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

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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 the Japan–Korea export controls on the trade patterns of the restricted and other related products 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, South Korea reallocated the sourcing of the restricted chemical inputs from Japan to other economies such as Belgium, the U.S., and Taiwan. Third, there was negative spillover effect on the South Korean imports of semiconductor manufacturing equipments, which is used complementarily with the restricted inputs in the semiconductor production. Fourth, South Korea increased the export of semiconductor manufacturing equipment to China, possibly because of its semiconductor production relocation to China. These results suggest a potential role of export controls in sourcing patterns and production relocation in the semiconductor industry.

JEL Classification: F12, F13, F51, F52

Keywords: Trade, Export controls, Semiconductors, Japan–Korea trade disputes

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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 an unanticipated Japan–Korea trade dispute in the semiconductor industry. On July 1st, 2019, the Japanese government announced to strengthen export controls to South Korea of three chemical inputs essential in semiconductor production[1]. As a result, the Japanese firms that seek to supply these chemical inputs to South Korea are required to apply for an export license in each transaction (with a potential denial), thus facing a larger policy-induced administrative costs and uncertainty. We use a difference-in-differences (DID) 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.

The 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). This means that a change in trade policy in one item produced in a country can easily propagate to third countries. 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

[1] It was effective on July 4th, 2019.

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 exports to South Korea of one of three restricted inputs, hydrogen fluoride, by 96.8% but not in two other restricted inputs, photoresist and fluorinated polyimide. Second, South Korea reallocated the sourcing of the restricted chemical inputs from Japan to other economies such as Belgium, the U.S., and Taiwan. Third, there was negative spillover effect on the South Korean imports of semiconductor manufacturing equipments, which is used complementarily with the restricted inputs in the semiconductor production. Fourth, South Korea increased its export of semiconductor manufacturing equipment to China, possibly because of its semiconductor production relocation to China. These results indicate a potential role of export controls in changing firms' sourcing patterns and production location by multinationals in the semiconductor industry. Because of these reactions by firms, the unilateral export controls may be ineffective in the current global economy. Taking these effects into account when making policy decisions is necessary to mitigate the unintended negative effects of such policies.

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). They analyze the effect of tightening the U.S. and Japanese export controls, including the same policy change studied here, on the Japanese exports. Their focus is mostly on the Japanese exports of the targeted products, and therefore they do not investigate how South Korean firms react to the export controls in their imports and exports. In contrast, our paper analyzes the effect on the Japanese exports, South Korean imports, exports, and production, thus elucidating a potential propagation effect of export controls via GVCs. In addition, we also investigate spillover effects of the policy change on trades in other related inputs. Such effect is crucial when we evaluate the overall effect of trade policy.

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, 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 the Japan–Korea trade dispute, and provides a data summary. After introducing our empirical framework in Section 3, Section 4 presents the selected estimation results and their robustness checks. Finally, Section 5 offers some concluding thoughts. All the DID results and the detail of the synthetic control method are reported

[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.

in the Appendix.

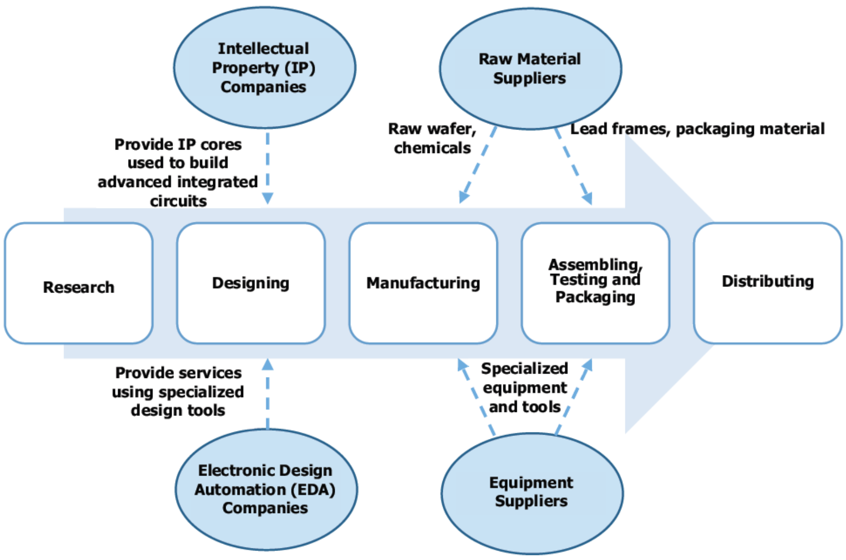
2 Background

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 pre-production stage where researchers try to increase the processing capability and speed of devices 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 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. 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.

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

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

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[4]. As a result, Japanese exporters of these three chemical materials are required to apply for individual export licences, rather than bulk export licences[5]. Thus, they lead to larger export administrative costs and more uncertainty on whether the license is permitted[6].

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 third countries.

In sum, given that the restricted materials are crucial in the production of advanced semiconductors, 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.

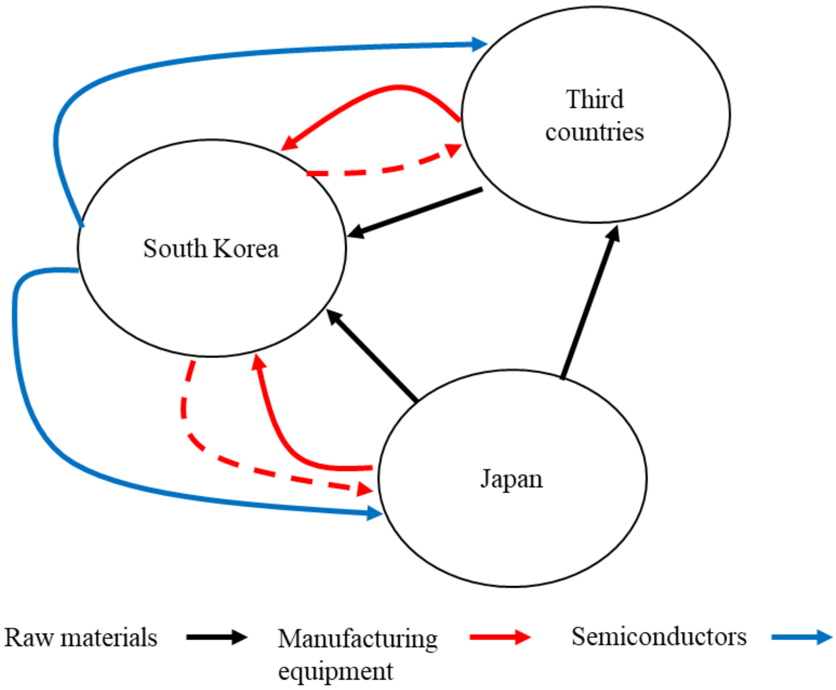
[4]According to the Ministry of Economy, Trade and Industry, they found some "inappropriate cases" regarding the treatment of these products by South Korea. These products are dual-use items (i.e., products that can be diverted to military use) and thus under the target of export controls. On the other hand, news media reported that the change in export controls was mostly as a retaliation against the Supreme Court of South Korea's decisions regarding compensation to forced labor during the World War II when Japan colonized the Korean Peninsula. In 2018, the South Korean Supreme Court ordered several Japanese companies to make compensations to the family of forced labor during the World War II, while the Japanese government protested the decisions and claimed that this issue was already settled in the 1965 treaty between Japan and South Korea.

[5]In the bulk export license, the government permits an exporter to make multiple export of controlled items, while in the individual export license, it requires an exporter to report detailed information on end-user, product specifications, technology, and so on for each export contract.

[6]According to Cho and Kim (2023), the South Korean trade policy uncertainty index is highest in July and August 2019 in the last two decades.

Figure 2 shows potential channels through which the Japanese strengthening export controls against South Korea can affect trade. First, the policy change is likely to affect exports of the three chemical materials to South Korea because the Japanese exporters face larger export costs and more uncertainty. This channel is drawn in Figure 2 by the black arrow from Japan to South Korea. Second, the policy change can also affect the Japanese exports of the chemical material to third countries, because Japanese exporters of the chemical material may need to find alternative foreign buyers or may do roundabout exports. This is drawn in the black arrow from Japan to third countries. Third, South Korean is expected to substitute the Japanese chemical materials with the materials from third countries after the policy change, which is drawn in the black arrow from third countries to South Korea. Fourth, the policy change in the raw material exports can also have spillover effects on trades in other inputs that are used complementarily in the semiconductor production process. In particular, the trade of semiconductor manufacturing equipments with Japan and third countries may be affected by the policy change, which is drawn with the red arrows. Finally, the blue arrows show potential effects of the policy change on South Korean exports of semiconductors to Japan and third countries. These patterns are examined using trade data and econometric approach in the next sections.

Figure 2. Direct and indirect effects of strengthening export controls against on trade flows



Note: The figure shows potential effects thorough which strengthening export controls against South Korea can have on (1) Japanese exports to South Korea, (2) South Korean imports from Japan and third countries, and (3) South Korean exports to Japan and third countries. The black arrows indicate the trade flows of the chemical materials directly targeted in the Japanese policy change. The red arrows show the trade flows of semiconductor manufacturing equipment. The blue arrows show the trade flows of semiconductors.

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[7]. Finally, the Korean production data are from financial reports collected from the firm website and Orbis.

The following tables and figures in this subsection show summary statistics and raw-data patterns. Table 1 shows the top five countries from which South Korea imported each of the restricted chemical materials in 2018. The top panel shows that the imports of hydrogen fluoride by South Korea were mostly from China (63%), Japan (32%), and Taiwan (4%). The middle panel 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 source countries and those from others, thus suggesting that substitution may be difficult. Finally, the bottom panel 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 affect significantly the South Korean sourcing strategy and that South Korea may face difficulty in substituting some products from third countries for Japanese-controlled sources.

Table 1: Ranking of imports in restricted chemical materials in 2018

Country	Value ($ 100 thousand)	Unit value (value/KG)	Share
	Hydrogen fluoride		
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
	Photoresist		
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
	Fluorinated polyimide		
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

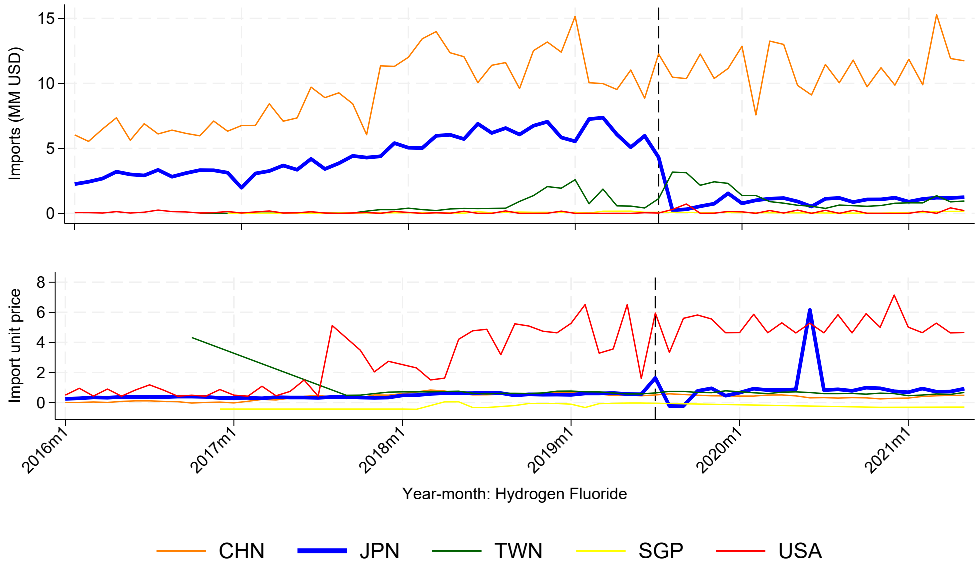
Note: The table shows the top 5 countries from which South Korea imports hydrogen fluoride (top), photoresist (middle), and fluorinated polyimide (bottom) in 2018. Unit values are calculated as import values divided by import quantities in kilograms. "Share" denotes the share of import values of the product from each country out of its total imports.

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

[7] This Japanese exports data from Trade Statistics of Japan by the Ministry of Finance is actually reported at the HS 9-digit product level. However, (1) because only one 9-digit category is reported within our treated products, i.e, hydrogen fluoride (HS 281111) and photoresist (HS 370790), and (2) for consistency with the trade data from the Global Trade Atlas, we aggregate it into the HS 6-digit level.

from major source countries from January 2016 to May 2021. While the imports from China increase throughout the period, those from Japan suddenly drop after July 2019 and stay low until 2021. This seems to be due to the Japanese export controls to South Korea.

Figure 3. Korean Import of hydrogen fluoride

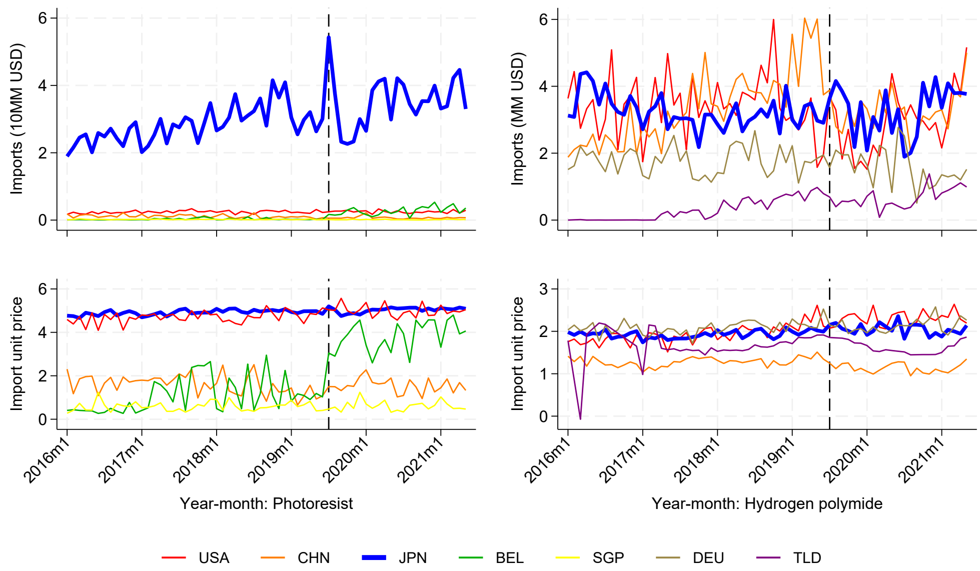


Note: The figure plots raw data on South Korean import value and import unit value of hydrogen fluoride from major sourcing countries.

Figure 4 shows the South Korean import and unit values of photoresist (left) and fluorinated polyimide (right) from major sourcing countries. The left figures of photoresist 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 relatively small effect can also be because the export controls by the Japanese government targeted only photoresists used for extreme-ultraviolet (EUV) 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 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. The right figures, on the other hand, does not show any noticeable patterns around the introduction of the export controls, probably due to the fact that only a subset of fluorinated polyimide is restricted by the policy change.

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 and fluorinated polyimide



Note: The figure plots raw data on South Korean import value and import unit value of photoresist in left and fluorinated polyimide in right 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) and event-study approach. Specifically, the estimation equation for the impact of export controls on Japanese exports is the following.

$$\ln\left(\text{export}_{kht}\right) = \sum_{\tau=2018Q2}^{2021Q2} \beta_\tau 1\{t \in \tau\} \times \text{Treat}_{kh} + \alpha_{kt} + \alpha_{ht} + \alpha_{kh} + \epsilon_{kht}, \quad (1)$$

where $\ln\left(\text{export}_{kht}\right)$ is the log of export values of product h to destination country k in year-month t, Treat_{kh} is a dummy variable equal to one if an observation is on the treated product. In our baseline analysis, a treated product is hydrogen fluoride (HS 281111), photoresist (HS 370790), or fluorinated polyimide (HS 391190) that is specifically exported to South Korea. In the analysis on the total Japanese exports of the treated products, Treat_{kh} is a dummy variable equal to one for the restricted products across all destination countries. $1\{t \in \tau\}$ is a dummy variable if an observation at year-month t belongs to year-quarter τ, ranging from the 2nd quarter of 2018 to the 2nd quarter of 2021. The base period is the 1st quarter of 2018. 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 2018 to May 2021.

β_τ is our key coefficient, representing how the Japanese exports of restricted chemical materials to South Korea are different in each year-quarter τ (both before and after strengthening the export controls in the 3rd quarter of 2019) relative to Japanese exports of those products to other destination countries and to Japanese exports of other products. The coefficients β_τ is expected to be close to zero before the policy change and negative after that because putting the export controls on the three chemical materials should reduce the Japanese exports of the restricted chemical materials to South Korea. We also expect a larger negative coefficient on hydrogen fluoride than those on photoresist and fluorinated polyimide. This is because, first, hydrogen fluoride is classified as a chemical weapons-related product and therefore its manufacturing process is examined stricter under the strengthening of export controls. Second, only a small fraction of the products in the HS 6-digit categories of photoresist and fluorinated polyimide (HS 370790 and 391190) is subject to the strengthening of the export controls. For instance, the export controls are strengthened only for extreme-ultraviolet (EUV) photoresist and others, and it consists of less than 1% of the HS-370790 product category in terms of quantity. In other words, the other 99% of the products in the HS 370790 category, some of which are used in semiconductor production, is exempt from the policy change[8].

Similar DID frameworks are also used to analyze (a) the effect on the Japanese exports of

[8] See CISTEC (2019).

the restricted chemical materials to other destination countries to see if Japanese suppliers could find alternative buyers, (b) the effect on Korean imports to see if Korean buyers could substitute sourcing locations, and (c) the effect on semiconductor manufacturing equipment and semiconductors to see if there were spillover effects on complementary inputs and outputs. In (a), we replace the dummy variable on the exports of the treated products to South Korea, Treat_{kh}, with those to third countries, such as China, USA, and etc. In (b), we take South Korean import data and use ln (import_{kht}) as a dependent variable, where k denotes a source country. In (c), the product category of the treated products used in Treat_{kh} is replaced with that of semiconductor manufacturing equipment (HS 848620) or semiconductors (HS 8541, HS 8542).

3.2 Identification and inference

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 third countries and other products, if there were no policy change. To guarantee that this 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 factors. In addition, our control group is restricted to the products that belong to the same HS 2-digit categories as the treated products. Such products are likely to have a similar trend if there were no policy changes in export controls.

To further check the validity of the common trend assumption, our event-study approach provides a pre-trend test, i.e., a test if the trend of Japanese exports on the restricted chemical materials to South Korea is comparable to that on other products and destination countries during the pre-treatment periods[9]. If there are some significant differences in the trends before the timing of policy change, it would imply a violation of the common trend assumption. To mitigate the concern on the different trends, we also calculate the estimated change in exports after the policy change relative to the change in exports prior to it, following Finkelstein (2007)[10]. Specifically, we derive

$$\Delta E^{\beta}_{kht} = (\bar{\beta}_{2019Q3\text{-}Q4} - \bar{\beta}_{2019Q1\text{-}Q2}) - (\bar{\beta}_{2019Q1\text{-}Q2} - \bar{\beta}_{2018Q3\text{-}Q4}). \qquad (2)$$

The results are reported in Appendix.

Another concern on our empirical approach is the statistical inference of DID. Because the error terms are likely to be serially correlated and correlated across observations within the same destinations-products, standard errors tend to be clustered in order to allow for correlations within the categories. However, it is inappropriate in our setting. 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 relying on asymptotic approximations. To address this inference problem, we implement a variant of Fisher's permutation or randomization test (Fisher, 1935). Specifically, to implement it, we

[9]This event-study approach also allows us to see the dynamic medium-run effect of the export controls.
[10]Flaaen et al. (2020) and Flaaen and Pierce (2022) apply this test in international trade.

first estimate equation (1) additional 1000 times by replacing Treat_{kh} with one of the other products or destinations in the control group as a "placebo" treatment group. The 1000 "placebo" treatment effects then allow us to construct its distribution and yield p-values for the hypothesis that the true treatment effect is different from zero. This test is known to be a very demanding one to obtain statistical significance at conventional levels (Bunchmueller et al, 2011). We also report usual p-values obtained with usual clustered standard errors in the Appendix.

To further mitigate the concerns on our identification and inference, we provide an additional analysis conducted by the synthetic control method that is proposed by Abadie and Gardeazabal (2003) and Abadie et al. (2010). Its advantage is that, first, they do not rely on the common trend assumption and therefore provide us robustness checks of our DID results if the validity of the common trend assumption is suspicious. Second, the statistical inference in the synthetic control method is conducted by a similar randomization test. Therefore, we can further check the robustness of statistical inference in the DID approach.

4 Results

In this section, we report the estimation results of the DID approach and the synthetic control method, mostly focusing on those that provide noticeable and statistically significant evidence. All figures and the tables on the results from calculating equation (2) are available in the Appendix.

4.1 Targeted chemical materials

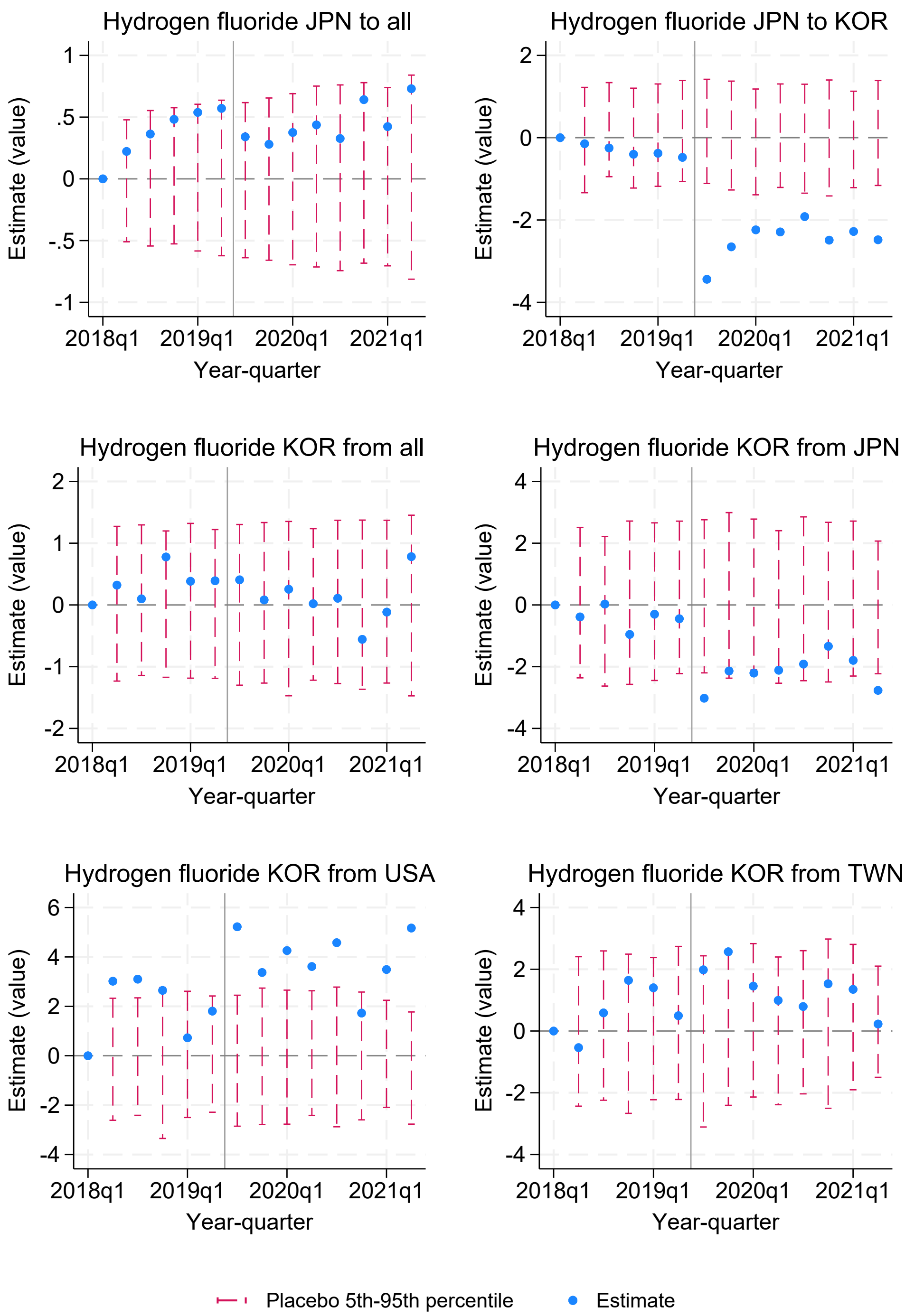
4.1.1 Hydrogen fluoride

Figure 5 shows the effect of strengthening the export controls on trade in hydrogen fluoride for Japan and South Korea. In each window, the plots represent the estimated coefficients on the treated hydrogen fluoride in each year-quarter (β_τ in equation 1), and the dashed vertical lines denote the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. According to the top left window, we do not observe statistically significant decline in the Japanese total export of hydrogen fluoride, relative to other products, at the timing of the policy change. However, the top right window shows that there is a negative and statistically significant decline in the Japanese exports of hydrogen fluoride to South Korea after strengthening the export controls. Based on the estimate in the 3rd quarter of 2019, the export value of hydrogen fluoride from Japan to South Korea declined by 96.8% [11]. Furthermore, the negative effect on the Japanese export of hydrogen fluoride to South Korea exists even in 2021. This suggests that South Korea replaced the Japanese hydrogen fluoride partly with its domestic production and/or imports from third countries.

The remaining windows in Figure 5 confirm that trade diversion of hydrogen fluoride is a part of the story that happened after the policy change. The middle left window shows that the total value of South Korean hydrogen-fluoride imports do not change that much before

[11] $[\exp(-3.440) - 1] \times 100 = -96.79$.

Figure 5. Estimated effect on trade of hydrogen fluoride



Note: The figure plots the estimated coefficients on the specific effect for hydrogen fluoride in each year-quarter (β_τ in equation 1). From the top left to bottom right, each window shows the effect on the Japanese export values of hydrogen fluoride to all destination countries, that on the Japanese export values to South Korea, that on the South Korean import values from all source countries, that on the South Korean import values from Japan, that on South Korean import values from the U.S., and that on the South Korean import values from Taiwan. The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

and after July 2019 relative to other products. The middle right window reaffirms that the estimates on the South Korean import values of hydrogen fluoride from Japan are negative and statistically significant after the policy change. The bottom windows show that, while there are some pre-trends in estimates, there are discontinuous and statistically significant increases in the South Korean imports of hydrogen fluoride from the U.S. and Taiwan after July 2019. This suggests that South Korea substitutes away from Japanese hydrogen-fluoride suppliers to those in other source economies, such as the U.S. and Taiwan, in response to the strengthening of the Japanese export controls.

4.1.2 Photoresist

Figure 6 shows the effect of strengthening the export controls on trade in photoresist for Japan and South Korea. The top left window shows that there is not much impact on the export value of photoresist from Japan to South Korea. This pattern is consistent with the fact that only a small fraction of photoresist is subject to the strengthening of the export controls. However, in the top right window, the imports of photoresist from Belgium increases just after the strengthening of the Japanese export controls, and the estimates are large and different from zero with statistical significance even in 2021. The estimate in the 3rd quarter of 2019 suggests a 947.5% increase in its import value[12].

In addition, the results on the unit value (bottom left) and quantity (bottom right) of photoresist imported from Belgium indicate that most of the effect on the import value comes from a change in the import unit value rather than import quantity, thus suggesting a change in import composition within photoresist. This is because, (a) most of traded photoresist in terms of quantity is that used in the production of less-advanced, large-sized chips and is not regulated under the Japanese export controls, and (b) the unit value per kilogram for the regulated EUV photoresist is about USD 3,500 to 4,400 and higher than the unit values for the other photoresist (Fuji Keizai, 2023). Therefore, the strengthening of the export controls is likely to cause a change in the composition of photoresist imported from Belgium, from lower-price non-regulated photoresist to higher-price regulated one.

This finding and the above suggested mechanism are consistent with what is reported in news media: Samsung started sourcing EUV photoresist from RMQC in Belgium, a joint venture of JSR from Japan and IMEC from Belgium. Thus, it suggests another successful substitution for South Korea from Japan to other source countries[13].

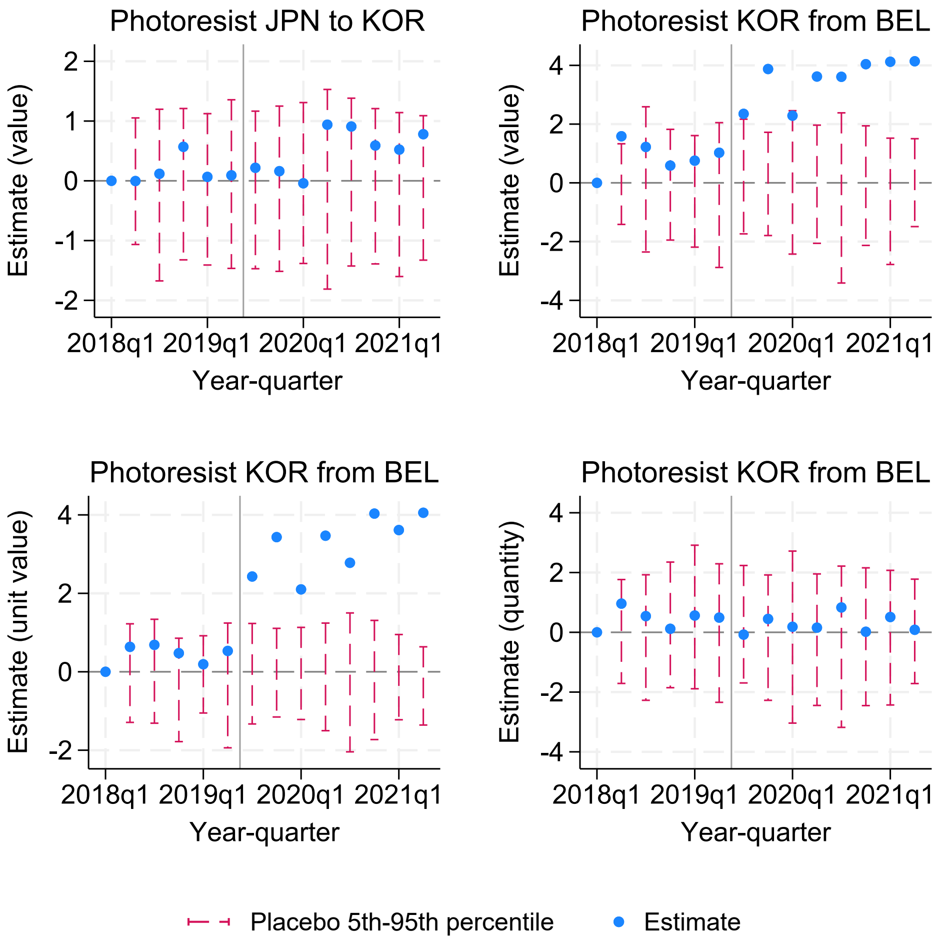
4.1.3 Fluorinated polyimide

In Figure 7, we report the effect of the export controls on trade in fluorinated polyimide for Japan and South Korea. All the windows do not show any noticeable changes at around the policy change in July 2019. This is probably because only a fraction of fluorinated polyimide is actually subject to the export controls (CISREC, 2019).

[12] $[\exp(2.349) - 1] \times 100 = 947.5$.

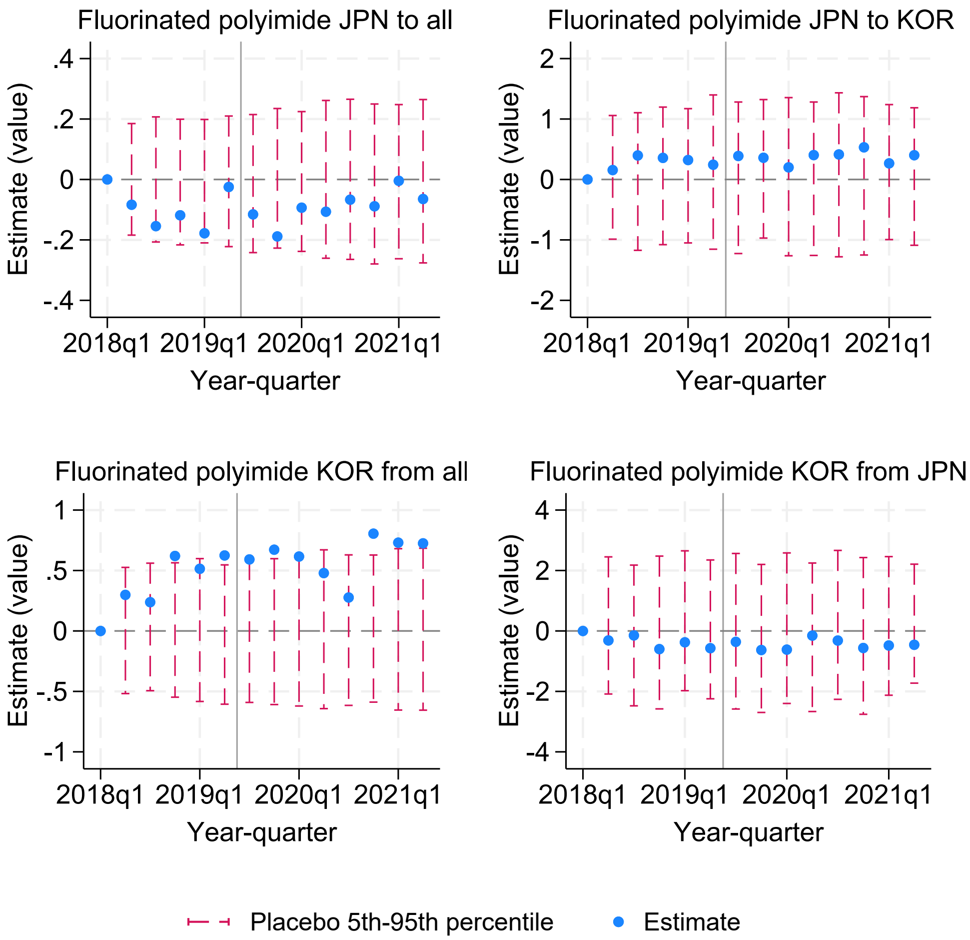
[13] https://asia.nikkei.com/Spotlight/Japan-South-Korea-rift/Samsung-secures-key-chip-supply-in-Belgiu

Figure 6. Estimated effect on trade of photoresist



Note: The figure plots the estimated coefficients on the specific effect for photoresist in each year-quarter (β_τ in equation 1). From the top left to bottom right, each window shows the effect on the Japanese export values of photoresist to South Korea, that on the South Korean import values from Belgium, that on the South Korean import unit values of Belgium, and that on the South Korean import quantities from Belgium. The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

Figure 7. Estimated effect on trade of fluorinated polyimide



Note: The figure plots the estimated coefficients on the specific effect for fluorinated polyimide in each year-quarter (β_τ in equation 1). From the top left to bottom right, each window shows the effect on the Japanese export values of fluorinated polyimide to all destination countries, that on the Japanese export values to South Korea, that on the South Korean import values from all source countries, and that on the South Korean import values from Japan. The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

4.2 Spillover effect

So far, what we have discussed is the effect of strengthening the export controls on the targeted chemical materials. The following subsection reports the effects on the products that use the restricted chemical materials as intermediate inputs and that are used complementarily with the targeted chemical materials in the semiconductor production process.

4.2.1 Semiconductors

Figure 8 shows the effect of strengthening the export controls on South Korean exports in semiconductors. The top left window shows that the total value of South Korean exports of semiconductors declines in the final quarter of 2019 relative to other exports. Note, however, that in this specification, identification comes from a variation in export values after controlling for the country-year-month and country-product fixed effects, but not for the product-year-month fixed effect. These estimates are, thus, likely to be contaminated by other supply and demand shocks that affect the entire semiconductor market. For instance, there was a fall in semiconductor demand in the second half of 2019 in the memory semiconductor market (Gartner, 2020). Therefore, we have to interpret the estimates with caution.

In the top right and bottom left windows, we provide the results on the South Korean export unit value and quantity of semiconductors, relative to other products. Again, we see a decline in the total export quantity of South Korean semiconductors in the final quarter of 2019, but not in the export unit value. They may imply a negative effect of the export controls in intermediate inputs on the final products in the semiconductor industry, though it is not conclusive.

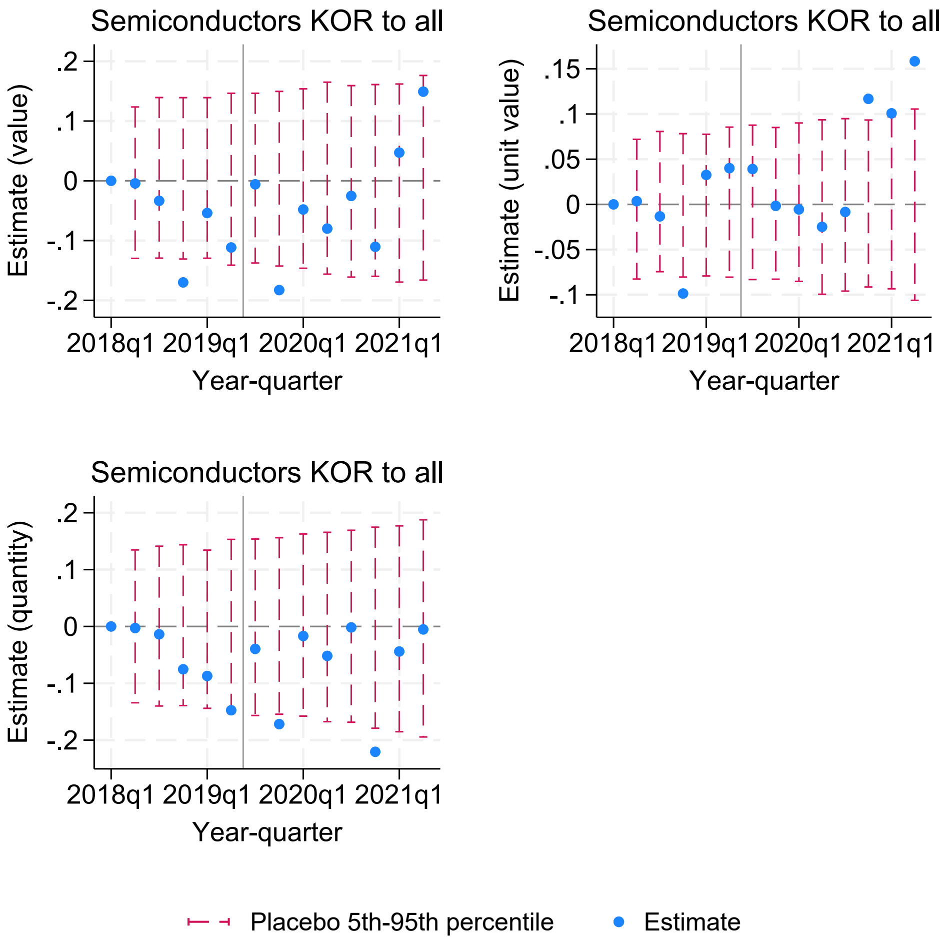
4.2.2 Semiconductor manufacturing equipments

Figure 9 shows the effect of strengthening the export controls on South Korean trades in semiconductor manufacturing equipment, an input that is used complementarily with the restricted chemical materials. The top left window indicates that there is a sharp and statistically significant decline in the total import value of semiconductor manufacturing equipment in the 3rd quarter of 2019. The top right and middle left windows also show that there is a sharp and short-run decline in the import value of the equipments from Netherlands and Germany. The estimates suggest a decline by 98.6% for Netherlands and 97.4% for Germany in the import values of the equipment in the 3rd quarter of 2019[14]. Furthermore, the decline in the import value of semiconductor manufacturing equipment comes mainly from a decline in the import quantity, not from a change in the import unit value (middle right and bottom left windows). This could suggest a possible response by South Korean firms that temporarily stopped the transactions of semiconductor manufacturing equipment because the chemical materials, that are used complementarily with the manufacturing equipment, are not readily available due to the Japanese exports controls[15].

[14] $[\exp(-4.297) - 1] \times 100 = -98.6$ for the import from Netherlands, and $[\exp(-3.646) - 1] \times 100 = -97.4$ for the import from Germany.

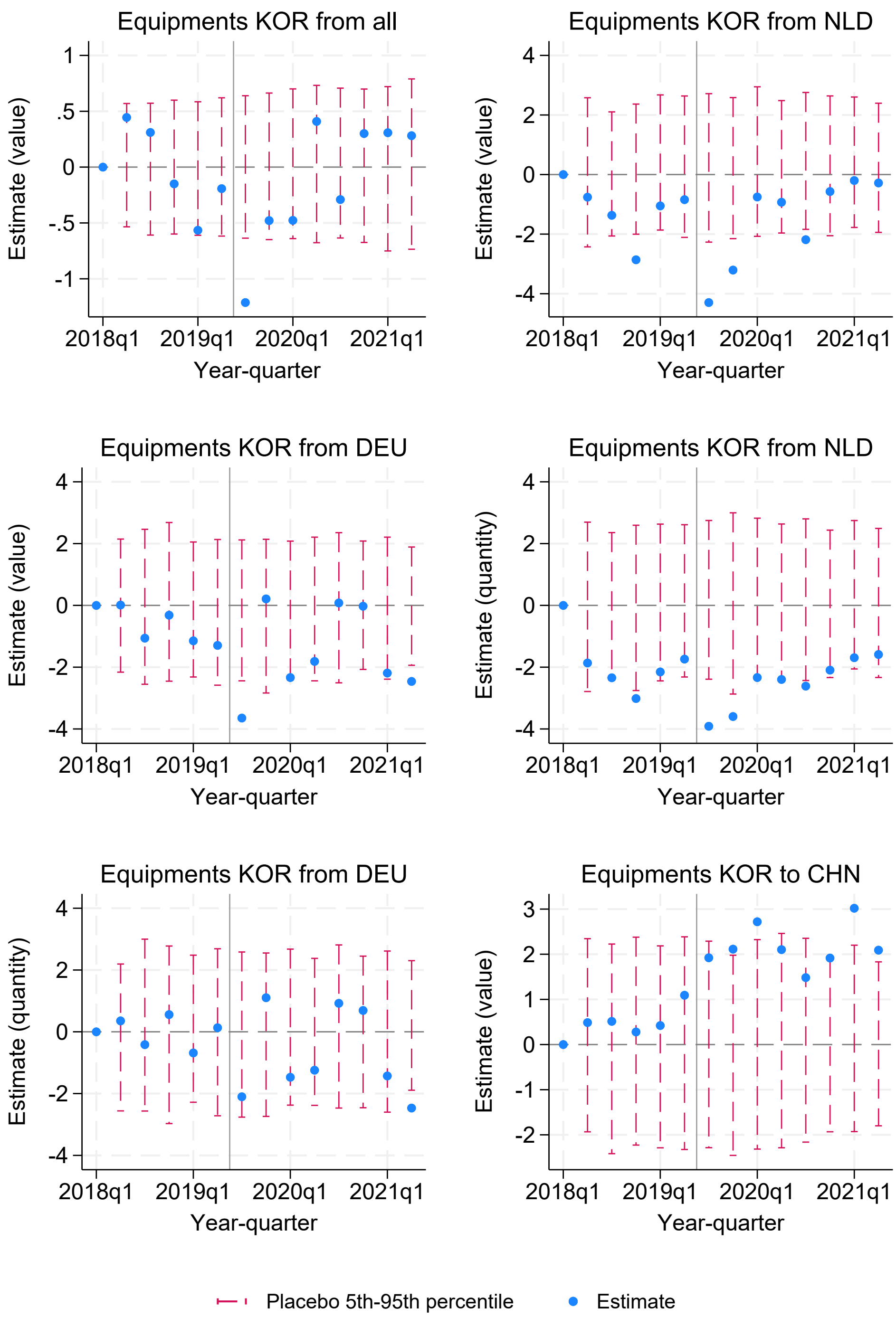
[15] Actually, a company in the Netherlands, the ASML, supplies 75% of lithography (one of the production steps in semiconductors) equipment in the global market and is the only company supplying extreme-ultraviolet (EUV) lithography equipment around the world, which is required to produce tiny-sized chips. On

Figure 8. Estimated effect on trade of semiconductors



Note: The figure plots the estimated coefficients on the specific effect for semiconductors in each year-quarter (β_τ in equation 1). From the top left to bottom right, each window shows the effect on the South Korean export values of semiconductors to all destination countries, that on the South Korean export unit values to all destination countries, and that on the South Korean export quantities to all destination countries. The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

Figure 9. Estimated effect on trade of semiconductor manufacturing equipments



Note: The figure plots the estimated coefficients on the specific effect for semiconductor manufacturing equipments in each year-quarter (β_τ in equation 1). From the top left to bottom right, each window shows the effect on the South Korean import values of the equipment from all source countries, that on the South Korean import values from Netherlands, that on the South Korean import values from Germany, that on the South Korean import quantities from Netherlands, that on South Korean import quantities from the Germany, and that on the South Korean export values to China. The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

The bottom right window in Figure 9 shows that their exports of semiconductor manufacturing equipment to China seem to increase substantially at the time of the introduction of the Japanese export controls. The coefficient suggests a 724.8% increase in the South Korean export of semiconductor manufacturing equipment to China [16]. 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. In addition, Samsung and SK Hynix have semiconductor production plants in China (Bown, 2020). It is consistent with the interpretation that these South Korean firms reallocate some of their semiconductor production to China to securely source the necessary chemical materials under the export controls and are thus necessary to export semiconductor manufacturing equipment to China[17].

4.3 The synthetic control method

This subsection discusses additional analyses to make sure that our main results are robust.

First, there may be other concurrent events that affect the South Korean and Japanese trade in semiconductor-related products with third 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 similar timing as the Japanese export controls in July 2019 and may therefore contaminate our results especially in the trades of Japan and South Korea 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.

Second, there may be a concern about pre-trends in our DID and event-study approach. To check whether our main results are robust against this identification problem, we 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).

the other hand, the high-quality photoresist is also used in the extreme-ultraviolet lithography step, which is restricted due to the export controls. 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.

[16] $[\exp(2.11) - 1] \times 100 = 724.8$.

[17] 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.

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 that have (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.

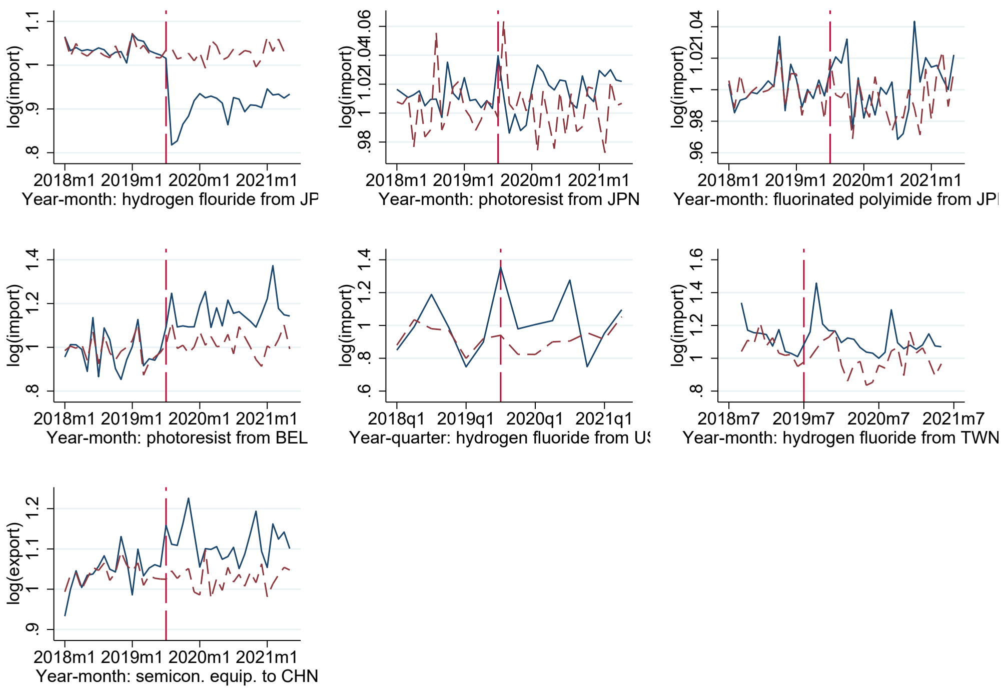
The results are reported in Figure 10. From the top left to bottom right, each window provides the result on the South Korean imports of hydrogen fluoride from Japan (top left), that of photoresist from Japan (top middle), that of fluorinated polyimide from Japan (top right), that of photoresist from Belgium (middle right) that of hydrogen fluoride from the U.S. (middle middle), that of fluorinated polyimide from Taiwan (middle right), and the South Korean exports of semiconductor manufacturing equipment to China (bottom right). They all show the same patterns found in the main DID analysis, thus supporting our main results[18]. In terms of their inference, Figure A7 in Appendix A3 shows the placebo tests for these synthetic control analyses. The gray dashed lines in each window are the estimates resulting from assigning "placebo" treatment status to untreated units as if they were treated. The solid black line shows the true treatment effect obtained from the synthetic control method. Because the true treatment effect is one of the most extreme among the placebo groups, it supports their statistical significance.

4.4 Discussion on production in South Korea and Japan

In this subsection, we discuss the possible impact of the export controls on the production of three specified items in South Korea and Japan. To this end, we manually collect financial reports from Orbis and the websites of several major South Korean and Japanese manufactures of three specified items. We show the time trend of firm sales and investment before and after Japan's export controls in 2019, without conducting econometric analysis due to small sample size. We find suggestive evidence that Japan's export controls led to (1) a significant increase in domestic production by Korean firms, (2) an increase in local production by Japanese foreign affiliates in South Korea, and (3) a sharp drop in sales of Japanese parent

[18]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 A13 in Appendix A2). 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 A14 in Appendix A2). Therefore, it should approximate well the counterfactual South Korean imports of hydrogen fluoride from Japan *in the absence of the dispute*.

Figure 10. Synthetic control method for the effect of the export controls



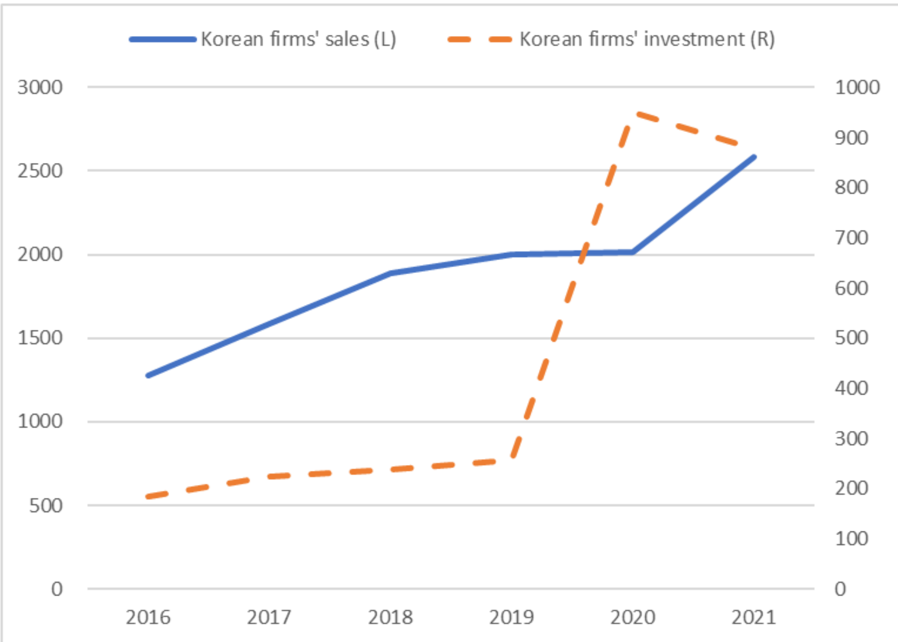
Note: The figure plots the results of the synthetic control method for South Korean imports of hydrogen fluoride from Japan (top left), their imports of photoresist from Japan (top middle), their imports of fluorinated polyimide from Japan (top right), their imports of photoresist from Belgium (middle 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).

firms in Japan.

4.4.1 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 the export controls, as strategic products, and would invest 7.8 trillion won in 7 years to promote their domestic production[19]. It aims at a secure supply of three specified items through domestic production. As a policy support, the South Korea government also 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 a part of the manufacturing process. The suppliers were South Korean chemical manufacturers, Soulbrain and RAM Technology. Furthermore, on January 2, 2020, South Korea's Ministry of Trade, Industry and Energy announced that Soulbrain has established a manufacturing technology that enables high-purity mass production of hydrogen fluoride. Soulbrain 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.

Figure 11. Trend of Korean firms' production



Note: This figure shows the trend of total sales and net fixed assets (both in million USD) of major Korean firms producing semiconductor-related chemical materials.

Figure 11 shows the trend of four major Korean firms' total sales and total net fixed as-

[19]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.

sets from 2016 to 2021[20]. The total sales of Korean firms increased approximately 38.7% from 2016–2018 period (pre-dispute average) to 2019-2021 period (post-dispute average). The total sales were increasing even before 2019, probably suggesting the increasing demand for semiconductor-related materials and products in South Korea. But the total sales further increased after 2019. More importantly, Korean firms significantly and persistently expanded their machine and equipment investment after the Japan's export controls in 2019. The total investment increased approximately threefold (270%) from 2019 to 2020. The investment is especially large for ENF Technology, which is consistent with media report[21]. Interestingly, this Korean firm used to import hydrogen fluoride from Japanese supplier Morita Chemical Industries.

4.4.2 Local production by Japanese affiliates in South Korea

The Japan's export controls has also pushed Japanese MNEs to expand their local production in South Korea. As Japanese firms have a large market share in the three specified items, they will lose their 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[22]. Figure 12 show the trend of four major Japanese foreign affiliates' total sales and capital investment in South Korea from 2016 to 2021[23]. The total sales of Japanese affiliates increased approximately 55.7% from 2016–2018 period (pre-dispute average) to 2019-2021 period (post-dispute average). More importantly, same as Korean firms, Japanese affiliates in South Korea increased twofold their capital investment in 2019.

4.4.3 Domestic production of Japanese parent firms

Contrary to Japanese affiliates in South Korea, due to the export controls, Japanese parent firms experienced a gradual but persistent decline in their sales after 2019 (Figure 13)[24]. Specifically, the sales growth rate was -2.6% during 2018–2019, -2.3% during 2019–2020, and -10.3% during 2020–2021. Furthermore, the capital investment in Japan also decreased in 2019 and 2020. 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.

It should be mentioned that these results are only suggestive evidence, without rigorous

[20] The four major South Korean firms are Soulbrain, SK Materials, RAM Technology, and ENF Technology.

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

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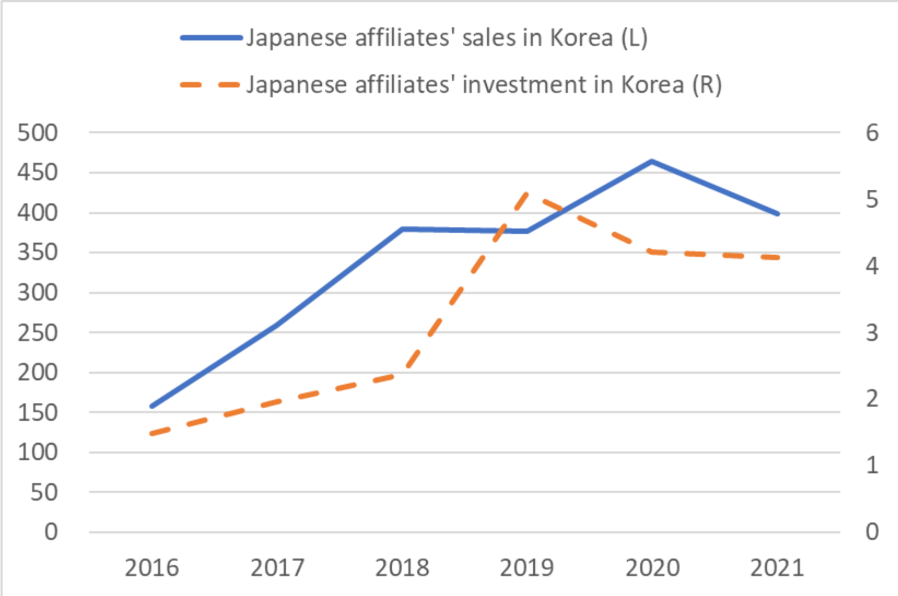
[23] The four major Japanese foreign affiliates are Morita Chemical Industries, Kanto Denka Kogyo, Central Grass, and ZEON.

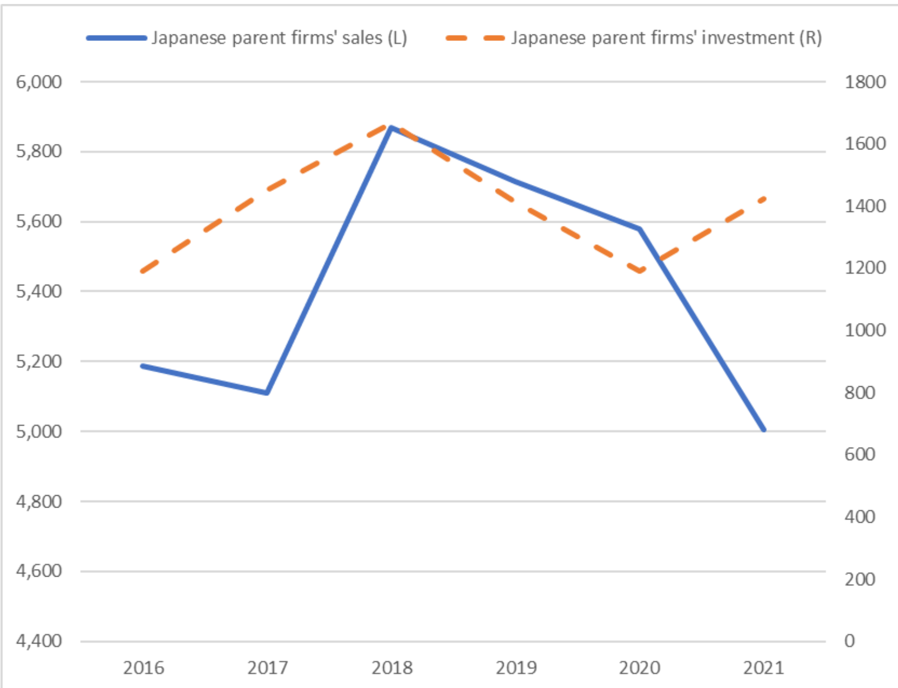
[24] The four major Japanese parent firms are Morita Chemical Industries, Kanto Denka Kogyo, Central Grass, and ZEON.

Figure 12. Trend of Japanese affiliates' production



Note: This figure shows the trend of total sales and capital investment (both in million USD) of major Japanese foreign affiliates producing semiconductor-related chemical materials in South Korea.

Figure 13. Trend of Japanese parents' production



Note: This figure shows the trend of total sales and capital investment (both in million USD) of major Japanese parent firms producing semiconductor-related chemical materials in Japan.

analysis. In future studies, it should be further investigated using regression analysis with firm-level data.

5 Conclusion

This paper analyzes the effects of the Japanese export controls of three chemical materials necessary in semiconductor production against South Korea on export and import for Japan and South Korea. 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, South Korea reallocated the sourcing of the restricted materials from Japan to other economies such as Belgium, the U.S., and Taiwan. Third, there was negative spillover effect on the South Korean imports of semiconductor manufacturing equipments, which is used complementarily with the restricted inputs in the semiconductor production. Fourth, South Korea increased the export of semiconductor manufacturing equipment to China, implying that some of their semiconductor production was relocated to China. There is also some preliminary evidence that production by South Korean domestic chemical firms and the Japanese affiliates of the targeted chemical firms in South Korea was increased.

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.

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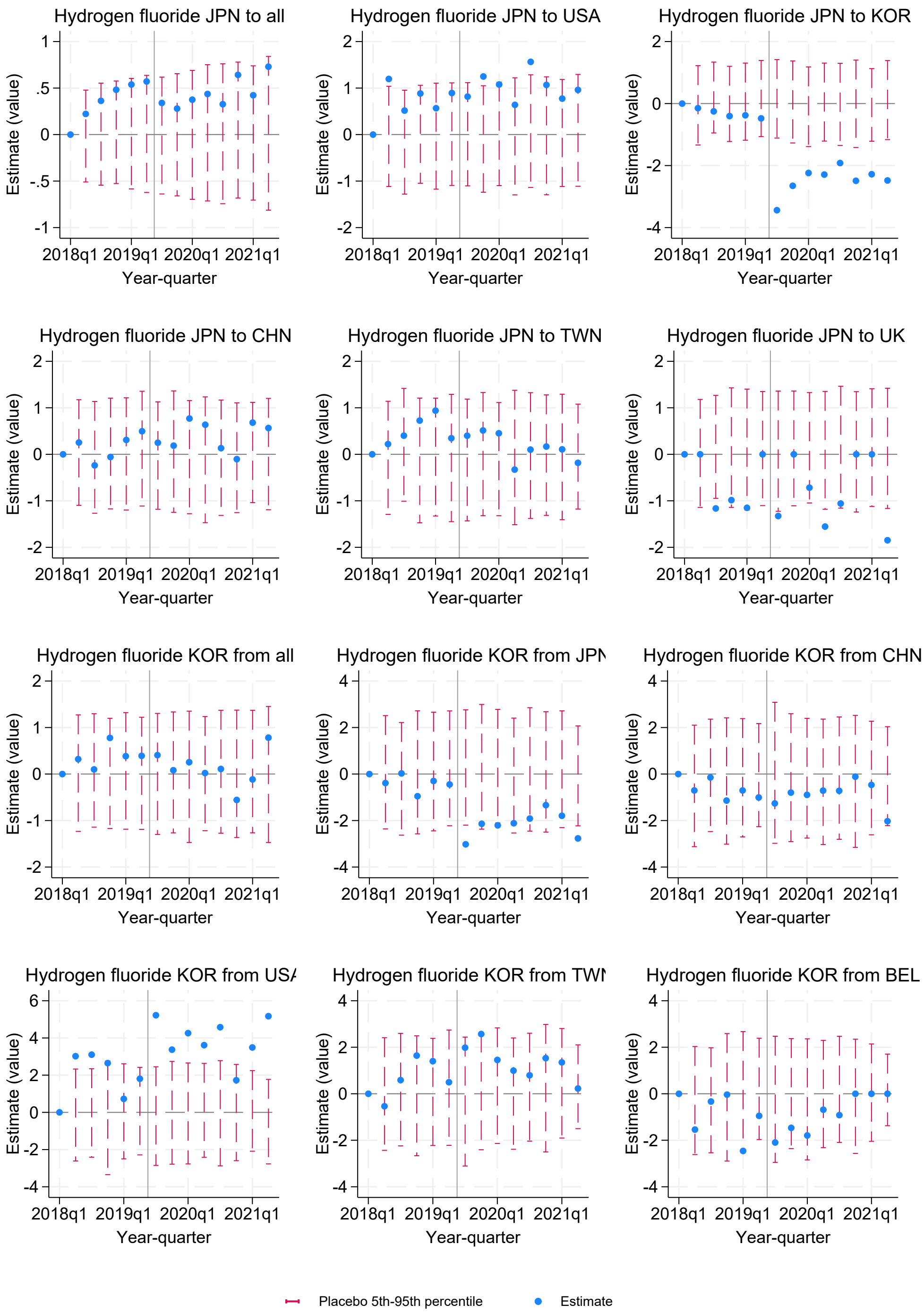
A1 Appendix: additional results for main analysis

A1.1 Figures

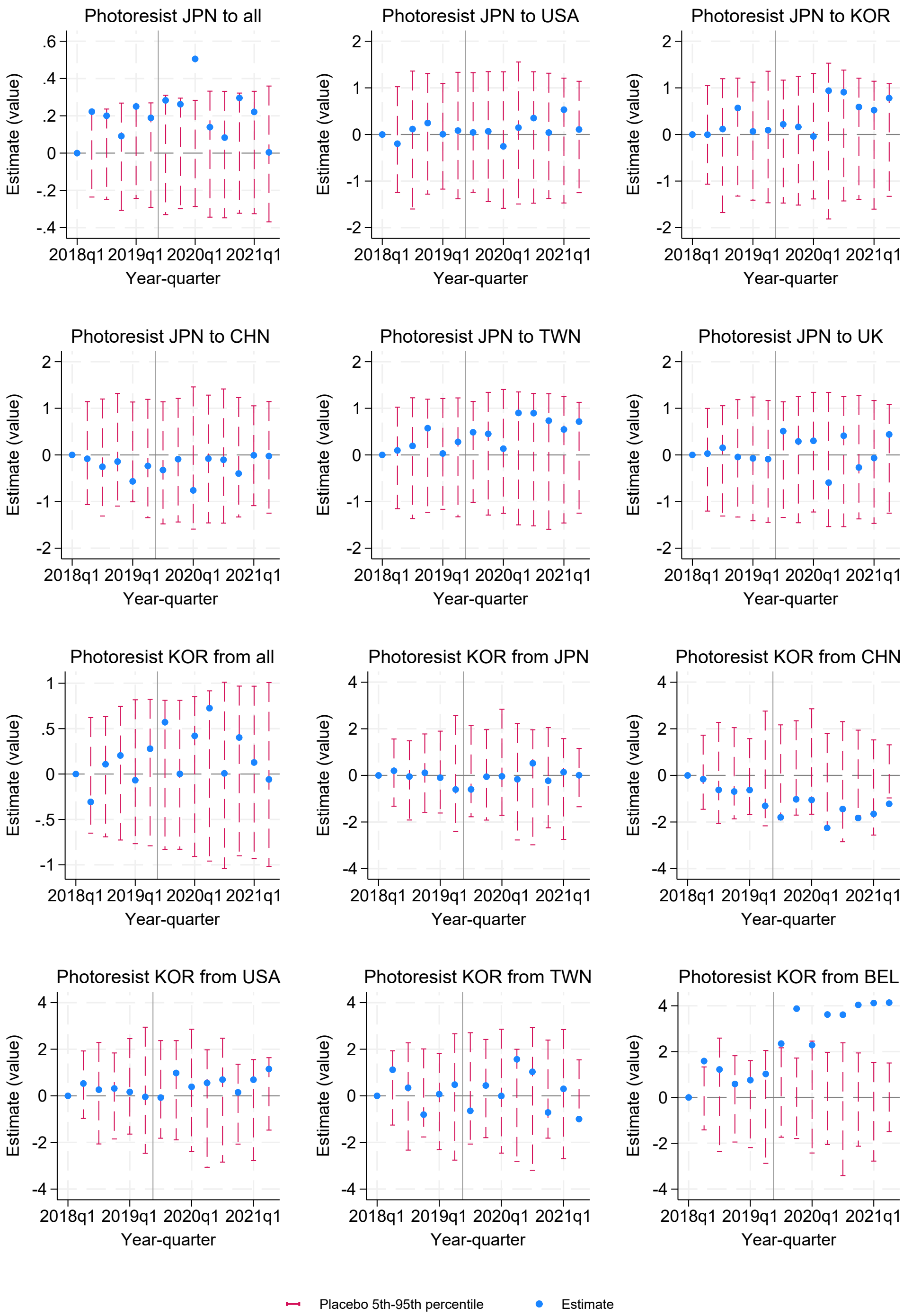
A1.1.1 Japanese exports and Korean imports

Figure A1. Japanese exports and Koran imports of hydrogen fluoride



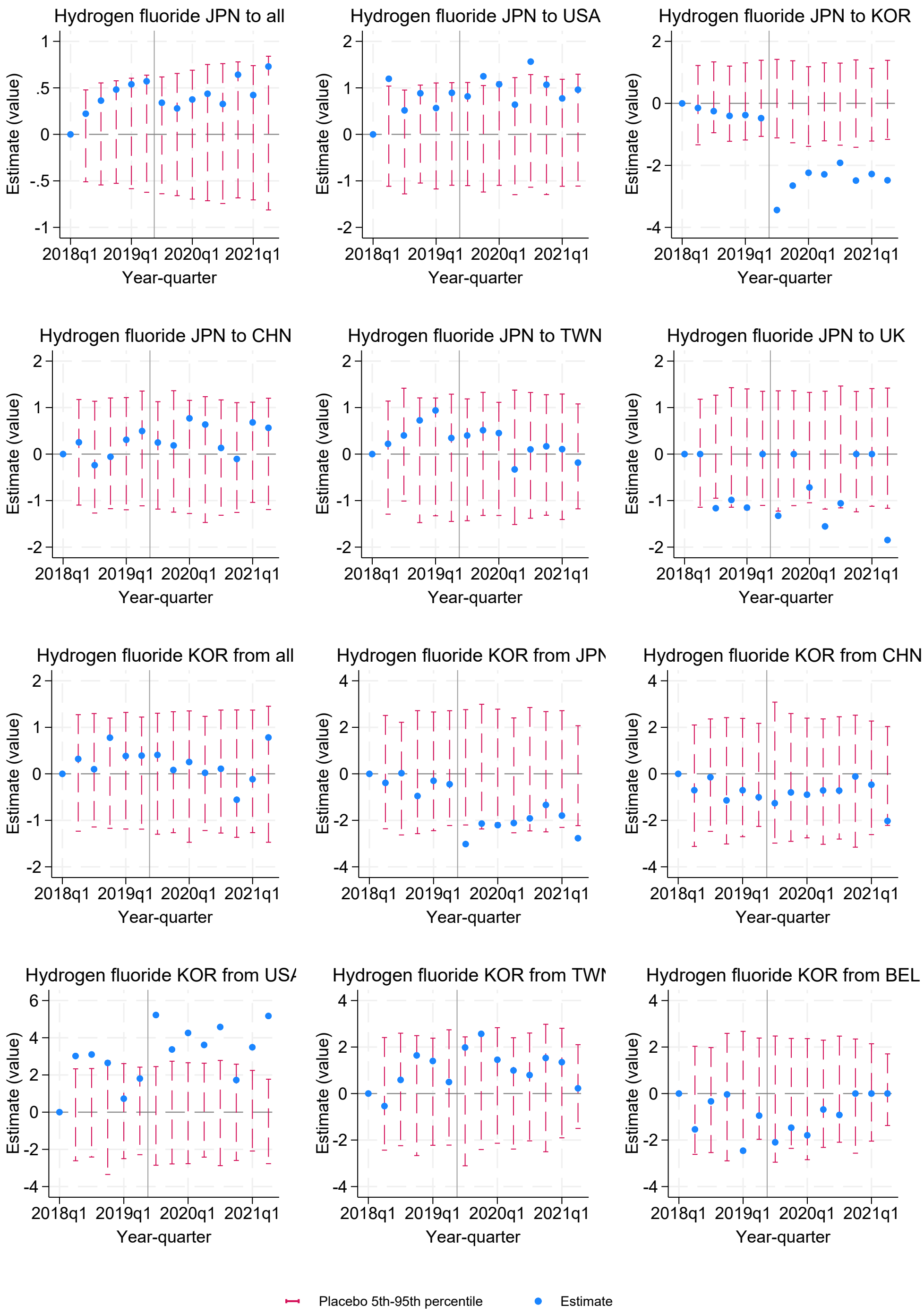
Note: The figure plots the coefficients on the specific effect of the treated hydrogen fluoride in each year-quarter (β_τ in equation 1) for the overall Japanese exports (1st row left) and for each of top destination countries (remaining 1st row and 2nd row), and for the overall South Korean imports (3rd row left) and for each of top source countries (remaining 3rd row and 4th row). The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

Figure A2. Japanese exports and Koran imports of photoresist



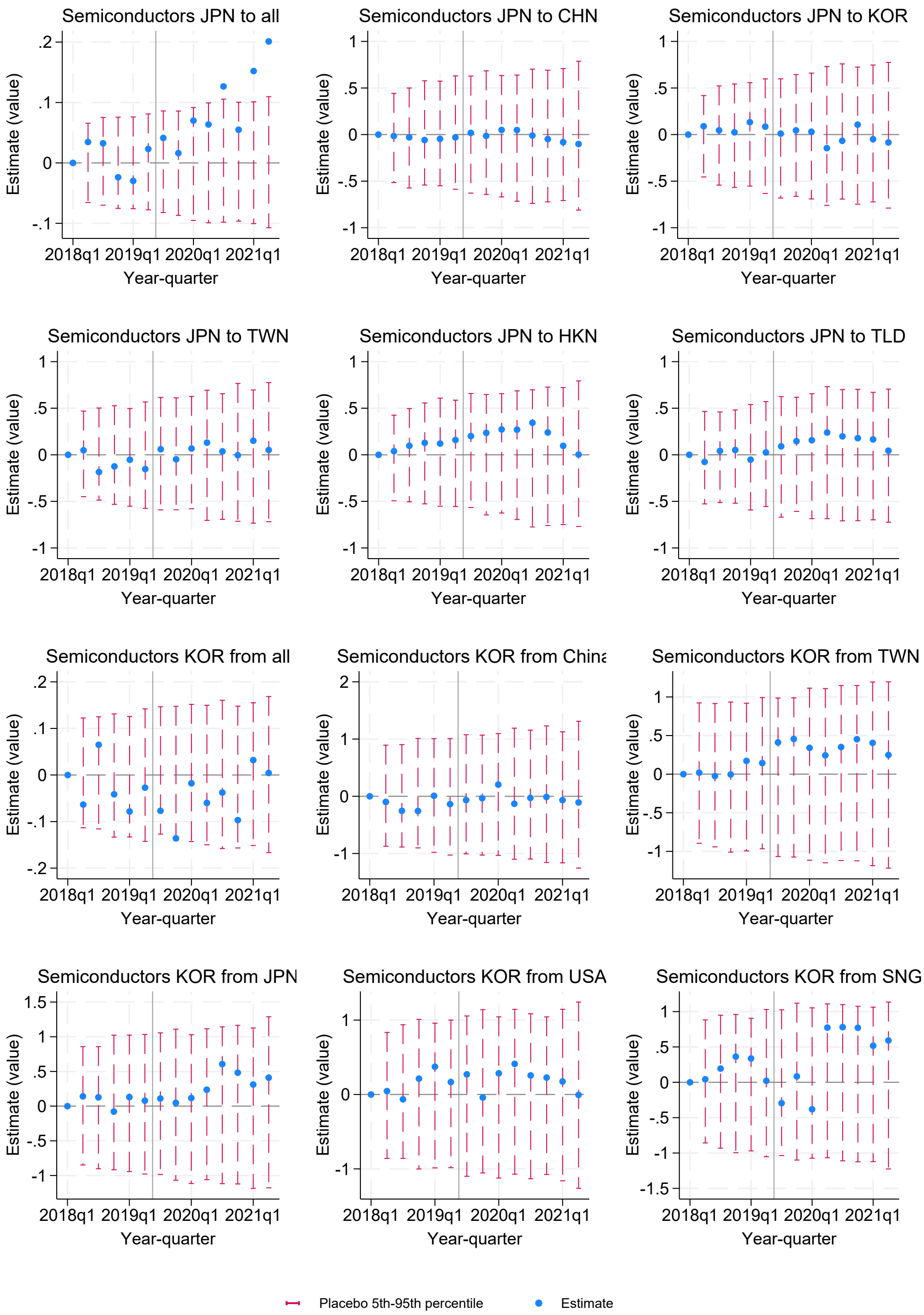
Note: The figure plots the coefficients on the specific effect of the treated photoresist in each year-quarter (β_τ in equation 1) for the overall Japanese exports (1st row left) and for each of top destination countries (remaining 1st row and 2nd row), and for the overall South Korean imports (3rd row left) and for each of top source countries (remaining 3rd row and 4th row). The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

Figure A3. Japanese exports and Koran imports of fluorinated polyimide



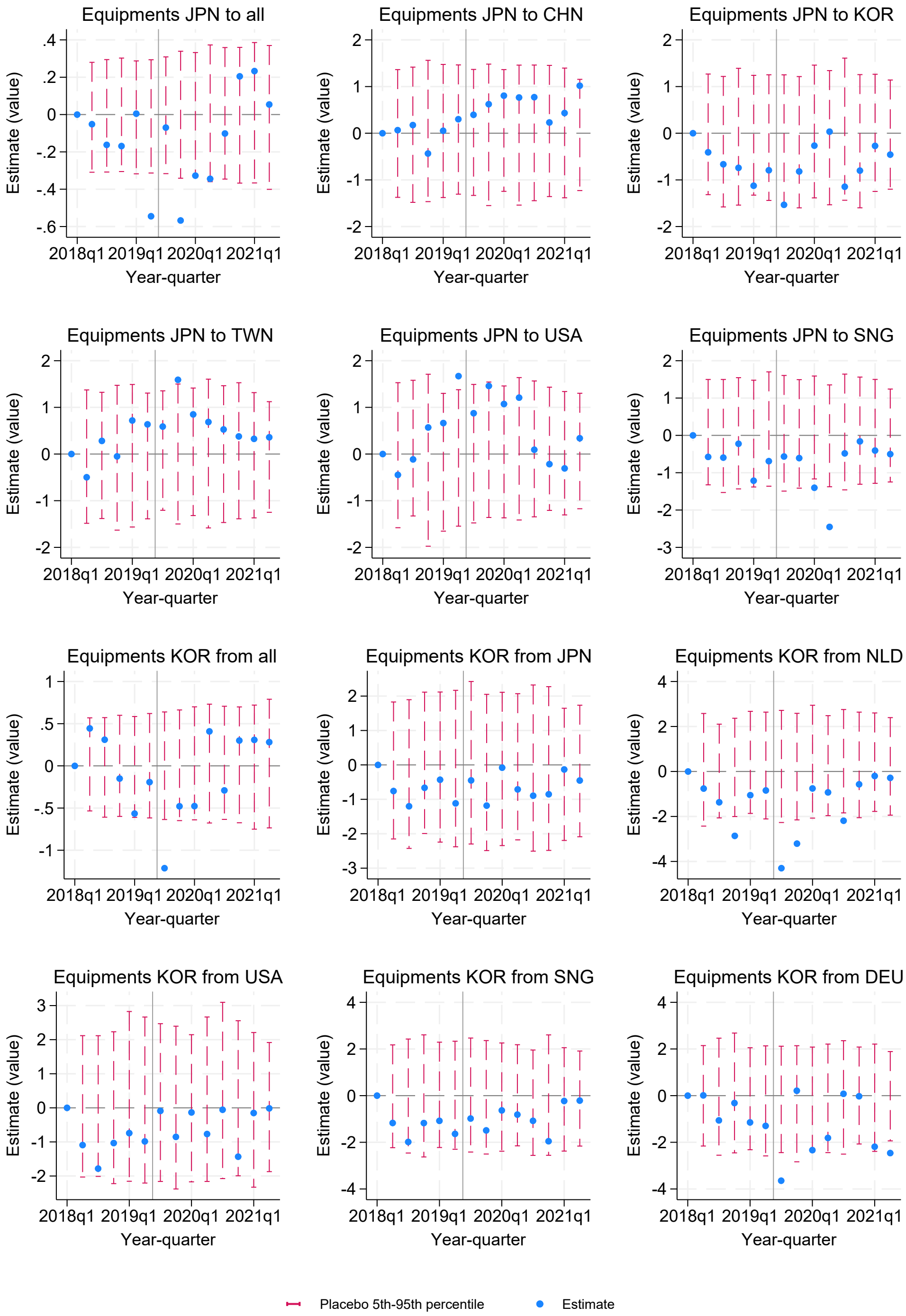
Note: The figure plots the coefficients on the specific effect of the treated fluorinated polyimide in each year-quarter (β_τ in equation 1) for the overall Japanese exports (1st row left) and for each of top destination countries (remaining 1st row and 2nd row), and for the overall South Korean imports (3rd row left) and for each of top source countries (remaining 3rd row and 4th row). The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

Figure A4. Japanese exports and Koran imports of semiconductors



Note: The figure plots the coefficients on the specific effect of the treated semiconductors in each year-quarter (β_τ in equation 1) for the overall Japanese exports (1st row left) and for each of top destination countries (remaining 1st row and 2nd row), and for the overall South Korean imports (3rd row left) and for each of top source countries (remaining 3rd row and 4th row). The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

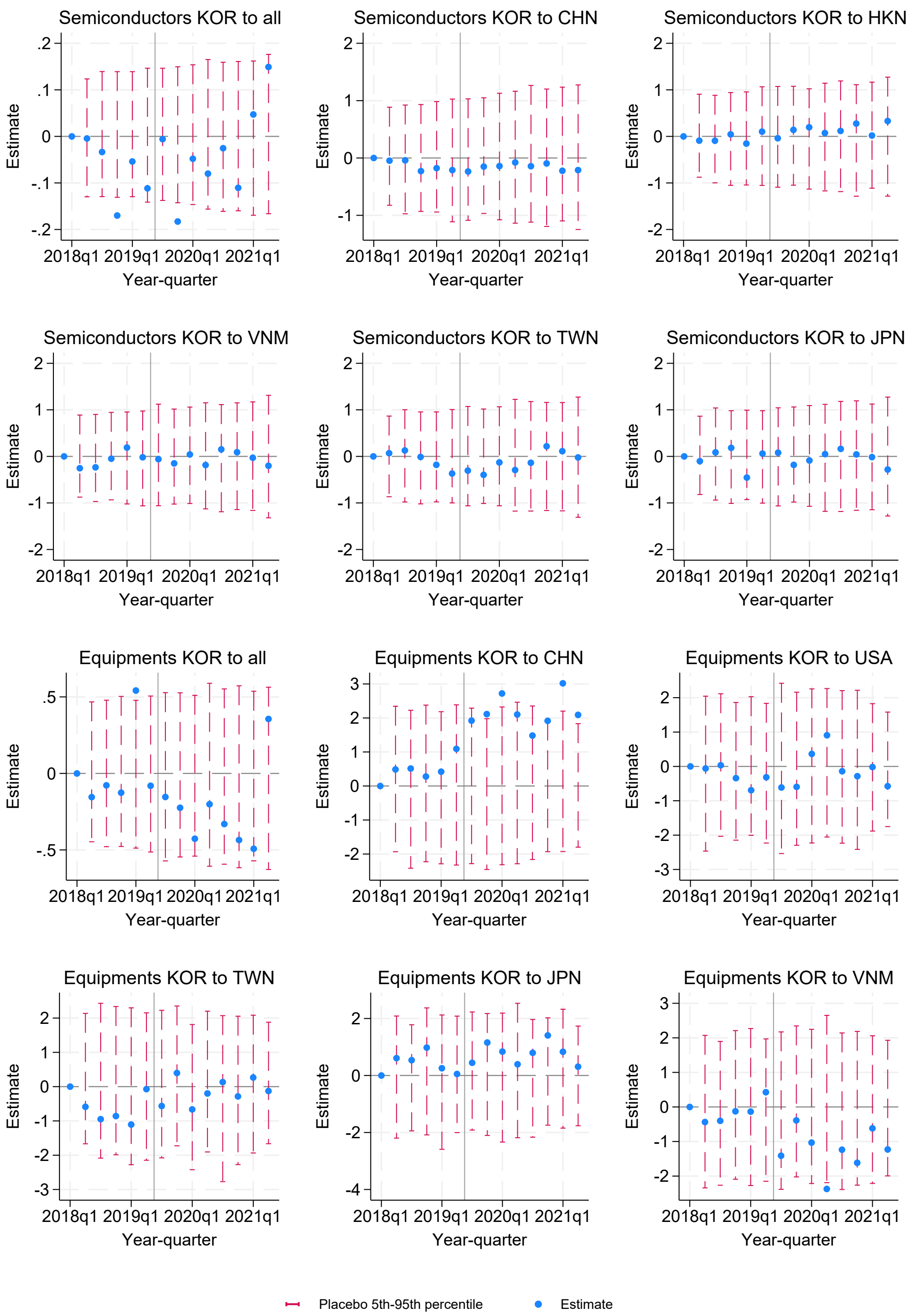
Figure A5. Japanese exports and Koran imports of semiconductor manufacturing equipments



Note: The figure plots the coefficients on the specific effect of the treated semiconductor manufacturing equipments in each year-quarter (β_τ in equation 1) for the overall Japanese exports (1st row left) and for each of top destination countries (remaining 1st row and 2nd row), and for the overall South Korean imports (3rd row left) and for each of top source countries (remaining 3rd row and 4th row). The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

A1.1.2 South Korean exports

Figure A6. South Korean exports of semiconductors and equipments



Note: The figure plots the coefficients in each year-quarter (β_τ in equation 1) on the treated semiconductors for the overall South Korean exports (1st row left) and for each of top destination countries (remaining 1st row and 2nd row), and on the treated manufacturing equipments for the overall South Korean exports (3rd row left) and for each of top destination countries (remaining 3rd row and 4th row). The dashed vertical lines are the 5th-95th percentiles of the distribution for the 1000 "placebo" estimates. The solid vertical line denotes the timing of strengthening export controls.

A1.2 Tables

A1.2.1 Japanese exports

Table A1: Effect on Japanese exports of hydrogen fluoride

Country	All	USA	KOR	CHN	TWN	UK
ΔE^{β}_{kht}	-.376	.272	-2.517**	-.736	-.265	-.588
p-value with t-stat	.278	.297	0	.002	.318	.117
5th percentile	-.658	-1.5	-1.575	-1.472	-1.316	-1.443
95th percentile	.679	1.386	1.609	1.491	1.659	1.449
Two-sided test p-value	.313	.501	.028	.28	.532	.332
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	46616	41562	46037	41562	41562	41562

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on Japanese exports of hydrogen fluoride. Columns 1 is the results for the total Japanese exports of hydrogen fluoride. Columns 2 to 6 are the results for the Japanese exports of hydrogen fluoride to the U.S. (column 2), South Korea (column 3), China (column 4), Taiwan (column 5), and the United Kingdom (column 6). In columns 2, 4, 5, and 6, the Japanese exports to South Korea are excluded from the sample because they are actually "treated". The second row for each estimate is a p-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a p-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A2: Effect on Japanese exports of photoresist

Country	All	USA	KOR	CHN	TWN	UK
ΔE^{β}_{kht}	-.021	.147	.375	.398	.543	.618
p-value with t-stat	.829	.543	.117	.341	.028	.044
5th percentile	-.26	-1.301	-1.307	-1.275	-1.301	-1.424
95th percentile	.245	1.432	1.516	1.624	1.723	1.515
Two-sided test p-value	.902	.643	.506	.47	.423	.349
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	10029	9341	9879	9341	9341	9341

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on Japanese exports of photoresist. Columns 1 is the results for the total Japanese exports of photoresist. Columns 2 to 6 are the results for the Japanese exports of photoresist to the U.S. (column 2), South Korea (column 3), China (column 4), Taiwan (column 5), and the United Kingdom (column 6). In columns 2, 4, 5, and 6, the Japanese exports to South Korea are excluded from the sample because they are actually "treated". The second row for each estimate is a p-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a p-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A3: Effect on Japanese exports of fluorinated polyimide

Country	All	USA	KOR	CHN	TWN	UK
ΔE^{β}_{kht}	-.086	-.203	.186	.233	-.411	-.479
p-value with t-test	.45	.14	.163	.081	.002	.003
5th percentile	-.241	-1.435	-1.542	-1.637	-1.42	-1.529
95th percentile	.245	1.339	1.372	1.315	1.256	1.331
Two-sided test p-value	.555	.628	.619	.589	.454	.415
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	105402	100715	105298	100715	100715	100715

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on Japanese exports of fluorinated polyimide. Columns 1 is the results for the total Japanese exports of fluorinated polyimide. Columns 2 to 6 are the results for the Japanese exports of fluorinated polyimide to the U.S. (column 2), South Korea (column 3), China (column 4), Taiwan (column 5), and the United Kingdom (column 6). In columns 2, 4, 5, and 6, the Japanese exports to South Korea are excluded from the sample because they are actually ”treated”. The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A4: Effect on Japanese exports of semiconductors

Country	All	CHN	KOR	TWN	HKN	TLD
ΔE^{β}_{kht}	.04	.033	-.156	.057	.051	.192
p-value with t-test	.314	.749	.315	.603	.622	.154
5th percentile	-.086	-.669	-.629	-.598	-.67	-.597
95th percentile	.082	.628	.643	.711	.656	.561
Two-sided test p-value	.417	.911	.666	.879	.877	.591
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	219556	219136	219136	219136	219136	219136

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on Japanese exports of semiconductors. Columns 1 is the results for the total Japanese exports of semiconductors. Columns 2 to 6 are the results for the Japanese exports of semiconductors to the China (column 2), South Korea (column 3), Taiwan (column 4), Hong Kong (column 5), and Thailand (column 6). The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A5: Effect on Japanese exports of semiconductor manufacturing equipment

Country	All	CHN	KOR	TWN	USA	SNG
ΔE^{β}_{kht}	.056	.025	.039	-.149	-.94	.907
p-value with t-stat	.79	.915	.871	.526	0	0
5th percentile	-.349	-1.883	-2.122	-1.883	-1.923	-2.096
95th percentile	.387	1.963	2.071	1.922	2.32	1.853
Two-sided test p-value	.807	.746	.744	.661	.287	.283
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	331443	329912	329912	329912	329912	329912

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on Japanese exports of semiconductor manufacturing equipment. Columns 1 is the results for the total Japanese exports of semiconductor manufacturing equipment. Columns 2 to 6 are the results for the Japanese exports of semiconductor manufacturing equipment to the China (column 2), South Korea (column 3), Taiwan (column 4), the U.S. (column 5), and Singapore (column 6). The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

A1.2.2 South Korean imports

Table A6: Effect on South Korean imports of hydrogen fluoride

Country	All	JPN	CHN	USA	TWN	BEL
ΔE^{β}_{kht}	-.093	-2.297	.038	4.637**	1.493	1.44
p-value with t-stat	.881	.001	.961	0	.06	.097
5th percentile	-1.212	-3.327	-3.506	-3.008	-3.542	-3.31
95th percentile	1.201	2.991	3.224	3.149	2.735	3.112
Two-sided test p-value	.893	.162	.643	.042	.272	.274
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	46681	46295	40634	40634	40634	40634

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean imports of hydrogen fluoride. Columns 1 is the results for the total South Korean imports of hydrogen fluoride. Columns 2 to 6 are the results for the South Korean imports of hydrogen fluoride from Japan (column 2), China (column 3), the U.S. (column 4), Taiwan (column 5), and Belgium (column 6). In columns 3 to 6, the South Korean imports from Japan are excluded from the sample because they are actually "treated". The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A7: Effect on South Korean imports of photoresist

Country	All	JPN	CHN	USA	TWN	BEL
ΔE^{β}_{kht}	.232	.406	-.137	.62	-.88	2.235
p-value with t-stat	.482	.393	.818	.261	.166	.001
5th percentile	-.903	-3.499	-3.521	-3.589	-3.589	-3.589
95th percentile	.737	3.127	2.519	2.994	3.142	3.354
Two-sided test p-value	.629	.459	.482	.378	.342	.175
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	4779	4598	3763	3763	3763	3763

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean imports of photoresist. Columns 1 is the results for the total South Korean imports of photoresist. Columns 2 to 6 are the results for the South Korean imports of photoresist from Japan (column 2), China (column 3), the U.S. (column 4), Taiwan (column 5), and Belgium (column 6). In columns 3 to 6, the South Korean imports from Japan are excluded from the sample because they are actually "treated". The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A8: Effect on South Korean imports of fluorinated polyimide

Country	All	JPN	CHN	USA	TWN	BEL
ΔE^{β}_{kht}	-.078	.076	-.849	.529	-.774	-.274
p-value with t-stat	.77	.798	.005	.088	.018	.468
5th percentile	-.651	-3.651	-3.256	-3.462	-3.559	-3.436
95th percentile	.696	2.911	3.658	3.596	3.703	3.489
Two-sided test p-value	.836	.73	.438	.533	.488	.622
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	84983	84944	80068	80068	80068	80068

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean imports of fluorinated polyimide. Columns 1 is the results for the total South Korean imports of fluorinated polyimide. Columns 2 to 6 are the results for the South Korean imports of fluorinated polyimide from Japan (column 2), China (column 3), the U.S. (column 4), Taiwan (column 5), and Belgium (column 6). In columns 3 to 6, the South Korean imports from Japan are excluded from the sample because they are actually "treated". The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A9: Effect on South Korean imports of semiconductors

Country	All	China	TWN	JPN	USA	SNG
ΔE^{β}_{kht}	.011	-.176	.104	-.106	-.351	-.185
p-value with t-stat	.896	.289	.664	.607	.034	.603
5th percentile	-.139	-1.099	-1.129	-1.074	-1.1	-1.046
95th percentile	.159	1.112	1.119	1.201	1.167	1.089
Two-sided test p-value	.883	.79	.848	.841	.572	.765
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	201668	201439	201439	201439	201439	201439

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean imports of semiconductors. Columns 1 is the results for the total South Korean imports of semiconductors. Columns 2 to 6 are the results for the South Korean imports of semiconductors from China (column 2), Taiwan (column 3), Japan (column 4), the U.S. (column 5), and Singapore (column 6). The second row for each estimate is a p-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a p-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A10: Effect on South Korean imports of semiconductor manufacturing equipment

Country	All	JPN	NLD	USA	SNG	DEU
ΔE^{β}_{kht}	-.008	-.202	-3.972*	-.153	-.095	.036
p-value with t-stat	.986	.695	0	.767	.857	.951
5th percentile	-.767	-3.547	-3.205	-3.685	-3.692	-3.34
95th percentile	.691	3.213	3.271	3.241	3.643	3.463
Two-sided test p-value	.985	.634	.067	.67	.702	.724
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	220268	218145	218145	218145	218145	218145

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean imports of semiconductor manufacturing equipment. Columns 1 is the results for the total South Korean imports of semiconductor manufacturing equipment. Columns 2 to 6 are the results for the South Korean imports of semiconductor manufacturing equipment from Japan (column 2), Netherlands (column 3), the U.S. (column 4), Singapore (column 5), and Germany (column 6). The second row for each estimate is a p-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a p-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

A1.2.3 South Korean exports

Table A11: Effect on South Korean exports of semiconductors

Country	All	CHN	HKN	VNM	TWN	JPN
ΔE^{β}_{kht}	-.031	.061	.077	-.419	.257	.479
p-value with t-stat	.656	.669	.749	.046	.178	.095
5th percentile	-.151	-1.108	-1.098	-1.045	-1.075	-.995
95th percentile	.153	1.083	1.226	1.204	1.119	1.117
Two-sided test p-value	.738	.914	.897	.482	.679	.443
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	244540	244014	244014	244014	244014	244014

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean exports of semiconductors. Columns 1 is the results for the total South Korean exports of semiconductors. Columns 2 to 6 are the results for the South Korean exports of semiconductors to each destination, China (column 2), Hong Kong (column 3), Vietnam (column 4), Taiwan (column 5), and Japan (column 6). The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

Table A12: Effect on South Korean exports of semiconductor manufacturing equipment

Country	All	CHN	USA	TWN	JPN	VNM
ΔE^{β}_{kht}	-.752**	.901	.25	.192	1.253	-1.456
p-value with t-stat	.08	.049	.585	.679	.006	.001
5th percentile	-.591	-3.557	-3.326	-2.788	-2.668	-2.899
95th percentile	.587	3.364	3.276	3.483	3.162	3.04
Two-sided test p-value	.041	.418	.668	.67	.319	.276
Country-year-month FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-country FE	Yes	Yes	Yes	Yes	Yes	Yes
HS6-year-month FE	No	Yes	Yes	Yes	Yes	Yes
N	317883	315716	315716	315716	315716	315716

Note: The table reports the results from calculating equation (2) on the effect of the Japanese export controls on South Korean exports of semiconductor manufacturing equipment. Columns 1 is the results for the total South Korean exports of semiconductor manufacturing equipment. Columns 2 to 6 are the results for the South Korean exports of semiconductor manufacturing equipment to each destination, China (column 2), the U.S. (column 3), Taiwan (column 4), Japan (column 5), and Vietnam (column 6). The second row for each estimate is a *p*-value calculated by t-statistics using the standard error clustered at the HS 6-digit times destination country. The third and fourth row presents 5th and 95th percentile of placebo ΔE^{β}_{kht} calculated from permutation test. The fifth row reports a *p*-value from a two-sided test based on a variant of randomization test. ** Significant at the 5% level. * Significant at the 10% level.

A2 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 A13: 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 A14: 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 A15: 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 A16: 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 A17: 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 A18: 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 A19: 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 A20: 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 A21: 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 A22: 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 A23: 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 A24: 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 A25: 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.

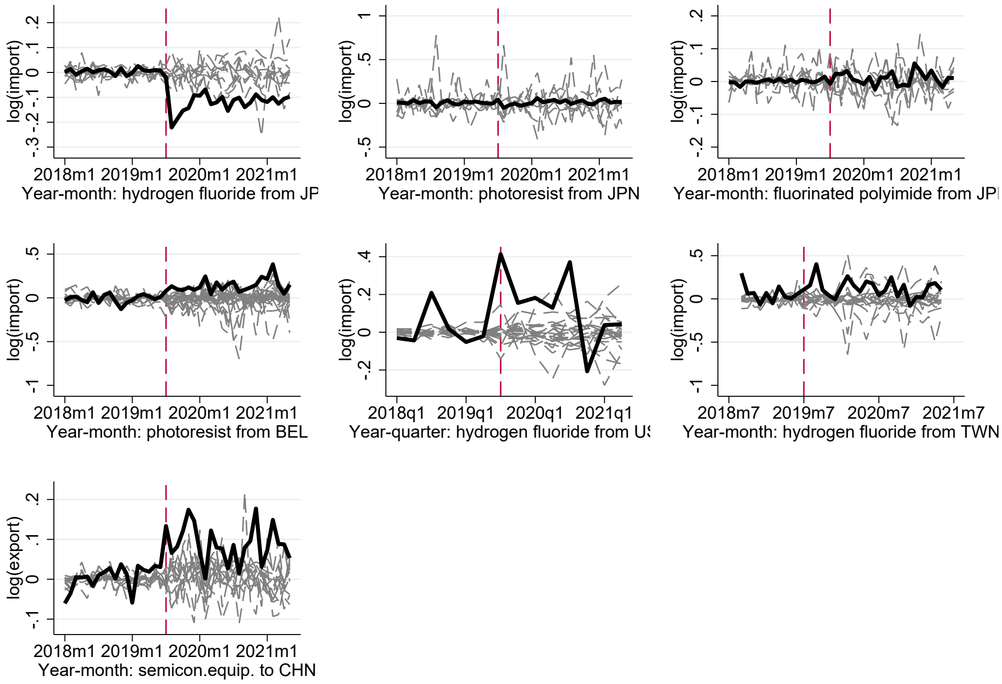
Table A26: Pre-treatment average of variables: South Korean exports of equipments to CHN

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.

A3 Appendix: results from placebo tests of the synthetic control method

Figure A7. Placebo test for the synthetic control method



Note: The figure plots the results of placebo tests for the synthetic control method reported in Figure 10. 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).