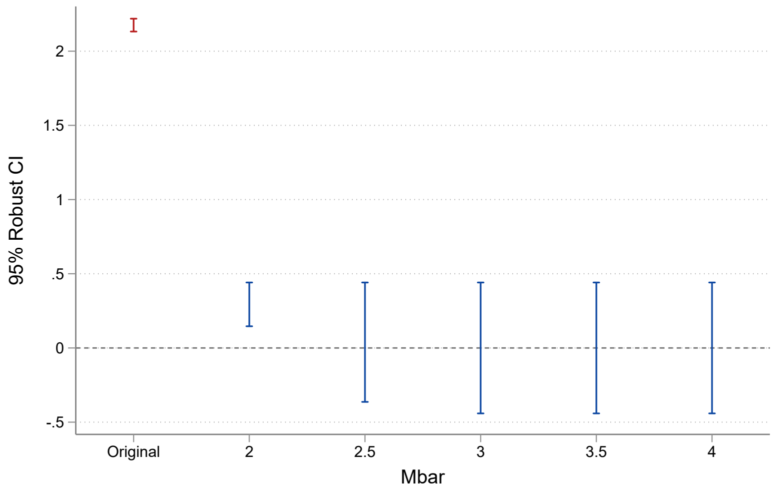
Note: This figure plots the results of Rambachan and Roth's (2022) methodology for the estimates on South Koraen imports of hydrogen fluoride (left) and, photoresist and fluorinated polyimide (right) from Taiwan. $\bar{M}$ on the x-axis denotes a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. For instance, the confidence intervals at $\bar{M} = 1.5$ is a 95% robust CIs of treatment effects when the post-treatment violation of parallel trends is restricted to be less than 1.5 times the maximum pre-treatment violation of parallel trends.

Figure A4. Sensitivity analysis on South Korean imports of three chemical materials from Belgium



Note: This figure plots the results of Rambachan and Roth's (2022) methodology for the estimates on South Korean imports of hydrogen fluoride (left) and, photoresist and fluorinated polyimide (right) from Belgium. $\bar{M}$ on the x-axis denotes a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. For instance, the confidence intervals at $\bar{M} = 0.5$ is a 95% robust CIs of treatment effects when the post-treatment violation of parallel trends is restricted to be less than half the maximum pre-treatment violation of parallel trends.

Figure A5. Sensitivity analysis on South Korean exports of semiconductor manufacturing equipment to China



Note: This figure plots the results of Rambachan and Roth's (2022) methodology for the estimates on South Korean exports of semiconductor manufacturing equipment to China. $\bar{M}$ on the x-axis denotes a degree of the restriction that the maximum post-treatment violation of parallel trends should be no larger than $\bar{M}$ times the maximum pre-treatment violation of parallel trends. For instance, the confidence intervals at $\bar{M} = 1.5$ is a 95% robust CIs of treatment effects when the post-treatment violation of parallel trends is restricted to be less than 1.5 times the maximum pre-treatment violation of parallel trends.

A2 Appendix: additional results for main analysis

Table A1: Effect on Japanese exports of semiconductor products and semiconductor manufacturing equipment to South Korea

	(1)	(2)	(3)	(4)
Treat:	Semicon		Equipment	
Outcome:	Value	Value	Value	Value
after#KOR#Treat	0.0101		-0.224***	
	(0.119)		(0.0106)	
2018#KOR#Treat		0.0177		-0.340***
		(0.100)		(0.00916)
2019h1#KOR#Treat		0.0499		-0.855***
		(0.130)		(0.0126)
2019h2#KOR#Traet		0.0955		-1.050***
		(0.165)		(0.0136)
2020#KOR#Treat		0.0171		-0.410***
		(0.191)		(0.0142)
2021#KOR#Treat		-0.0308		-0.202***
		(0.158)		(0.0162)
HS6-Ctry FE	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes
Observations	2,961,097	2,961,097	2,961,097	2,961,097
R-squared	0.861	0.861	0.861	0.861

Note: The table reports the results from estimating equation (1) to investigate the effect of the Japanese export controls on Japanese exports of semiconductor products and semiconductor manufacturing equipment to South Korea. Columns 1 and 2 are the results for the exports of semiconductor products and columns 3 and 4 for those of semiconductor manufacturing equipment. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#KOR#Treat” denotes an interaction term of year-2018, South Korea, and treatment product (either semiconductor products or semiconductor manufacturing equipment) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A2: Effect on Japanese exports of semiconductor products to other economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ctry dummy:	China		Taiwan		Hong Kong		Thailand	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#semicon	0.0134		0.188*		0.155		0.223**	
	(0.0683)		(0.103)		(0.101)		(0.0901)	
2018#Ctry#semicon		-0.0174		-0.0129		-0.0189		0.159***
		(0.0589)		(0.0648)		(0.0522)		(0.0478)
2019h1#Ctry#semicon		-0.0393		-0.0939		0.0599		0.183**
		(0.0750)		(0.113)		(0.0993)		(0.0897)
2019h2#Ctry#semicon		-0.0326		0.0282		0.151		0.345***
		(0.106)		(0.136)		(0.125)		(0.113)
2020#Ctry#semicon		0.0475		0.184		0.231		0.337***
		(0.100)		(0.138)		(0.146)		(0.111)
2021#Ctry#semicon		-0.0816		0.278		-0.00108		0.263**
		(0.109)		(0.180)		(0.147)		(0.124)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097
R-squared	0.861	0.861	0.861	0.861	0.861	0.861	0.861	0.861

Note: The table reports the results from estimating equation (1) to investigate the effect of the Japanese export controls on Japanese exports of semiconductor products to other major destination economies. Columns 1 and 2 are the results for the exports to China, columns 3 and 4 for those to Taiwan, columns 5 and 6 for those to Hong Kong, and columns 7 and 8 for those to Thailand. The dependent variable is log export values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#semicon" denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 8541, 8542) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A3: Effect on Japanese exports of semiconductor manufacturing equipment to other economies

Ctry dummy:	China		Taiwan		USA		Singapore	
	(1)	(2)	(3)	(4)				
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value
after#Ctry#equipment	0.684***		0.402***		0.248***		-0.334***	
	(0.0108)		(0.00901)		(0.0102)		(0.0121)	
2018#Ctry#equipment		0.337***		-0.476***		-0.326***		0.0491***
		(0.00930)		(0.00899)		(0.00951)		(0.0114)
2019h1#Ctry#equipment		0.580***		0.304***		0.880***		-0.538***
		(0.0125)		(0.0124)		(0.0133)		(0.0149)
2019h2#Ctry#equipment		0.848***		0.702***		0.876***		-0.124***
		(0.0134)		(0.0125)		(0.0139)		(0.0156)
2020#Ctry#equipment		0.961***		0.188***		0.246***		-0.730***
		(0.0150)		(0.0126)		(0.0144)		(0.0165)
2021#Ctry#equipment		0.978***		-0.0375**		-0.284***		-0.0409**
		(0.0172)		(0.0150)		(0.0167)		(0.0192)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097	2,961,097
R-squared	0.861	0.861	0.861	0.861	0.861	0.861	0.861	0.861

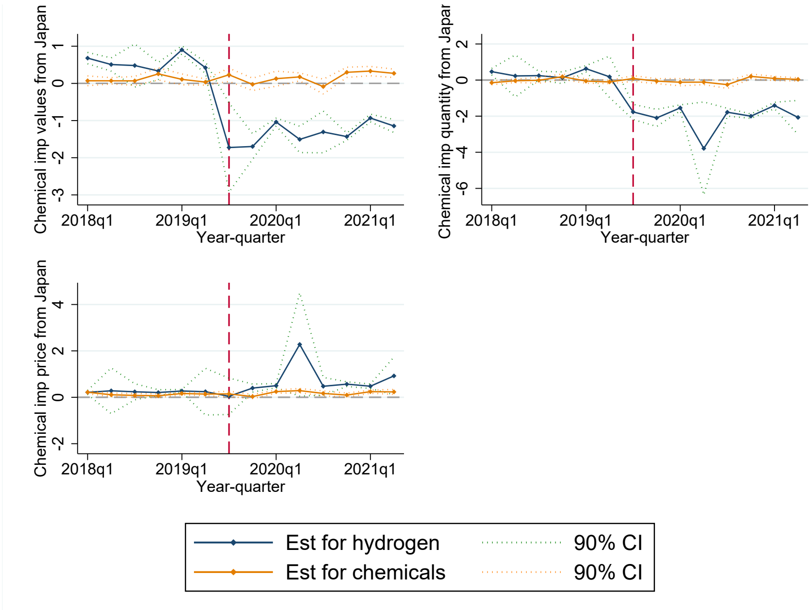
Note: The table reports the results from estimating equation (1) to investigate the effect of the Japanese export controls on Japanese exports of semiconductor products to other major destination economies. Columns 1 and 2 are the results for the exports to China, columns 3 and 4 for those to Taiwan, columns 5 and 6 for those to the U.S., and columns 7 and 8 for those to Singapore. The dependent variable is log export values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#quipment" denotes an interaction term of year-2018, country under consideration, and semiconductor manufacturing equipment (HS 848620) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A4: Effect on South Korean imports of three restricted chemical materials from Japan

Outcome:	(1) Value	(2) Value	(3) Qtty	(4) Qtty	(5) Uval	(6) Uval
after#japan#hydrogen	-1.488***		-1.732***		0.243***	
	(0.0142)		(0.0174)		(0.0102)	
2018#japan#hydrogen		0.541***		0.565***		-0.0220**
		(0.0145)		(0.0172)		(0.0103)
2019h1#japan#hydrogen		0.466***		0.696***		-0.233***
		(0.0187)		(0.0220)		(0.0136)
2019h2#japan#hydrogen		-1.562***		-1.113***		-0.449***
		(0.0193)		(0.0232)		(0.0141)
2020#japan#hydrogen		-0.928***		-1.416***		0.485***
		(0.0196)		(0.0239)		(0.0143)
2021#japan#hydrogen		-1.301***		-1.530***		0.229***
		(0.0237)		(0.0284)		(0.0168)
after#japan#chemical	0.139*		0.141		-0.0111	
	(0.0831)		(0.144)		(0.0533)	
2018#japan#chemical		0.121***		-0.00635		0.126**
		(0.0138)		(0.0552)		(0.0581)
2019h1#japan#chemical		-0.0974		-0.107		0.0238
		(0.0806)		(0.173)		(0.0874)
2019h2#japan#chemical		0.0748***		0.0314		0.0501
		(0.0186)		(0.165)		(0.167)
2020#japan#chemical		0.190***		0.165***		0.0309**
		(0.0674)		(0.0611)		(0.0156)
2021#japan#chemical		0.226		0.106		0.0679
		(0.157)		(0.0760)		(0.128)
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,741,702	2,741,702	2,734,246	2,734,246	2,737,440	2,737,440
R-squared	0.812	0.812	0.852	0.852	0.838	0.838

Note: The table reports the results from estimating equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of three chemical materials from Japan. The dependent variable is log import values (columns 1 and 2), log import quantity (columns 3 and 4), and log unit values (columns 5 and 6). For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#japan#hydrogen" denotes an interaction term of year-2018, Japan, and hydrogen fluoride (HS 281111) dummy variables. "2018#japan#chemical" denotes a similar interaction term but for other two restricted materials (HS 370790, 391190). "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Figure A6. Coefficient on Korean import of three restricted products from Japan



Note: This figure plots the coefficients on the interactions between year-quarter, Japan, and product dummies as in even columns in Table A4 of Appendix A2, but using the year-quarter aggregated data and including HS 6-digit × country × quarter fixed effects. The coefficients are thus estimated with respect to their respective values in the year 2017 (all 12 months of 2017 are omitted). The vertical dashed line corresponds to the 3rd quarter in 2019 when the export control was placed. The dotted lines show the 90% confidence intervals.

Table A5: Effect on South Korean imports of semiconductor products and semiconductor manufacturing equipment from Japan

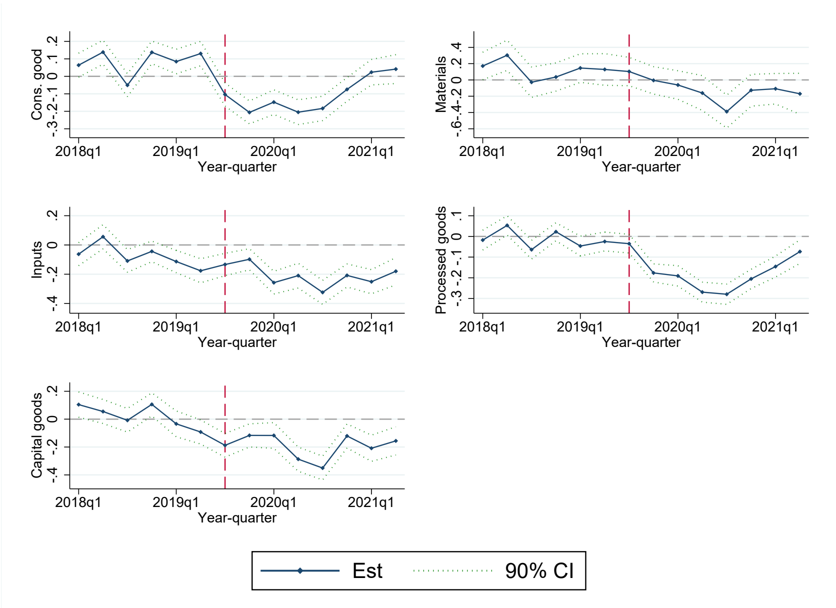
	(1)	(2)	(3)	(4)
Treat:	Semicon		Equipment	
Outcome:	Value	Value	Value	Value
after#japan#Treat	0.162		-0.240***	
	(0.158)		(0.0147)	
2018#japan#Treat		-0.149*		-0.548***
		(0.0842)		(0.0147)
2019h1#japan#Treat		-0.238*		-0.776***
		(0.130)		(0.0192)
2019h2#japan#Treat		-0.156		-0.837***
		(0.208)		(0.0202)
2020#japan#Treat		0.147		-0.639***
		(0.214)		(0.0200)
2021#japan#Treat		0.0860		-0.291***
		(0.231)		(0.0233)
HS6-Ctry FE	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes
Observations	2,741,702	2,741,702	2,741,702	2,741,702
R-squared	0.812	0.812	0.812	0.812

Note: The table reports the results from estimating equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of semiconductor products and semiconductor manufacturing equipment from Japan. Columns 1 and 2 are the results for the exports of semiconductor products and columns 3 and 4 for those of semiconductor manufacturing equipment. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#japan#Treat” denotes an interaction term of year-2018, Japan, and treatment product (either semiconductor products or semiconductor manufacturing equipment) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times sourcing country, HS 6-digit category times year-month, and sourcing country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

A3 Appendix: effect of consumer boycotts

This section independently investigates the effect of the Japanese export controls on Japanese exports to South Korea in products other than semiconductors, because the restriction led also to consumer boycott activities in South Korea against Japanese products. To achieve this, we use a similar difference-in-differences framework as equation (1), but utilizing the year-quarter aggregated data and including HS 6-digit $\times$ country $\times$ quarter fixed effects. The product categories include: consumer products, materials , inputs, processed goods, and capital goods from the RIETI-TID database. Figure A2 plots the coefficients on the interaction terms of product category, South Korea (as a destination country), and year-quarter.

Figure A7. Coefficient on Korean imports of aggregated product categories



Note: This figure plots the coefficients on the interactions between year-quarter, Japan, and product dummies as in column (2) of Table A4 in Appendix A2, but using the year-quarter aggregated data and including HS 6-digit $\times$ country $\times$ quarter fixed effects. For the product category, we use consumer products (top left), materials (top right), inputs (middle left), processed goods (middle right), and capital goods (bottom left), using information in RIETI-TID database (https://www.rieti.go.jp/en/projects/rieti-tid/). The coefficients are thus estimated with respect to their respective values in the year 2017 (all 12 months of 2017 are omitted). The vertical dashed line corresponds to the 3rd quarter in 2019 when the export control was placed. The dotted lines show the 90% confidence intervals.

A4 Appendix: results from restricting control groups

Table A6: Effect on Japanese exports of three restricted chemical materials to major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Korea		USA		China		Taiwan		UK	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#hydrogen	0.688***	0.263***	0.193***	-0.245***	0.169***	-0.260***	1.336***	1.194***	-0.473***	-0.0704
	(0.0108)	(0.0288)	(0.0111)	(0.0323)	(0.0109)	(0.0376)	(0.0108)	(0.0260)	(0.0216)	(0.0776)
2019h1#Ctry#hydrogen	0.586***	0.0317	0.478***	-0.0497	0.656***	0.171***	1.724***	1.502***	-1.285***	-0.887***
	(0.0146)	(0.0424)	(0.0149)	(0.0440)	(0.0145)	(0.0479)	(0.0142)	(0.0380)	(0.0334)	(0.122)
2019h2#Ctry#hydrogen	-2.170***	-2.571***	0.674***	0.632***	0.402***	0.297***	1.491***	1.650***	-1.219***	0.108
	(0.0162)	(0.0471)	(0.0162)	(0.0464)	(0.0158)	(0.0523)	(0.0148)	(0.0382)	(0.0332)	(0.102)
2020#Ctry#hydrogen	-1.379***	-1.831***	0.622***	0.675***	0.560***	0.466***	1.153***	1.284***	-0.974***	-0.349***
	(0.0161)	(0.0448)	(0.0163)	(0.0475)	(0.0173)	(0.0585)	(0.0147)	(0.0383)	(0.0306)	(0.0892)
2021#Ctry#hydrogen	-1.506***	-1.950***	0.383***	0.441***	0.822***	0.829***	1.001***	1.168***	-1.446***	-0.883***
	(0.0184)	(0.0531)	(0.0189)	(0.0520)	(0.0196)	(0.0611)	(0.0175)	(0.0442)	(0.0389)	(0.145)
2018#Ctry#chemical	0.140	0.102	0.0677	0.0689	0.0512**	0.0535	0.0659**	0.107***	0.00864	0.0988
	(0.121)	(0.130)	(0.0663)	(0.0738)	(0.0212)	(0.0411)	(0.0294)	(0.0396)	(0.0606)	(0.0838)
2019h1#Ctry#chemical	0.170**	0.142	0.0903	0.0834	0.0996***	0.0951*	0.213***	0.244***	-0.0157	0.0588
	(0.0829)	(0.103)	(0.0969)	(0.101)	(0.0193)	(0.0505)	(0.0732)	(0.0754)	(0.156)	(0.166)
2019h2#Ctry#chemical	0.294***	0.221**	-0.0226	-0.0274	0.193***	0.187***	0.173	0.222*	-0.238***	-0.266***
	(0.0953)	(0.101)	(0.0168)	(0.0489)	(0.0139)	(0.0464)	(0.130)	(0.133)	(0.0281)	(0.0606)
2020#Ctry#chemical	0.548**	0.488*	-0.0388	-0.0287	0.296**	0.252*	0.591***	0.619***	-0.180	-0.219
	(0.246)	(0.252)	(0.0425)	(0.0681)	(0.126)	(0.134)	(0.0137)	(0.0382)	(0.258)	(0.285)
2021#Ctry#chemical	0.558**	0.459	-0.0624*	-0.00493	0.306	0.226	0.659***	0.665***	0.120	0.140
	(0.277)	(0.295)	(0.0358)	(0.0611)	(0.248)	(0.266)	(0.0986)	(0.109)	(0.318)	(0.343)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,473,470	220,624	2,471,674	220,624	2,497,961	220,624	2,473,156	220,624	2,537,390	220,624
R-squared	0.846	0.879	0.850	0.879	0.852	0.879	0.844	0.879	0.844	0.879

Note: The table reports the results of the robustness checks by excluding major destination countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) to investigate the effect of the Japanese export controls on Japanese exports of three chemical materials to major destination economies including South Korea. Columns 1 and 2 are the results for the Japanese exports to South Korea, columns 3 and 4 for the U.S., columns 5 and 6 for China, columns 7 and 8 for Taiwan, and columns 9 and 10 for the UK. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#hydrogen” denotes an interaction term of year-2018, country under consideration, and hydrogen fluoride (HS 281111) dummy variables. Similarly, ”2018#Ctry#chemical” denotes a similar interaction term but for other two restricted materials (HS 370790, 391190) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A7: Effect on Japanese exports of semiconductor products to major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ctry dummy:	Korea		China		Taiwan		Hong Kong		Thailand	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#semicon	0.0261	0.0277	-0.00873	0.0555	-0.00969	-0.0430	-0.00796	0.0237	0.162***	0.243***
	(0.106)	(0.106)	(0.0667)	(0.0664)	(0.0718)	(0.0734)	(0.0545)	(0.0630)	(0.0542)	(0.0578)
2019h1#Ctry#semicon	0.0624	0.1000	-0.0221	0.0443	-0.0853	-0.0779	0.0765	0.0968	0.191**	0.230**
	(0.135)	(0.138)	(0.0841)	(0.0847)	(0.119)	(0.120)	(0.101)	(0.113)	(0.0898)	(0.101)
2019h2#Ctry#semicon	0.130	0.0260	0.00310	0.0895	0.0567	0.0339	0.179	0.177	0.369***	0.364***
	(0.171)	(0.174)	(0.116)	(0.115)	(0.145)	(0.142)	(0.129)	(0.140)	(0.112)	(0.128)
2020#Ctry#semicon	0.0743	-0.0272	0.0930	0.0977	0.212	0.0871	0.272*	0.244	0.376***	0.436***
	(0.197)	(0.199)	(0.112)	(0.113)	(0.143)	(0.144)	(0.147)	(0.164)	(0.112)	(0.127)
2021#Ctry#semicon	0.0151	-0.0750	-0.0508	-0.0132	0.286	0.132	0.0359	0.00353	0.289**	0.354**
	(0.164)	(0.172)	(0.124)	(0.124)	(0.186)	(0.188)	(0.149)	(0.165)	(0.128)	(0.142)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,432,983	320,664	2,456,819	320,664	2,432,115	320,664	2,413,143	320,664	2,422,389	320,664
R-squared	0.849	0.878	0.855	0.878	0.848	0.878	0.846	0.878	0.848	0.878

Note: The table reports the results of the robustness checks by excluding major destination countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) to investigate the effect of the Japanese export controls on Japanese exports of semiconductor products to major destination economies including South Korea. Columns 1 and 2 are the results for the Japanese exports to South Korea, columns 3 and 4 for China, columns 5 and 6 for Taiwan, columns 7 and 8 for Hong Kong, and columns 9 and 10 for Thailand. The dependent variable is log export values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#semicon" denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 8541, 8542) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A8: Effect on Japanese exports of semiconductor manufacturing equipment to major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ctry dummy:	Korea		China		Taiwan		USA		Singapore	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#equipment	-0.380***	-0.297***	0.262***	0.301***	-0.509***	-0.461***	-0.368***	-0.310***	-0.0132	0.0314
	(0.00965)	(0.0256)	(0.00970)	(0.0267)	(0.00952)	(0.0294)	(0.00990)	(0.0268)	(0.0119)	(0.0311)
2019h1#Ctry#equipment	-0.778***	-0.782***	0.582***	0.542***	0.319***	0.305***	0.862***	0.871***	-0.476***	-0.545***
	(0.0133)	(0.0354)	(0.0132)	(0.0326)	(0.0132)	(0.0362)	(0.0138)	(0.0333)	(0.0156)	(0.0378)
2019h2#Ctry#equipment	-0.892***	-1.004***	0.899***	0.878***	0.759***	0.714***	0.919***	0.869***	-0.0126	-0.184***
	(0.0142)	(0.0365)	(0.0139)	(0.0350)	(0.0131)	(0.0369)	(0.0144)	(0.0352)	(0.0162)	(0.0406)
2020#Ctry#equipment	-0.363***	-0.396***	0.932***	0.985***	0.196***	0.209***	0.250***	0.214***	-0.667***	-0.746***
	(0.0151)	(0.0360)	(0.0156)	(0.0349)	(0.0133)	(0.0368)	(0.0151)	(0.0342)	(0.0171)	(0.0427)
2021#Ctry#equipment	-0.158***	-0.184***	0.949***	1.014***	-0.0167	-0.0584	-0.243***	-0.363***	-0.0153	-0.0614
	(0.0171)	(0.0406)	(0.0178)	(0.0393)	(0.0159)	(0.0483)	(0.0174)	(0.0424)	(0.0200)	(0.0516)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,444,196	513,516	2,468,762	513,516	2,444,151	513,516	2,442,855	513,516	2,404,019	513,516
R-squared	0.845	0.838	0.851	0.838	0.844	0.838	0.849	0.838	0.841	0.838

Note: The table reports the results of the robustness checks by excluding major destination countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) to investigate the effect of the Japanese export controls on Japanese exports of semiconductor manufacturing equipment to major destination economies including South Korea. Columns 1 and 2 are the results for the Japanese exports to South Korea, columns 3 and 4 for China, columns 5 and 6 for Taiwan, columns 7 and 8 for the U.S., and columns 9 and 10 for Singapore. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#equipment” denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 848620) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A9: Effect on Korean imports of three restricted chemical materials from major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ctry dummy:	Japan		China		USA		Germany		Taiwan		Singapore		Belgium	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#hydrogen	0.413***	0.642***	0.236***	0.496***	-1.563***	-1.682***	-0.175***	-0.0911	1.069***	1.364***	1.157***	1.283***	0.0921**	0.558***
	(0.0187)	(0.0473)	(0.0177)	(0.0604)	(0.0199)	(0.0686)	(0.0209)	(0.0603)	(0.0308)	(0.105)	(0.0349)	(0.138)	(0.0465)	(0.137)
2019h1#Ctry#hydrogen	0.291***	0.568***	-0.0746***	0.138*	-2.563***	-2.805***	0.166***	0.424***	1.383***	1.750***	1.783***	1.582***	-0.636***	-0.182
	(0.0232)	(0.0613)	(0.0221)	(0.0773)	(0.0235)	(0.0826)	(0.0255)	(0.0795)	(0.0376)	(0.137)	(0.0431)	(0.156)	(0.0469)	(0.143)
2019h2#Ctry#hydrogen	-0.933***	-1.585***	0.698***	0.0368	1.123***	0.372***	0.701***	0.0997	3.182***	2.884***			-0.520***	-0.832***
	(0.0246)	(0.0656)	(0.0240)	(0.0775)	(0.0257)	(0.0885)	(0.0269)	(0.0836)	(0.0391)	(0.139)			(0.0373)	(0.115)
2020#Ctry#hydrogen	-0.704***	-0.871***	0.638***	0.424***	-0.00753	-0.406***	-0.317***	-0.586***	1.919***	2.001***	1.166***	0.904***		
	(0.0245)	(0.0679)	(0.0235)	(0.0852)	(0.0246)	(0.0844)	(0.0263)	(0.0812)	(0.0394)	(0.134)	(0.0731)	(0.238)		
2021#Ctry#hydrogen	-1.165***	-1.212***	0.0621**	-0.180*	0.436***	0.246**	-0.131***	-0.163*	1.562***	1.651***	2.263***	1.710***		
	(0.0292)	(0.0802)	(0.0273)	(0.0932)	(0.0287)	(0.102)	(0.0342)	(0.0962)	(0.0453)	(0.141)	(0.0604)	(0.214)		
2018#Ctry#chemical	0.157***	0.198***	-0.0212	-0.0443	0.117	-0.0459	0.414***	0.348***	0.243	0.226	-0.354***	-0.468**	-0.139	-0.0363
	(0.0590)	(0.0431)	(0.276)	(0.252)	(0.197)	(0.169)	(0.0304)	(0.101)	(0.763)	(0.783)	(0.0935)	(0.200)	(0.259)	(0.223)
2019h1#Ctry#chemical	-0.0884	-0.0187	-0.191	-0.246	-0.323**	-0.536***	0.148*	0.172**	0.944	0.943	0.127	0.00216	0.000502	0.176
	(0.187)	(0.107)	(0.531)	(0.476)	(0.160)	(0.102)	(0.0890)	(0.0719)	(1.320)	(1.321)	(0.559)	(0.470)	(0.765)	(0.666)
2019h2#Ctry#chemical	0.109*	0.00549	-0.467**	-0.652***	-0.223***	-0.526***	0.228***	0.202	1.190	1.163	-0.605***	-0.733***	1.553***	1.803***
	(0.0588)	(0.0653)	(0.232)	(0.230)	(0.0723)	(0.131)	(0.0654)	(0.134)	(1.137)	(1.190)	(0.0542)	(0.193)	(0.284)	(0.341)
2020#Ctry#chemical	0.208***	0.197**	-0.446	-0.613*	-0.0973*	-0.370***	0.166	0.162	0.722*	0.791*	0.0881	0.0601	1.695***	1.905***
	(0.0499)	(0.0764)	(0.296)	(0.342)	(0.0534)	(0.102)	(0.145)	(0.163)	(0.379)	(0.441)	(0.571)	(0.594)	(0.274)	(0.291)
2021#Ctry#chemical	0.179*	0.293*	-0.604***	-0.739***	-0.164***	-0.212**	-0.297***	-0.159	0.505	0.589	0.323	0.404	1.769***	1.783***
	(0.101)	(0.151)	(0.198)	(0.201)	(0.0298)	(0.104)	(0.0888)	(0.152)	(1.044)	(1.098)	(0.280)	(0.300)	(0.491)	(0.535)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,121,465	176,159	2,157,441	161,424	2,134,264	161,424	2,084,754	161,424	2,032,964	161,424	1,947,323	161,424	1,947,323	161,424
R-squared	0.794	0.820	0.805	0.812	0.791	0.812	0.786	0.812	0.782	0.812	0.782	0.812	0.782	0.812

Note: The table reports the results of the robustness checks by excluding major sourcing countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of three chemical materials from major sourcing economies include Japan. Columns 1 and 2 are the results for the import values from Japan, columns 3 and 4 for those form China, columns 5 and 6 for those from the U.S., columns 7 and 8 for those from Germany, columns 9 and 10 for those from Taiwan, columns 11 and 12 for those from Singapore, and columns 13 and 14 for those from Belgium. The dependent variable is log import values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#hydrogen” denotes an interaction term of year-2018, country under consideration, and hydrogen fluoride (HS 281111) dummy variables. ”2018#Ctry#chemical” denotes a similar interaction term but for other two restricted materials (HS 370790, 391190). ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A10: Effect on Korean imports of semiconductor products from major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ctry dummy:	Japan		China		Taiwan		USA		Singapore	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#semicon	-0.156*	-0.106	-0.186*	-0.209*	-0.0911	-0.164	-0.0211	-0.0225	-0.109	0.0435
	(0.0887)	(0.0983)	(0.106)	(0.113)	(0.0992)	(0.116)	(0.0999)	(0.114)	(0.118)	(0.142)
2019h1#Ctry#semicon	-0.226*	-0.0675	-0.0546	-0.137	-0.0785	-0.0301	0.208	0.178	-0.0199	0.0486
	(0.131)	(0.147)	(0.139)	(0.152)	(0.129)	(0.153)	(0.176)	(0.191)	(0.168)	(0.206)
2019h2#Ctry#semicon	-0.166	-0.0943	-0.0736	-0.110	0.150	0.246*	0.0306	0.0279	-0.306	-0.242
	(0.216)	(0.216)	(0.188)	(0.201)	(0.112)	(0.142)	(0.204)	(0.218)	(0.277)	(0.301)
2020#Ctry#semicon	0.197	0.196	0.0967	-0.0373	0.285**	0.178	0.270	0.229	0.326	0.379
	(0.226)	(0.224)	(0.188)	(0.203)	(0.140)	(0.158)	(0.256)	(0.267)	(0.262)	(0.285)
2021#Ctry#semicon	0.114	0.175	-0.0396	-0.143	0.268**	0.157	0.0184	0.0243	0.375	0.420
	(0.250)	(0.243)	(0.169)	(0.180)	(0.126)	(0.147)	(0.314)	(0.321)	(0.249)	(0.274)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,208,445	268,155	2,244,827	255,636	2,119,524	255,636	2,221,201	255,636	2,084,754	255,636
R-squared	0.796	0.811	0.807	0.806	0.786	0.806	0.794	0.806	0.786	0.806

Note: The table reports the results of the robustness checks by excluding major sourcing countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of semiconductor products from major sourcing economies. including Japan Columns 1 and 2 are the results for the import values from Japan, columns 3 and 4 for those from China, columns 5 and 6 for those from Taiwan, columns 7 and 8 for those from the U.S., and columns 9 and 10 for those from Singapore. The dependent variable is log import values. For the explanatory variables, "after" denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. "2018#Ctry#semicon" denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 8541, 8542) dummy variables. "2019h1" denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and "2019h2" is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A11: Effect on Korean imports of semiconductor manufacturing equipment from major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ctry dummy:	Japan		Netherlands		USA		Singapore		Germany	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#equipment	-0.913***	-0.589***	-1.137***	-0.919***	-1.356***	-1.018***	-1.413***	-1.117***	-0.918***	-0.737***
	(0.0161)	(0.0444)	(0.0303)	(0.0785)	(0.0162)	(0.0409)	(0.0305)	(0.0686)	(0.0183)	(0.0412)
2019h1#Ctry#equipment	-1.227***	-0.740***	-0.984***	-0.658***	-1.398***	-0.954***	-1.791***	-1.451***	-2.013***	-1.679***
	(0.0208)	(0.0581)	(0.0355)	(0.102)	(0.0207)	(0.0563)	(0.0393)	(0.0927)	(0.0244)	(0.0590)
2019h2#Ctry#equipment	-1.511***	-0.762***	-3.810***	-3.435***	-1.232***	-0.522***	-1.911***	-1.285***	-2.651***	-2.137***
	(0.0219)	(0.0575)	(0.0386)	(0.0943)	(0.0226)	(0.0583)	(0.0412)	(0.0963)	(0.0242)	(0.0524)
2020#Ctry#equipment	-1.037***	-0.555***	-1.056***	-0.774***	-1.107***	-0.622***	-1.504***	-1.139***	-1.640***	-1.403***
	(0.0215)	(0.0521)	(0.0374)	(0.0872)	(0.0216)	(0.0527)	(0.0415)	(0.0940)	(0.0239)	(0.0505)
2021#Ctry#equipment	-0.600***	-0.170***	-0.265***	0.141	-0.580***	-0.0959*	-0.508***	-0.213*	-2.785***	-2.649***
	(0.0246)	(0.0648)	(0.0439)	(0.0962)	(0.0245)	(0.0578)	(0.0471)	(0.119)	(0.0268)	(0.0576)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,307,394	287,012	2,192,634	267,639	2,319,988	267,639	2,182,030	267,639	2,269,258	267,639
R-squared	0.813	0.783	0.805	0.775	0.810	0.775	0.806	0.775	0.808	0.775

Note: The table reports the results of the robustness checks by excluding major sourcing countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) but using South Korean import data to investigate the effect of the Japanese export controls on South Korean imports of semiconductor manufacturing equipment from major sourcing economies including Japan. Columns 1 and 2 are the results for the import values from Japan, columns 3 and 4 for those form the Netherlands, columns 5 and 6 for those from the U.S., columns 7 and 8 for those from Singapore, and columns 9 and 10 for those from Germany. The dependent variable is log import values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#equipment” denotes an interaction term of year-2018, country under consideration, and semiconductor manufacturing equipment (HS 848620) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A12: Effect on Korean exports of semiconductor products to major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ctry dummy:	China		Hong Kong		Vietnam		Taiwan		Philippines		Japan	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#semicon	-0.160	-0.165	-0.0333	-0.0711	0.471**	0.527**	-0.166	-0.141	-0.0407	-0.0850	-0.116	-0.139
	(0.108)	(0.110)	(0.114)	(0.127)	(0.220)	(0.227)	(0.103)	(0.119)	(0.112)	(0.125)	(0.105)	(0.0974)
2019h1#Ctry#semicon	-0.208	-0.270*	-0.143	-0.0471	0.672**	0.753**	-0.388**	-0.450***	-0.0689	-0.107	-0.377**	-0.357**
	(0.148)	(0.158)	(0.120)	(0.154)	(0.283)	(0.307)	(0.162)	(0.171)	(0.148)	(0.164)	(0.164)	(0.170)
2019h2#Ctry#semicon	-0.237	-0.250	-0.0298	0.0381	0.594*	0.583	-0.408*	-0.496**	-0.251*	-0.217	-0.287	-0.207
	(0.157)	(0.167)	(0.135)	(0.168)	(0.350)	(0.377)	(0.217)	(0.224)	(0.142)	(0.167)	(0.237)	(0.243)
2020#Ctry#semicon	-0.237	-0.181	0.0113	0.132	0.691**	0.699*	-0.253	-0.249	-0.0972	-0.146	-0.231	-0.125
	(0.170)	(0.184)	(0.134)	(0.180)	(0.336)	(0.363)	(0.226)	(0.239)	(0.140)	(0.176)	(0.214)	(0.236)
2021#Ctry#semicon	-0.370**	-0.307	-0.175	0.110	0.594*	0.562	-0.202	-0.124	-0.124	-0.0623	-0.434*	-0.291
	(0.181)	(0.212)	(0.154)	(0.205)	(0.331)	(0.364)	(0.340)	(0.365)	(0.213)	(0.247)	(0.239)	(0.265)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,934,589	372,306	2,875,127	372,306	2,924,502	372,306	2,890,829	372,306	2,868,014	372,306	2,789,083	372,306
R-squared	0.787	0.784	0.780	0.784	0.783	0.784	0.781	0.784	0.778	0.784	0.780	0.784

Note: The table reports the results of the robustness checks by excluding major destination countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) but using South Korean export data to investigate the effect of the Japanese export controls on South Korean exports of semiconductor products including Japan. Columns 1 and 2 are the results for the export values to China, columns 3 and 4 for those to Hong Kong, columns 5 and 6 for those to Vietnam, columns 7 and 8 for those to Taiwan, columns 9 and 10 for those to the Philippine, and columns 11 and 12 for those to Japan. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#semicon” denotes an interaction term of year-2018, country under consideration, and semiconductor products (HS 8541, 8542) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A13: Effect on Korean exports of semiconductor manufacturing equipment to major economies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ctry dummy:	China		USA		Taiwan		Japan		Vietnam	
Outcome:	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
2018#Ctry#equipment	0.607***	0.497***	-0.263***	-0.397***	-0.186***	-0.334***	0.676***	0.569***	0.938***	1.040***
	(0.0159)	(0.0411)	(0.0161)	(0.0453)	(0.0190)	(0.0507)	(0.0153)	(0.0438)	(0.0173)	(0.0461)
2019h1#Ctry#equipment	1.026***	0.906***	-0.645***	-0.818***	-0.0873***	-0.325***	0.330***	0.184***	1.285***	1.415***
	(0.0216)	(0.0500)	(0.0212)	(0.0561)	(0.0261)	(0.0670)	(0.0208)	(0.0602)	(0.0225)	(0.0585)
2019h2#Ctry#equipment	2.212***	2.155***	-0.719***	-0.932***	0.322***	0.156**	0.959***	0.824***	0.439***	0.359***
	(0.0229)	(0.0541)	(0.0227)	(0.0602)	(0.0267)	(0.0738)	(0.0222)	(0.0679)	(0.0240)	(0.0599)
2020#Ctry#equipment	2.104***	2.159***	-0.0296	-0.157***	0.182***	-0.0456	0.903***	0.840***	-0.320***	-0.343***
	(0.0232)	(0.0551)	(0.0232)	(0.0570)	(0.0271)	(0.0700)	(0.0227)	(0.0625)	(0.0244)	(0.0621)
2021#Ctry#equipment	2.792***	2.795***	-0.356***	-0.570***	0.665***	0.355***	0.755***	0.638***	0.416***	0.389***
	(0.0271)	(0.0632)	(0.0265)	(0.0612)	(0.0324)	(0.0845)	(0.0270)	(0.0759)	(0.0289)	(0.0719)
Sample	Country	Product	Country	Product	Country	Product	Country	Product	Country	Product
HS6-Ctry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HS6-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry-Year-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,835,172	506,944	2,823,609	506,944	2,791,805	506,944	2,820,462	506,944	2,825,251	506,944
R-squared	0.777	0.739	0.774	0.739	0.769	0.739	0.773	0.739	0.771	0.739

Note: The table reports the results of the robustness checks by excluding major destination countries from the control group (odd columns) and restricting the control groups to the same product groups as the treatment group (even columns). They estimate equation (1) but using South Korean export data to investigate the effect of the Japanese export controls on South Korean exports of semiconductor manufacturing equipment including Japan. Columns 1 and 2 are the results for the export values to China, columns 3 and 4 for those to the U.S., columns 5 and 6 for those to Taiwan, columns 7 and 8 for those to Japan, and columns 9 and 10 for those to Vietnam. The dependent variable is log export values. For the explanatory variables, ”after” denotes a dummy variable that is equal to one for periods after July 2019 and zero otherwise. ”2018#Ctry#equipment” denotes an interaction term of year-2018, country under consideration, and semiconductor manufacturing equipment (HS 848620) dummy variables. ”2019h1” denotes a dummy variable for the first half of 2019 (Januart 2019 to June 2019) and ”2019h2” is a dummy variable for the second half of 2019 (July 2019 to December 2019). Omitted categories are dummy variables for year 2017. The regressions also include a series of fixed effects, such as HS 6-digit category times destination country, HS 6-digit category times year-month, and destination country times year-month. Clustered standard errors at the HS 6-digit level are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

A5 Appendix: details of synthetic control method

In Section 4.6, the synthetic control method is implemented to confirm the robustness of our main results. This section discusses a detail of the analysis: the synthetic weights and pre-treatment averages between treatment and synthetic control groups, for each of import and export values that have provided noticeable patterns in the main text.

Table A14: Synthetic control weights for South Korean imports of hydrogen fluoride from JPN

Country	Hs6	Description	Weight
China	281111	Hydrogen Fluoride	.376
China	281119	Inorganic Acids	0
Germany	281119	Inorganic Acids	.04
Israel	281119	Inorganic Acids	.079
Japan	281119	Inorganic Acids	0
Taiwan	281119	Inorganic Acids	0
United States	281119	Inorganic Acids	0
United States	281121	Carbon Dioxide	0
Belgium	281122	Silicon Dioxide	0
China	281122	Silicon Dioxide	0
France	281122	Silicon Dioxide	.004
Germany	281122	Silicon Dioxide	0
Japan	281122	Silicon Dioxide	0
Malaysia	281122	Silicon Dioxide	0
Taiwan	281122	Silicon Dioxide	0
United Kingdom	281122	Silicon Dioxide	0
United States	281122	Silicon Dioxide	.099
China	281129	Inorganic Oxygen Compounds	0
Japan	281129	Inorganic Oxygen Compounds	.378
United States	281129	Inorganic Oxygen Compounds	.023
RMSPE			.0086

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean imports of hydrogen fluoride from Japan. Column 1 shows the source countries of imports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

Table A15: Pre-treatment average of variables: South Korean imports of hydrogen fluoride from JPN

Variable	Treat	Control
ln (value) in 2018m1	1.065	1.064
ln (value) in 2018m2	1.033	1.02
ln (value) in 2018m3	1.04	1.05
ln (value) in 2018m4	1.033	1.028
ln (value) in 2018m5	1.035	1.021
ln (value) in 2018m6	1.033	1.032
ln (value) in 2018m7	1.039	1.031
ln (value) in 2018m8	1.035	1.022
ln (value) in 2018m9	1.021	1.017
ln (value) in 2018m10	1.03	1.044
ln (value) in 2018m11	1.031	1.015
ln (value) in 2018m12	1.005	1.02
ln (value) in 2019m1	1.071	1.073
ln (value) in 2019m2	1.058	1.032
ln (value) in 2019m3	1.054	1.046
ln (value) in 2019m4	1.033	1.027
ln (value) in 2019m5	1.028	1.018
ln (value) in 2019m6	1.023	1.016

Note: The table provides the pre-treatment averages of outcome variables for the South Korean imports of hydrogen fluoride from Japan. Column 2 is the average of import values in the treatment group and column 3 is that for the synthetic control group.

Table A16: Synthetic control weights for South Korean imports of photoresist from JPN

Country	Hs6	Description	Weight
China	370710	Chemical Sensitizing Emulsions For Photographic Uses	.074
Germany	370710	Chemical Sensitizing Emulsions For Photographic Uses	.055
Japan	370710	Chemical Sensitizing Emulsions For Photographic Uses	.127
Belgium	370790	Chemical Preparation For Photographic Uses	0
China	370790	Chemical Preparation For Photographic Uses	0
Germany	370790	Chemical Preparation For Photographic Uses	.049
Taiwan	370790	Chemical Preparation For Photographic Uses	0
United States	370790	Chemical Preparation For Photographic Uses	.695
RMSPE			.0155

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean imports of photoresist from Japan. Column 1 shows the source countries of imports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

Table A17: Pre-treatment average of variables: South Korean imports of photoresist from JPN

Variable	Treat	Control
ln (value) in 2018m1	1.016	1.008
ln (value) in 2018m2	1.014	1.006
ln (value) in 2018m3	1.011	1.012
ln (value) in 2018m4	1.013	.977
ln (value) in 2018m5	1.015	1.013
ln (value) in 2018m6	1.005	.983
ln (value) in 2018m7	1.009	.988
ln (value) in 2018m8	1.01	1.056
ln (value) in 2018m9	.997	.988
ln (value) in 2018m10	1.035	.998
ln (value) in 2018m11	1.014	1.018
ln (value) in 2018m12	1.009	1.022
ln (value) in 2019m1	1.025	1.003
ln (value) in 2019m2	1.009	.998
ln (value) in 2019m3	1.009	.988
ln (value) in 2019m4	1.004	.996
ln (value) in 2019m5	1.009	1.008
ln (value) in 2019m6	1.003	1.006

Note: The table provides the pre-treatment averages of outcome variables for the South Korean imports of photoresis from Japan. Column 2 is the average of import values in the treatment group and column 3 is that for the synthetic control group.

Table A18: Synthetic control weights for South Korean imports of fluorinated polyimide from JPN

Country	Hs6	Description	Weight
China	391110	Petroleum Resins, Coumarone	.122
Japan	391110	Petroleum Resins, Coumarone	.173
Netherlands	391110	Petroleum Resins, Coumarone	0
Taiwan	391110	Petroleum Resins, Coumarone	.208
Thailand	391110	Petroleum Resins, Coumarone	.04
United States	391110	Petroleum Resins, Coumarone	0
Belgium	391190	Polysulfides, Polysulfones, And Synthetic Polymers	.063
Canada	391190	Polysulfides, Polysulfones, And Synthetic Polymers	0
China	391190	Polysulfides, Polysulfones, And Synthetic Polymers	0
France	391190	Polysulfides, Polysulfones, And Synthetic Polymers	.099
Germany	391190	Polysulfides, Polysulfones, And Synthetic Polymers	0
India	391190	Polysulfides, Polysulfones, And Synthetic Polymers	.053
Malaysia	391190	Polysulfides, Polysulfones, And Synthetic Polymers	0
Thailand	391190	Polysulfides, Polysulfones, And Synthetic Polymers	0
United Kingdom	391190	Polysulfides, Polysulfones, And Synthetic Polymers	.009
United States	391190	Polysulfides, Polysulfones, And Synthetic Polymers	.233
RMSPE			.0050

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean imports of fluorinated polyimide from Japan. Column 1 shows the source countries of imports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

Table A19: Pre-treatment average of variables: South Korean imports of fluorinated polyimide from JPN

Variable	Treat	Control
ln (value) in 2018m1	1.004	1.006
ln (value) in 2018m2	.985	.988
ln (value) in 2018m3	.993	1.01
ln (value) in 2018m4	.994	.994
ln (value) in 2018m5	.998	.999
ln (value) in 2018m6	.997	1.002
ln (value) in 2018m7	1.001	.999
ln (value) in 2018m8	1.006	1
ln (value) in 2018m9	1.002	1.003
ln (value) in 2018m10	1.034	1.026
ln (value) in 2018m11	.987	.989
ln (value) in 2018m12	1.016	1.01
ln (value) in 2019m1	1.007	1.01
ln (value) in 2019m2	.989	.984
ln (value) in 2019m3	1	.999
ln (value) in 2019m4	.994	.998
ln (value) in 2019m5	1.006	1.003
ln (value) in 2019m6	.996	.981

Note: The table provides the pre-treatment averages of outcome variables for the South Korean imports of fluorinated polyimide from Japan. Column 2 is the average of import values in the treatment group and column 3 is that for the synthetic control group.

Table A20: Synthetic control weights for South Korean imports of photoresist from BEL

Country	Hs6	Description	Weight
Belgium	370110	X-Ray Plates And Flat Film, Sensitized	.138
Japan	370110	X-Ray Plates And Flat Film, Sensitized	0
United States	370110	X-Ray Plates And Flat Film, Sensitized	0
China	370120	Instant Print Film In The Flat	.103
Japan	370120	Instant Print Film In The Flat	0
China	370130	Photographic Plates And Flat Film	0
Germany	370130	Photographic Plates And Flat Film	.538
Japan	370130	Photographic Plates And Flat Film	0
Malaysia	370130	Photographic Plates And Flat Film	0
Taiwan	370130	Photographic Plates And Flat Film	0
United States	370130	Photographic Plates And Flat Film	0
China	370199	Photographic Plates And Flat Film	0
Japan	370199	Photographic Plates And Flat Film	0
Singapore	370199	Photographic Plates And Flat Film	0
Taiwan	370199	Photographic Plates And Flat Film	0
United States	370199	Photographic Plates And Flat Film	0
United States	370231	Photographic Film In Rolls	0
China	370242	Photographic Film In Rolls	0
Japan	370242	Photographic Film In Rolls	0
Malaysia	370242	Photographic Film In Rolls	0
Taiwan	370242	Photographic Film In Rolls	0
Belgium	370243	Photographic Film In Rolls	0
Belgium	370244	Photographic Film In Rolls	.067
China	370244	Photographic Film In Rolls	0
Japan	370244	Photographic Film In Rolls	0
Japan	370254	Photographic Film Rolls	0
United States	370254	Photographic Film Rolls	0
United States	370296	Photographic Film Of A Width	0
United States	370320	Photographic Paper, Paperboard And Textiles	0
China	370390	Photographic Paper, Paperboard And Textiles	.05
United States	370390	Photographic Paper, Paperboard And Textiles	0
China	370500	Photographic Plates And Film	0
Germany	370500	Photographic Plates And Film	0
Japan	370500	Photographic Plates And Film	0
Taiwan	370500	Photographic Plates And Film	0
United States	370500	Photographic Plates And Film	0
China	370710	Chemical Sensitizing Emulsions For Photographic Uses	.103
Germany	370710	Chemical Sensitizing Emulsions For Photographic Uses	0
Japan	370710	Chemical Sensitizing Emulsions For Photographic Uses	0
China	370790	Chemical Preparation For Photographic Uses	0
Germany	370790	Chemical Preparation For Photographic Uses	0
Taiwan	370790	Chemical Preparation For Photographic Uses	0
United States	370790	Chemical Preparation For Photographic Uses	0
RMSPE			.0373

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean imports of photoresist from Belgium. Column 1 shows the source countries of imports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

Table A21: Pre-treatment average of variables: South Korean imports of photoresist from BEL

Variable	Treat	Control
ln (value) in 2018m1	.956	.985
ln (value) in 2018m2	1.013	1.006
ln (value) in 2018m3	1.012	.996
ln (value) in 2018m4	.991	1.015
ln (value) in 2018m5	.89	.94
ln (value) in 2018m6	1.136	1.072
ln (value) in 2018m7	.866	.924
ln (value) in 2018m8	1.089	1.054
ln (value) in 2018m9	1.034	.975
ln (value) in 2018m10	.903	.943
ln (value) in 2018m11	.853	.982
ln (value) in 2018m12	.943	1
ln (value) in 2019m1	1.003	1.03
ln (value) in 2019m2	1.127	1.106
ln (value) in 2019m3	.916	.873
ln (value) in 2019m4	.948	.931
ln (value) in 2019m5	.941	.956
ln (value) in 2019m6	.987	.977

Note: The table provides the pre-treatment averages of outcome variables for the South Korean imports of photoresist from Belgium. Column 2 is the average of import values in the treatment group and column 3 is that for the synthetic control group.

Table A22: Synthetic control weights for South Korean imports of hydrogen fluoride from USA

Country	Hs6	Description	Weight
China	281111	Hydrogen Fluoride	0
China	281119	Inorganic Acids	0
Germany	281119	Inorganic Acids	.348
Indonesia	281119	Inorganic Acids	0
Israel	281119	Inorganic Acids	0
Japan	281119	Inorganic Acids	0
Taiwan	281119	Inorganic Acids	0
United Kingdom	281119	Inorganic Acids	.652
United States	281119	Inorganic Acids	0
United States	281121	Carbon Dioxide	0
Belgium	281122	Silicon Dioxide	0
China	281122	Silicon Dioxide	0
France	281122	Silicon Dioxide	0
Germany	281122	Silicon Dioxide	0
India	281122	Silicon Dioxide	0
Indonesia	281122	Silicon Dioxide	0
Japan	281122	Silicon Dioxide	0
Malaysia	281122	Silicon Dioxide	0
Taiwan	281122	Silicon Dioxide	0
United Kingdom	281122	Silicon Dioxide	0
United States	281122	Silicon Dioxide	0
Vietnam	281122	Silicon Dioxide	0
China	281129	Inorganic Oxygen Compounds Of Nonmetals	0
Japan	281129	Inorganic Oxygen Compounds Of Nonmetals	0
United States	281129	Inorganic Oxygen Compounds Of Nonmetals	0
RMSPE			.0706

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean imports of hydrogen fluoride from the United States. Column 1 shows the source countries of imports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

Table A23: Pre-treatment average of variables: South Korean imports of hydrogen fluoride from USA

Variable	Treat	Control
ln (value) in 2018q1	.85	.88
ln (value) in 2018q2	.992	1.035
ln (value) in 2018q3	1.189	.98
ln (value) in 2018q4	.988	.97
ln (value) in 2019q1	.748	.799
ln (value) in 2019q2	.899	.92

Note: The table provides the pre-treatment averages of outcome variables for the South Korean imports of hydrogen fluoride from the United States. Column 2 is the average of import values in the treatment group and column 3 is that for the synthetic control group. Because our treatment group, i.e., South Korean imports of hydrogen fluoride from the United States, has zero import values in several months after January 2017, we aggregated the observations into year-quarter to make data a balanced panel.

Table A24: Synthetic control weights for South Korean imports of hydrogen fluoride from TWN

Country	Hs6	Description	Weight
China	281111	Hydrogen Fluoride	0
China	281119	Inorganic Acids	0
Germany	281119	Inorganic Acids	.199
Israel	281119	Inorganic Acids	.474
Japan	281119	Inorganic Acids	0
Taiwan	281119	Inorganic Acids	0
United States	281119	Inorganic Acids	0
United States	281121	Carbon Dioxide	0
Belgium	281122	Silicon Dioxide	0
China	281122	Silicon Dioxide	0
France	281122	Silicon Dioxide	.13
Germany	281122	Silicon Dioxide	0
Japan	281122	Silicon Dioxide	0
Malaysia	281122	Silicon Dioxide	0
Taiwan	281122	Silicon Dioxide	0
United Kingdom	281122	Silicon Dioxide	0
United States	281122	Silicon Dioxide	0
China	281129	Inorganic Oxygen Compounds Of Nonmetals	0
Japan	281129	Inorganic Oxygen Compounds Of Nonmetals	.197
United States	281129	Inorganic Oxygen Compounds Of Nonmetals	0
RMSPE			.1152

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean imports of hydrogen fluoride from Taiwan. Column 1 shows the source countries of imports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

Table A25: Pre-treatment average of variables: South Korean imports of hydrogen fluoride from TWN

Variable	Treat	Control
ln (value) in 2018m9	1.338	1.041
ln (value) in 2018m10	1.171	1.111
ln (value) in 2018m11	1.156	1.087
ln (value) in 2018m12	1.152	1.216
ln (value) in 2019m1	1.145	1.076
ln (value) in 2019m2	1.074	1.125
ln (value) in 2019m3	1.175	1.031
ln (value) in 2019m4	1.042	1.018
ln (value) in 2019m5	1.029	1.024
ln (value) in 2019m6	1.01	.95

Note: The table provides the pre-treatment averages of outcome variables for the South Korean imports of hydrogen fluoride from Taiwan. Column 2 is the average of import values in the treatment group and column 3 is that for the synthetic control group. We use the log of import values (relative to those in 2017) after September 2018 as targeted variables because log imports before are missing.

Table A26: Synthetic control weights for South Korean exports of equipments to CHN

Country	Hs6	Description	Weight
China	848610	Machines And Apparatus	0
Taiwan	848610	Machines And Apparatus	0
Germany	848620	Machines And Apparatus	.027
Japan	848620	Machines And Apparatus	.328
Malaysia	848620	Machines And Apparatus	0
Singapore	848620	Machines And Apparatus	0
Taiwan	848620	Machines And Apparatus	0
United States	848620	Machines And Apparatus	0
Vietnam	848620	Machines And Apparatus	0
China	848630	Machines And Apparatus	0
Taiwan	848630	Machines And Apparatus	0
United States	848630	Machines And Apparatus	.021
Vietnam	848630	Machines And Apparatus	0
China	848640	Machines And Apparatus	0
Japan	848640	Machines And Apparatus	0
Malaysia	848640	Machines And Apparatus	0
Philippines	848640	Machines And Apparatus	0
Singapore	848640	Machines And Apparatus	.011
Taiwan	848640	Machines And Apparatus	0
Thailand	848640	Machines And Apparatus	0
United States	848640	Machines And Apparatus	0
Vietnam	848640	Machines And Apparatus	0
Belgium	848690	Machines And Apparatus	.063
Brazil	848690	Machines And Apparatus	.059
China	848690	Machines And Apparatus	0
France	848690	Machines And Apparatus	.125
Germany	848690	Machines And Apparatus	0
Hong Kong	848690	Machines And Apparatus	0
Hungary	848690	Machines And Apparatus	.006
Indonesia	848690	Machines And Apparatus	.068
Israel	848690	Machines And Apparatus	0
Italy	848690	Machines And Apparatus	.212
Japan	848690	Machines And Apparatus	0
Malaysia	848690	Machines And Apparatus	0
Malta	848690	Machines And Apparatus	.031
Mexico	848690	Machines And Apparatus	0
Netherlands	848690	Machines And Apparatus	0
Philippines	848690	Machines And Apparatus	0
Russia	848690	Machines And Apparatus	0
Singapore	848690	Machines And Apparatus	0
Taiwan	848690	Machines And Apparatus	0
Thailand	848690	Machines And Apparatus	0
United Kingdom	848690	Machines And Apparatus	0
United States	848690	Machines And Apparatus	0
Vietnam	848690	Machines And Apparatus	.049
RMSPE			.0229

Note: The table provides the synthetic weights used to construct the synthetic control group for the South Korean exports of semiconductor manufacturing equipment to China. Column 1 shows the source countries of exports, column 2 is product categories in the 6-digit HS code, column 3 the product descriptions, and column 4 provides the obtained synthetic weights. RMSPE is the Root Mean Squared Prediction Error during the pre-treatment period.

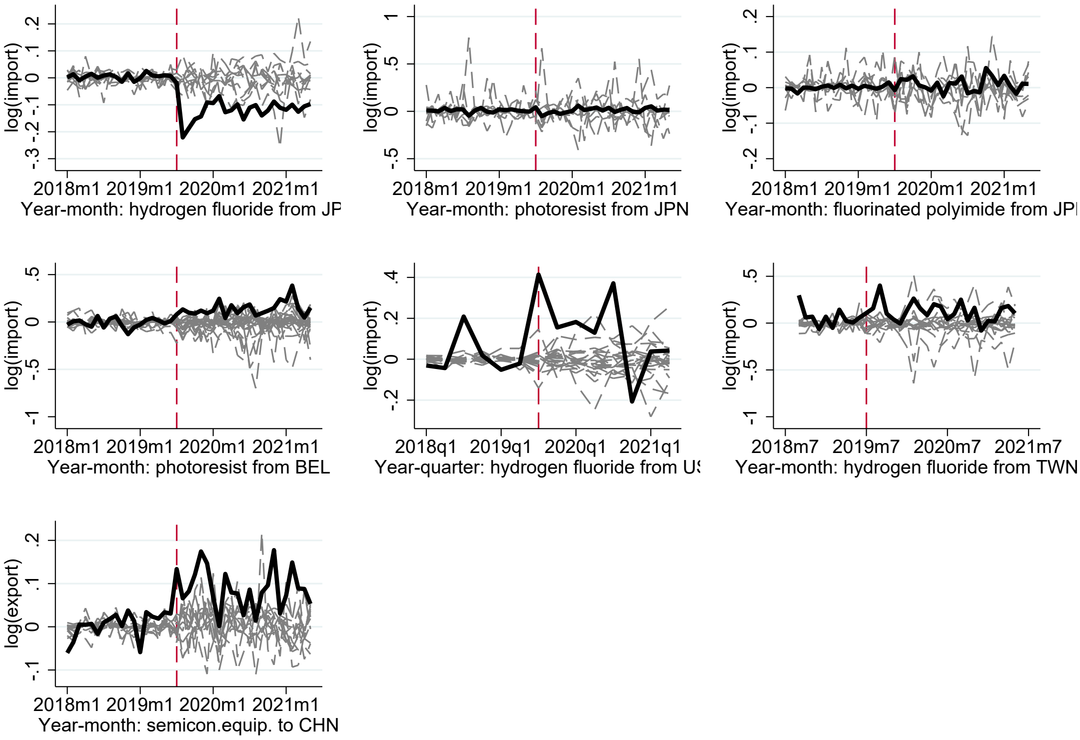
Table A27: Pre-treatment average of variables: South Korean exports of equipments to CHN

Variable	Treat	Control
ln (value) in 2018m1	.933	.994
ln (value) in 2018m2	.999	1.035
ln (value) in 2018m3	1.046	1.041
ln (value) in 2018m4	1.004	1
ln (value) in 2018m5	1.035	1.028
ln (value) in 2018m6	1.038	1.054
ln (value) in 2018m7	1.057	1.047
ln (value) in 2018m8	1.083	1.065
ln (value) in 2018m9	1.05	1.022
ln (value) in 2018m10	1.043	1.041
ln (value) in 2018m11	1.131	1.093
ln (value) in 2018m12	1.074	1.06
ln (value) in 2019m1	.986	1.045
ln (value) in 2019m2	1.099	1.065
ln (value) in 2019m3	1.033	1.01
ln (value) in 2019m4	1.053	1.034
ln (value) in 2019m5	1.061	1.027
ln (value) in 2019m6	1.056	1.025

Note: The table provides the pre-treatment averages of outcome variables for the South Korean exports of hydrogen fluoride to China. Column 2 is the average of export values in the treatment group and column 3 is that for the synthetic control group.

A6 Appendix: results from placebo tests of the synthetic control method

Figure A8. Placebo test for the synthetic control method



Note: The figure plots the results of placebo tests for the synthetic control method reported in Figure 16. Within each window, the black line is a difference in log import values or log export values between treatment and synthetic control groups (i.e., treatment effect). The gray lines denote a placebo treatment effect, which is calculated by treating an observation in the control group as if it were treated and taking the difference between the fake treated grouyp and its synthetic control group. The vertical red line denotes the timing of the Japanese export controls (July 2019 or third quarter in 2019).