Responding to Semiconductor Supply Chain Disruptions: Evidence from South Korea*

Younghoon Kim†

February 2024

Abstract

How might semiconductor producers respond to the possibility of restricted access to key imported intermediate goods? And how might this response vary across inputs? I use the response from Korean semiconductor producers amid the 2019 Korea-Japan political dispute to answer these questions. In July 2019, Japan announced potential export controls on South Korea for three key semiconductor inputs, leaving implementation to Japanese officials. Although no export restrictions were applied in practice, the announcement itself triggered uncertainty over the global supply chain, leading to drastically different responses from Korean producers across the three targeted inputs. I present a model featuring two adjustment margins—–inventories and global sourcing decisions—with heterogeneity across inputs in the initial share of sourcing from Japan. I show that the calibrated model matches the heterogeneous patterns across the three inputs, suggesting that these two adjustment margins played an important role in practice. Using the model, I also solve for how Korean producers would have responded had Japan extended its export controls to other key semiconductor inputs. These counterfactual responses align with actual responses, indicating that semiconductor producers feared an extension of Japanese export controls.

*I am grateful to Jonathan Vogel, Ariel Burstein, Pablo Fajgelbaum, and Oleg Itskhoki for their invaluable guidance and support. I also thank John Asker, Jinyong Hahn, Yasutaka Koike-Mori, and the participants at UCLA proseminar for helpful comments and suggestions.

†Department of Economics, UCLA, Ph.D. candidate (email: kimyounghoon@ucla.edu).

1 Introduction

The semiconductor industry has emerged as a pivotal sector in recent trade and industrial policies. Several nations have initiated industrial strategies to bolster domestic semiconductor production, including "US CHIPS Act," "European Initiative on Processors and Semiconductors," and "Made in China 2025." Since October 2022, amid tensions with China, the US has mandated that multinational firms seeking to export advanced semiconductors and related manufacturing equipment to China must obtain prior authorization. In response, China announced in July 2023 export controls on key minerals essential for semiconductor production. These recent policy changes in the semiconductor industry raise several questions regarding the global supply chain.

In this paper, I use data on the response from Korean semiconductor producers amid the 2019 Korea-Japan political dispute to answer the following questions: How do semiconductor producers respond when confronted by trade policies that increase the likelihood of global supply chain disruptions? And does this response depend on observable characteristics of the global supply chain? The margins of adjustment at the heart of my analysis are simple: facing the threat of import bans, firms may stockpile imports (inventorying) or seek alternative countries for their intermediate sourcing (substitution). Despite the simplicity of my model, I show that it captures the heterogeneous responses of Korean producers across different inputs during the 2019 Korea-Japan dispute.

In late 2018, tensions between Korea and Japan have reignited following a Korean Supreme Court ruling that ordered Japanese companies to compensate Korean victims forced into labor during the 1940s, a decision Japan strenuously contested. In July 2019, the Japanese government responded to this decision by enabling export controls on three chemicals essential to Korea's semiconductor industry: photoresist, fluorinated polyimide, and hydrogen fluoride. These export controls require that Japanese firms exporting these three chemicals to Korea must obtain government approval for every single shipment of these chemicals. Approval was uncertain: the Japanese government was legally authorized to ban shipments to Korea. Despite this possibility, in practice the Japanese government has not enforced any export restrictions on the chemicals to date.

Korean semiconductor producers promptly responded to this Japanese export policy and the resulting uncertainty by changing their sourcing strategies. In Section 3, I show that these responses differed strikingly across the three chemicals. Imports of photoresist doubled during the month of the announcement (with this excess supply being stockpiled), then decreased by 66%, and finally returned to the pre-shock level one year thereafter. Meanwhile, imports of hydrogen fluoride declined by 80% during the month of the announcement, and have remained well below the pre-shock level thereafter. Finally, after Japan's announcement, it appears that Korean firms adjusted their global sourcing of hydrogen fluoride, mostly buying it from non-Japanese suppliers including domestic ones.

Using a model integrating two adjustment margins—inventory and global sourcing decisions—I investigate the heterogeneous responses of Korean semiconductor producers across the targeted inputs. In the model, a producer decides where to source inputs and how much of them to inventory. In post-shock period, I incorporate two features of the Japanese export controls into the model: uncertainty of access to Japanese inputs and change in the levels of non-tariff barriers. First, because the decision to permit exports to Korea has been left to Japanese officials, Korean producers have faced uncertainty over access to Japanese inputs since the shock. The first feature causes the producers to stockpile more targeted chemicals than usual (inventorying) as they brace themselves for possible export denials. Second, since the announcement, non-tariff barriers for Korean firms have risen due to additional administrative procedures introduced to their imports from Japan. The second feature causes the producers to seek alternative countries for their intermediate sourcing (substitution) as the importing costs have increased. Since these two features force the responses in opposite directions, whether the firms stockpile or substitute the Japanese chemicals depends on the probability of execution of the export controls, and three characteristics of each targeted chemical: 1) its initial share of sourcing from Japan; 2) its elasticity of substitution between Japan and other sources; and 3) the extent of the change in non-tariff barriers imposed by Japan.

I calibrate these three characteristics of each chemical on pre-shock data and literature. First, the initial share of sourcing from Japan is calibrated as observed in the data. Second, I take a parameter for the elasticity of substitution from Broda and Weinstein (2006). They estimated almost 14,000 elasticities of items based on 10-digit Harmonized System codes using trade data for 1990-2001. Third, I calibrate the change in the non-tariff barriers using the US-Korea Free Trade Agreement, a previous event that induced these changes in the opposite direction. However, the probability of executing the export controls is challenging to calibrate based on either pre-shock data or literature, as the perceived probability by Korean producers is unobservable. Instead, I parameterize the probability using the number of news articles that mention the Korea-Japan dispute, and calibrate it to match a total of six moments—two for each targeted chemical—in the post-shock period.

Simulations of the calibrated model align closely with the observed data. The results match the heterogeneous changes in the Japanese share across the three targeted chemicals in the post-shock period (July 2019 to December 2020). These simulations also correspond with the heterogeneous responses of these chemicals in July 2019, the onset of the event. Specifically, imports of Japanese photoresist increased significantly, imports of Japanese fluorinated polyimide remained unchanged, and imports of Japanese hydrogen fluoride decreased substantially in July 2019. The model successfully replicates these diverse patterns. Notably, the results—both qualitative and quantitative—are robust even when incorporating homogeneity across the three targeted chemicals both in the elasticity of substitution and the level of non-tariff barriers. This suggests that the initial share of sourcing from Japan plays an important role in determining whether producers will stockpile or substitute Japanese inputs.

Using the same model, I further explore how Korean producers would have responded if the Japanese government had extended its export controls to other key intermediates used in semiconductor production. I use the same calibrated parameters from the baseline—the elasticity of substitution, the change in non-tariff barriers and the probability of export controls—which are homogeneous across all potential target intermediates. As in the baseline, the results suggest that the initial share of Japanese intermediates serves as a reliable predictor for how Korean producers would respond. Specifically, potential targets with a higher Japanese share exhibit stockpiling behaviors, reflecting the observed pattern in photoresist. Conversely, those with a lower Japanese share show substitution away from Japan, consistent with the pattern observed in hydrogen fluoride. Moreover, counterfactual responses for some potential targets align with observed trends in actual data, even without being directly targeted by the export controls. This indicates that Korean semiconductor producers are proactive, possibly stockpiling or substituting Japanese intermediates in anticipation of extended export controls.

Related literature. This paper contributes to five strands of literature. First, it is related to a body of literature that explains dynamics of international trade through the lens of inventory management (Khan and Thomas (2007); Alessandria et al. (2010); Bekes et al. (2017); Alessandria et al. (2019); Carreras-Valle (2021)). I combine inventorying with sourcing decisions, enabling the exploration of diverse change in sourcing patterns observed in a supply chain disruption event in the semiconductor industry. The decision for a firm to either inventory an input from its current source or to import from another source depends on the elasticity of substitution between these source countries and the initial share of the current source in the imports.

Second, this paper is connected to the extensive literature on global sourcing and trade of inputs, which primarily focuses on optimal sourcing decisions and substitutability across sources (Antràs and Helpman (2004); Halpern et al. (2015); Antràs et al. (2017); Blaum et al. (2018); Handley et al. (2020)). This research broadens the scope by incorporating an inventorying adjustment margin, highlighting its importance alongside substitution in the face of global sourcing disruptions. The significance of inventorying adjustment becomes increasingly pronounced in firms with limited sourcing partners, a situation prevalent in highly advanced industries such as advanced semiconductors and related manufacturing equipment.

Third, this paper contributes to the growing literature on trade policy uncertainties. While reductions in uncertainty typically increase trade (Handley and Limao (2015); Pierce and Schott (2016); Feng et al. (2017); Crowley et al. (2018)), rises in uncertainty can also have the same effect (Alessandria et al. (2019)). This study illustrates that these seemingly contradictory outcomes can indeed occur simultaneously in response to a single uncertainty shock. The same shock can provoke heterogeneous responses, depending on industry-level and product-level characteristics, such as elasticity of substitution and dependence on specific sourcing countries.

This paper is also related to an emerging literature on trade wars and sanctions. Amiti et al. (2019), Fajgelbaum et al. (2020) and Fajgelbaum and Khandelwal (2022) assess the economic effects of substantial tariff increases resulting from the US-China trade war. Itskhoki and Mukhin (2022) and Lorenzoni and Werning (2022) examine the various effects of the Russian invasion of Ukraine through exchange rates. My contribution in this area is to demonstrate, using a well-identified shock, that even if a sanction is not enforced, the announcement itself can significantly impact sourcing patterns, with heterogeneous effects across industries.

Lastly, this paper is related to literature on the semiconductor industry (Irwin and Klenow (1994); Cabral and Leiblein (2001); Aizcorbe and Kortum (2005); Pillai (2013); Siebert (2019); Asmat (2021)). These works primarily explore technological development and market structure of the industry. I contribute to this literature by extending the focus to the industry's response to supply chain disruptions and demonstrating how the input sourcing structure significantly determines this response. Additionally, I provide suggestive evidence on the ease of substituting key inputs within the semiconductor industry.

Outline. The remainder of the paper is structured as follows. Section 2 provides the background on the Japanese export controls. Section 3 illustrates changes in import patterns following the announcement of the controls, and summarizes the mechanisms driving the heterogeneous changes across the target chemicals. Section 4 outlines a model that incorporates inventory and sourcing decisions, and demonstrates its ability to successfully replicate the observed heterogeneous changes in imports following the event. Section 5 explores how firms would have responded if the same export controls had been extended to other intermediates. Section 6 concludes.

2 Background

Decades-long disputes between Korea and Japan stem from a historical issue of reparations for Korean forced laborers who served under Japanese colonial occupation during World War II. Since late 2018, political tensions between Korea and Japan have escalated once more, following a ruling by the Korean Supreme Court that mandated Japanese corporations to compensate Korean victims who were coerced into labor for Japanese entities in the 1940s. Japan has vehemently opposed the Korean court's decision, claiming that the 1965 Korea-Japan treaty had already resolved Korean claims for indemnification for forced labor.

In the midst of heightened tensions, the Japanese government announced abruptly in July 2019 that it would tighten export controls on South Korea for the shipment of three chemicals—photoresist, fluorinated polyimide and hydrogen fluoride—, citing national security. The new measures require Japanese firms exporting these chemicals to South Korea to obtain government authorization for each individual shipment. In response, the Korean government immediately expressed concerns regarding the announcement, as Korean companies importing these chemicals from Japan now face uncertainty over being permitted to import from Japan. Furthermore, these chemicals are essential inputs for manufacturing semiconductors, a key industry in South Korea, and Japan is among the largest suppliers of these chemicals.

In August 2019, Japan removed South Korea, its third largest trading partner, from its "White List" of 27 preferred countries, leading South Korea to lose its status as a preferential trade partner with Japan. In retaliation, the Korean government took a similar action against Japan, and refused to renew the General Security of Military Information Agreement with Japan, a military agreement of significant importance to the United States. In September 2019, the Korean government filed a complaint with the WTO regarding Japan's export controls on three chemicals. In December 2019, Japan eased the export controls on photoresist, but the restrictions on other two chemicals had persisted. The escalating measures on both sides intensified bilateral tensions, eventually leading to a trade dispute between the two countries.

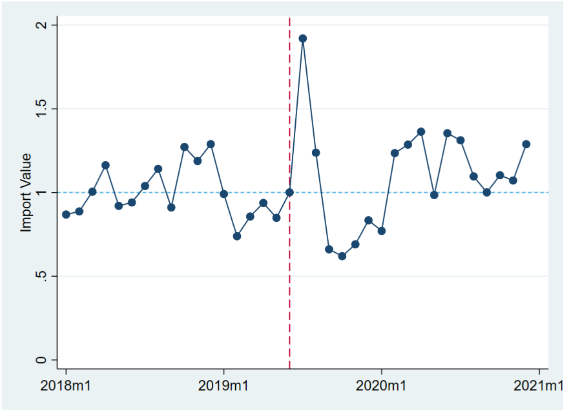
Despite the tension, for nearly four years, the Japanese government had not implemented any actual export restrictions, suggesting it was more of a coercive tactic to influence the resolution of the historical dispute in Japan's favor. In March 2023, the leaders of South Korea and Japan held their first summit in four years, agreeing to normalize trade relations to their pre-dispute status. In June 2023, the Japanese government officially lifted the export controls.

3 Heterogeneous Responses and Mechanisms

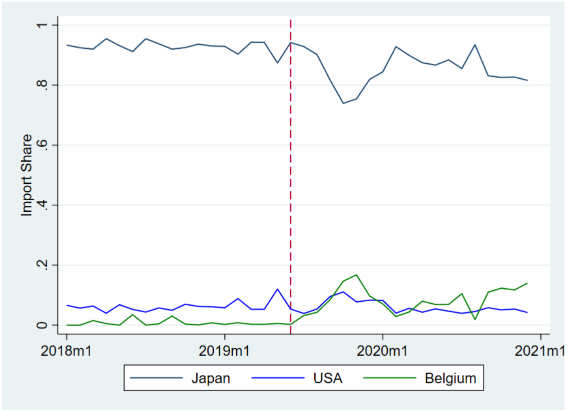
Even though Japan had not enforced any substantial export bans or restrictions, Korea's imports of the three chemicals have changed noticeably since July 2019, the onset of the dispute, and the three responses are even more heterogeneous. Figure 1 illustrates the changes in import patterns of Korea.[1] The sample period spans a total of three years from January 2018 to December 2020. The pre-shock period refers to the 18-month period preceding the event (January 2018 to June 2019), and the post-shock period refers to the 18-month period following the event (July 2019 to December 2020).

Photoresist (PR). PR imports from Japan increased sharply by 92% in July 2019, the month of the announcement, as shown in Panel A of Figure 1. However, two months later, they declined by 66% and remained at this level for six months. Then, the imports surged and stayed at the increased level for another six months. It appears that Korean semiconductor producers sourcing PR from Japan stockpiled Japanese PR in response to the export controls imposed on it. Finally, after one year, the imports returned to the pre-shock level. Panel B of Figure 1 plots Korea's monthly import share of PR from the world, including Japan. The import share from Belgium (green line in Panel B) increased by around 7% points compared to the pre-shock period, whereas the share from Japan (navy line in Panel B) decreased by around 7% points. The import share from the US (blue line in Panel B) remained the same as in the pre-shock period. It seems that Belgium PR partially replaced Japanese PR in the Korean market. However, Belgium appears to have been used as an intermediary location by Japanese exporters and Korean importers to circumvent the Japanese export controls. Panel A of Figure A2 illustrates that there were contemporaneous increases in Japan's PR exports to Belgium and Korea's PR imports from Belgium. In fact, Samsung Electronics, the largest memory

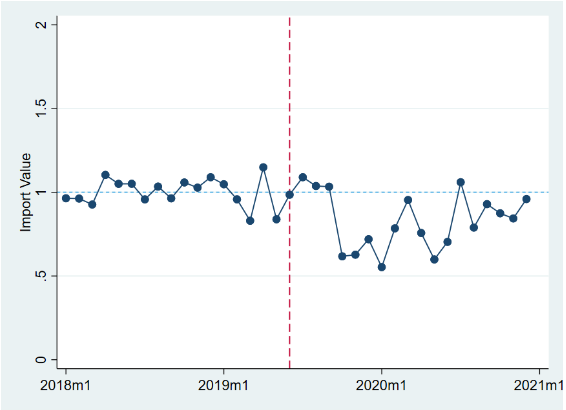
[1] Section 3 examines the import values of the three chemicals. Refer to Figure A1 for illustrations of the import quantities of these chemicals. The patterns observed in both values and quantities are almost identical, implying that changes in the import values are driven by changes in the corresponding quantities, not prices. See the Appendix A for details.



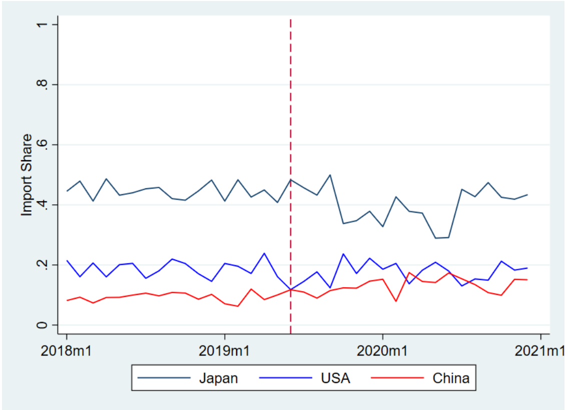
(A) PR: import from Japan



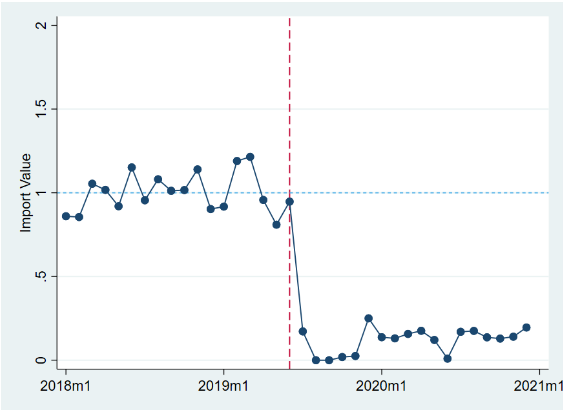
(B) PR: import share by country



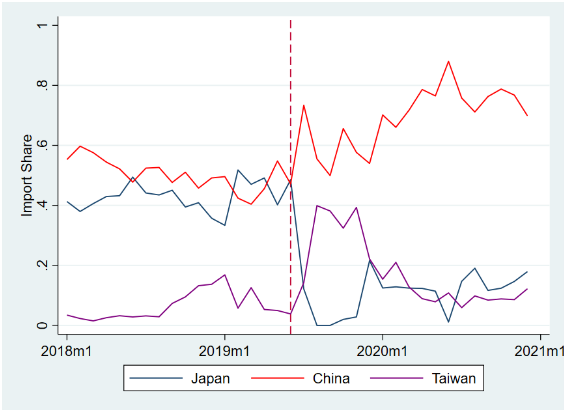
(C) FP: import from Japan



(D) FP: import share by country



(E) HF: import from Japan



(F) HF: import share by country

Figure 1: Korea's Monthly Imports

Notes: PR is classified under HSK 3707901010. FP is classified under HSK 3906909000. HF is classified under HSK 2811111000. The import values of each chemical are normalized by the average import values during the pre-shock period (18 months prior to the shock). Refer to Figure A1 for the import quantities of each target chemical.
Source: Korea Customs Service (2018-2020)

chip manufacturer in the world located in South Korea, procured six to ten months' worth of PR from a Belgium supplier that is owned by a Japanese chemical company named JSR.[2] Therefore, it should be noted that the Japanese PR was not truly replaced by Belgian PR. See the Appendix A for details.

Fluorinated Polyimide (FP). FP imports from Japan increased by approximately 5% in the three months following the announcement, but declined significantly in October and November of 2019 as shown in Panel C of Figure 1. They then rose again through March 2020. Panel D of Figure 1 reports Korea's import share of FP from its main trading partners during the sample period. The import share from Japan (navy line in Panel D) decreased by about 5% points within the 18 months after the announcement compared to the corresponding period before the event. Conversely, the import share from China (red line in Panel D) increased by roughly 4% points. The import share from the US (blue line in Panel D) remained nearly the same as before. It is suggestive that Korean firms importing FP appeared to partially substitute their imports from Japan with those from China.

Hydrogen Fluoride (HF). HF imports from Japan fell by 82% in July 2019, the month of the announcement, and have remained at this decreased level as shown in Panel E of Figure 1. Panel F of Figure 1 displays Korea's import share of HF from its three largest source countries. In the post-shock period the import share from Japan (navy line in Panel F) decreased by approximately 32% points compared to the pre-shock period. In contrast, the import share from China (red line in Panel F) and Taiwan (purple line in Panel F) increased by 20% points and 10% points, respectively. Chinese HF seems to have largely replaced Japanese HF in the Korean market. However, the import values of Chinese HF substantially decreased as Japanese HF did, as depicted in Panel C of Figure A3. The import values from China and Japan decreased by approximately 35% and 88%, respectively. See the Appendix A for details.

Then, what explains these changes despite the absence of actual restrictions? One possible explanation for these changes can be derived from the official remarks of the Deputy Prime Minister of Korea during a government meeting on the Japanese export controls (Ministry of Economy and Finance (2019)): "Although Japan has permitted imports of these three chemicals since July, Korean firms still face uncertainties as the

[2] A news article from Nikkei Asia on August 14, 2019, "Samsung Secures Key Chip Supply in Belgium as Tokyo Curbs Exports." (https://asia.nikkei.com/Spotlight/Japan-South-Korea-rift/Samsung-secures-key-chip-supply-in-Belgium-as-Tokyo-curbs-exports)

Item		(1) Pre 2018m1-2019m6	(2) Onset 2019m7	(3) Post 1 2019m7-2019m12	(4) Post 2 2019m7-2020m12	(5) Mechanism
PR	Value	1.00	1.92	0.99	1.10	Stockpiling
	Share	93.6	95.4	92.4	93.8	
FP	Value	1.00	1.09	0.85	0.83	Stockpiling,
	Share	44.6	45.7	41.4	39.9	Substitution
HF	Value	1.00	0.17	0.08	0.12	Substitution
	Share	42.8	12.1	7.0	10.9	

Table 1: Korea's Imports from Japan

Notes: PR, FP, and HF are classified under HSK 3707901010, HSK 3906909000, and HSK 2811111000, respectively. The import values of each chemical are normalized by the average import values during the pre-shock period. Each chemical's import share is calculated by dividing its imports from Japan by its total imports. In terms of the PR share, imports from Belgium are excluded due to the possibility of circumventing imports from Japan. See the Appendix A for details. Column (1) corresponds to the pre-shock period, spanning from January 2018 to June 2019. Column (2) signifies the onset of the shock, July 2019. Column (3) covers the post-shock period in 2019, from July through December 2019. Column (4) covers an extended post-shock period, from July 2019 through December 2020. Column (5) provides the distinct responses in stockpiling and substitution for the three chemicals.
Source: Korea Customs Service (2018-2020)

imports depend on Japan's arbitrary discretion."[3] These uncertainties appear to have manifested in the mechanisms of stockpiling and substitution observed in Korean semiconductor producers' importing behavior.

Mechanisms. Following the announcement of the export controls, the imports of the three chemicals—PR, FP and HF—displayed heterogeneous responses, both immediately and in subsequent 18-month thereafter. Table 1 numerically summarizes these distinct changes. Column (2) of Table 1 captures the immediate reactions following the announcement of the export controls. Korean firms seemed to stockpile PR and FP from Japan during this period, with PR imports nearly doubling and FP imports increasing by about 10%. Conversely, HF imports from Japan decreased significantly, plummeting by over 80%, indicating a swift shift to alternative sources. Turning to the subsequent 18 months, as detailed in Column (4) of Table 1, Japanese FP and HF saw a decrease in import shares by about 5% points and 32% points, respectively, while PR's share remained stable. In summary, the mechanisms at play were stockpiling for PR, a short-

[3] A press release from the Ministry of Economy and Finance of Korea on August 14, 2019, "Results of the second public-private meeting on the Japanese export controls."

term stockpiling followed by long-term substitution for FP, and substitution for HF. The stockpiling mechanism arose from the uncertainty about permissions to import from Japan. The substitution mechanism is driven by the rise in importing costs due to the more complicated export process following the announcement of the export controls.

4 Model: Inventorying and Sourcing

In this section, using a model featuring inventorying and sourcing decisions I investigate two different mechanisms—stockpiling and substitution—behind the heterogeneous changes in import patterns due to the export controls announcement. The model builds on Alessandria et al. (2010) and Carreras-Valle (2021).

4.1 Environment

I consider a partial equilibrium problem for a monopolistically competitive firm that produces a final product, q, by combining two foreign intermediates: q_J from Japan and q_O from another country. The production function for this firm is given by:

$$q = \left[\theta^{\frac{1}{\rho}} q_J^{\frac{\rho-1}{\rho}} + (1-\theta)^{\frac{1}{\rho}} q_O^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}} \tag{1}$$

In this function, the foreign inputs are combined using a constant elasticity of substitution, ρ, with a weight, θ. The cost of importing from country i is $(1+\tau_i)\omega_i$, where τ_i is a tariff applied when importing from country i, and ω_i represents non-tariff barriers, such as administrative procedures and regulatory measures, incurred when importing from country i.

The firm faces a one-period delivery leg, meaning that the amount the firm imports today, m_i, cannot be used for production until the next period. Instead of awaiting the imports in transit, the firm uses its current inventory of foreign inputs, s_i, for production, which constrains the inputs used for production, q_i, to not exceed the inventory levels for each input: $s_i \geq q_i$. Both the current inventory of foreign inputs, s_i, and the imported inputs in transit, m_i, depreciate at a rate of $(1-\delta)$. Hence, the law of motion for each input inventory is given by the remainder of the input left after production, $s_i - q_i$, and the amount of the imports, m_i, both of which are discounted at the depreciation rate:

$$s_i' = (1-\delta)[s_i - q_i + m_i] \tag{2}$$

The firm faces a demand function with a constant elasticity, σ_d, and a demand shock, ν. Let p denote the domestic price charged by the firm. The demand function takes the following form:

$$q = e^{\nu} p^{-\sigma_d}, \quad \text{where} \quad \nu \sim^{iid} N(0, \sigma_\nu^2) \tag{3}$$

The demand shock ν follows an independent and identically distributed normal distribution.

Firm's problem. The firm makes decisions on from where and how much to import intermediates, based on the anticipation that imports will be permitted in the next period. The firm's problem can be represented as a dynamic optimization problem, as follows:

$$V(s_J, s_O, \nu) = \max_{q_J, q_O, m_J, m_O} pq(s_J, s_O, \nu) - (1+\tau_J)\omega_J m_J - (1+\tau_O)\omega_O m_O + \beta EV\left[s'_J, s'_O, \nu'\right] \tag{4}$$

The maximization problem is subject to the six constraints described above: the production technology (equation (1)); the usage constraints for each of the two foreign inputs ($s_i \geq q_i$); the law of motions for each of the two inputs' inventory (equation (2)); and the demand function (equation (3)).

The problem is defined by the value function, $V(s_J, s_O, \nu)$; the firm determines the quantity of each input used for production, q_J and q_O, and the import quantity of each input, m_J and m_O, to maximize present and future profits. These decisions are made given each input's current inventory level, s_J and s_O, and current demand shock, ν, and the expectation over the possible demand shocks in future periods, ν'. The firm's present profits consist of the sales revenue from the final good, $pq(s_J, s_O, \nu)$, subtracting the importing costs from each source, $(1+\tau_i)\omega_i m_i$.

Trade policy shock. I introduce a trade policy shock to this problem to reflect the characteristics of the Korea-Japan dispute event. The shock consists of two features: 1) the probability of denial of import from Japan ($m_J = 0$), and 2) an increase in non-tariff barriers when importing from Japan ($\omega_{J,pre} < \omega_{J,post}$). As for the first feature, Korean importing firms have indeed been concerned about the possibility of denied imports from Japan, as the permission has been granted at the discretion of Japanese officials since the announcement of the export controls. The second feature addresses the increased complexity that Korean firms have faced when importing from Japan, such as additional documentation requirements. Thus, in the post-shock period, a new state variable is added to the value function to indicate if imports from Japan are allowed (a)

or banned (b), as shown below:

$$V(s_J, s_O, \nu, a) = \max_{q_J, q_O, m_J, m_O} pq(s_J, s_O, \nu) - (1+\tau_J)\omega_{J,post} m_J - (1+\tau_O)\omega_O m_O + \beta\Big[\pi(a|a) EV(s'_J, s'_O, \nu', a) + \pi(b|a) EV(s'_J, s'_O, \nu', b)\Big] \quad (5)$$

$$V(s_J, s_O, \nu, b) = \max_{q_J, q_O, m_O} \quad pq(s_J, s_O, \nu) - (1+\tau_O)\omega_O m_O + \beta\Big[\pi(a|b) EV(s'_J, s'_O, \nu', a) + \pi(b|b) EV(s'_J, s'_O, \nu', b)\Big] \quad (6)$$

This maximization problem in the post-shock period is also subject to the same six constraints as in the pre-shock period: the production technology (equation (1)); the usage constraints for each of the two foreign inputs ($s_i \geq q_i$); the laws of motion of each of the two inputs' inventory (equation (2)); and the demand function (equation (3)). Note that if the firm starts with state a, it is allowed to import from Japan in the current period, albeit with increased non-tariff barriers level, $\omega_{J,post}$. Conversely, if the firm begins with state b, it is banned from importing from Japan, resulting in $m_J = 0$. Given either state a or b in the current period, the state will change to either a or b in the next period according to the transition probability $\pi(\cdot|\cdot)$. However, since the Japanese government has not imposed any restrictions or bans on exports to Korea, the firm in the model always starts with state a in every period, signifying that imports from Japan are permitted. Nonetheless, the firm continues to face uncertainty regarding the future approval of imports in all forthcoming periods until the Japanese government lifts the export controls. Hence, the firm's problem in every post-shock period consistently follows the form of equation (5).

Before moving onto the calibration section, it is essential to emphasize how the model works in response to the shock, specifically whether the firm decides to stockpile or substitute the Japanese input. This allows us to clearly identify which parameters play a key role in these two mechanisms. The first feature of the shock—the probability of denial of import from Japan—encourages the firm to stockpile more the Japanese input than usual, as there is a concern that imports from Japan may be denied. The second feature of the shock—an increase in non-tariff barriers—pushes the firm to substitute away from the Japanese input as the importing costs have increased. Since these two features influence the import patterns in opposite directions, the firm's decision to either stockpile or substitute the Japanese input depends on the probability of denial of import from Japan, $\pi(b|a)$, and its three characteristics: i) the extent to which its non-tariff barriers have increased, represented by $\omega_{J,post}$ in equation (5); ii) the initial share, represented by θ in equation (1); and iii) the elasticity of substitution, represented by ρ in equation (1).

4.2 Calibration

In this section, I calibrate the key parameters related to the firm's decision to either stockpile or substitute the Japanese input, using data and literature.

Non-tariff barriers. The calibration of the increase in non-tariff barriers, represented by the shift from $\omega_{J,pre}$ to $\omega_{J,post}$, leverages the information from the US-Korea Free Trade Agreement (FTA), a prior event that induced such a change. The FTA came into effect in 2012, leading to a decrease in not only tariffs but also non-tariff barriers on imports from the US. As a result, the US share in Korea's imports increased. Using the aforementioned model and Korea's tariff schedule for imports from the US, I calibrate the decreases in non-tariff barriers on US imports, represented by the shift from $\omega_{U,pre}$ to $\omega_{U,post}$. For each chemical, the matching moment is the observed increase in the US share in the Korean imports between 2010 and 2014, two years before and after the enactment of the FTA. With an emphasis on leveraging pre-shock data, identifying an event impacting non-tariff barriers, and referencing an event involving a major trade partner of Korea, I make an assumption: the magnitude of the change in non-tariff barriers for Japanese imports, ω_J, is equivalent to that for US imports, ω_U. This can be expressed as:

$$\frac{|\omega_{U,pre} - \omega_{U,post}|}{\omega_{U,pre}} = \frac{|\omega_{J,pre} - \omega_{J,post}|}{\omega_{J,pre}}$$

The pre-level of non tariff barriers for each country, $\omega_{U,pre}$ and $\omega_{J,pre}$, is normalized to 1. The calibration results for each chemical are presented in Panel A, B, and C of Table 2 below. Note that for the baseline simulations, the calibrated level of non-tariff barriers is heterogeneous across the targeted chemicals to reflect heterogeneous changes in share after the enactment of the FTA. I also incorporate a homogeneous level of non-tariff barriers across these chemicals, the average of three different calibrated non-tariff barriers, for the robustness checks.

Weight and standard deviation of demand shocks. The weight in the production function (equation (1)), denoted as θ, is another key parameter to be calibrated. The weight captures the relative share of an input sourced from Japan compared to that from another country. For each targeted chemical, θ is calibrated to align with Japan's share in the Korean import markets during the pre-shock period from January 2018 to June 2019.

Similarly, the standard deviation of demand shocks, σ_ν, is calibrated for each chemical to match the corresponding standard deviation of the total imports in Korea during the same period. The calibration results for each chemical are presented in Panel A, B, and C of Table 2 below.

Elasticity of substitution. The elasticity of substitution between foreign sources, ρ, for the three targeted chemicals—photoresist (PR), fluorinated polyimide (FP), and hydrogen fluoride (HF)—follows the findings from Broda and Weinstein (2006). They estimated almost 14,000 elasticities of items based on 10-digit Harmonized System Code using trade data for 1990-2001. I use their estimated elasticities for the targeted chemicals in the simulations, as shown in Panel A, B, and C of Table 2 below.[4] Note that for the baseline simulations, the elasticity of substitution is heterogeneous across the targeted chemicals following Broda and Weinstein (2006). I also incorporate a homogeneous elasticity across these chemicals, the average of three different elasticities, for the robustness checks.

Other parameters. The remaining parameters, which include the depreciation rate, δ, the demand elasticity, σ_d, and the time discount factor, β, are common across the targeted chemicals. They are assigned values consistent with the related literature. The bi-weekly depreciation rate, δ, is set to 0.013, in line with the values suggested in inventory model literature such as Alessandria et al. (2010) and Carreras-Valle (2021).[5] The demand elasticity for a firm's final product, represented by σ_d, is set to 1.5, a commonly accepted value in the international business cycle literature. Lastly, the bi-weekly time discount factor, β, is set to $0.99^{(1/24)}$ to reflect the Korean annual real interest rate between 2018 and 2020, which was around 1%.[6] The calibration results are presented in Panel D of Table 2.

Probability of import denial. The last key variable influencing a firm's decision to either stockpile or substitute the Japanese input is the probability of import denial from

[4]In this study, PR, FP, and HF are categorized based on the Korean classification system, HSK 3707901010, HSK 3906909000, and HSK 2811111000, respectively. However, Broda and Weinstein (2006) classified items according to the U.S. system, HTS. Hence, the estimates used for PR, FP, and HF correspond to HTS 3707903000, HTS 3906905000, and HTS 2811110000, respectively. This is feasible because the first six digits of the classification codes are identical in both the HSK and HTS systems, allowing for cross-referencing in international trade data.

[5]The delivery time from placing an import order to receiving the inputs is set to two weeks, given that the majority of these chemicals are shipped by air and Korea is geographically close to its source countries.

[6]Refer to the previous footnote for the same reasoning.

Panel A. Photoresist (PR)

Calibrated parameter		Value	Moment	Data	Model
Non-tariff barriers	$\omega_{U,post}$	0.92	US Share in 2010	0.035	0.035
	$\omega_{J,post}$	1.08	US Share in 2014	0.047	0.047
Weight	θ	0.95	JPN share in pre-shock period	0.94	0.94
S.D. of demand shocks	σ_v	0.27	S.D. of total imports in pre-period	0.15	0.15
Predetermined parameter		**Value**	**Source**		
Elasticity of substitution	ρ	2.16	Broda and Weinstein (2006)		

Panel B. Fluorinated Polyimide (FP)

Calibrated parameter		Value	Moment	Data	Model
Non-tariff barriers	$\omega_{U,post}$	0.88	US Share in 2010	0.094	0.094
	$\omega_{J,post}$	1.12	US Share in 2014	0.177	0.177
Weight	θ	0.54	JPN share in pre-shock period	0.45	0.45
S.D. of demand shocks	σ_v	0.18	S.D. of total imports in pre-period	0.09	0.09
Predetermined parameter		**Value**	**Source**		
Elasticity of substitution	ρ	3.61	Broda and Weinstein (2006)		

Panel C. Hydrogen Fluoride (HF)

Calibrated parameter		Value	Moment	Data	Model
Non-tariff barriers	$\omega_{U,post}$	0.80	US Share in 2010	0.001	0.001
	$\omega_{J,post}$	1.20	US Share in 2014	0.005	0.005
Weight	θ	0.49	JPN share in pre-shock period	0.43	0.43
S.D. of demand shocks	σ_v	0.20	S.D. of total imports in pre period	0.11	0.11
Predetermined parameter		**Value**	**Source**		
Elasticity of substitution	ρ	5.12	Broda and Weinstein (2006)		

Panel D. Common Parameters

Calibrated parameter		Value	Moment	Data	Model
Probability of import denial	α_0	-1.804	Sum of % differences in share	2.50	2.37
	α_1	0.226	and s.d. changes post-shock		
Predetermined parameter		**Value**	**Source**		
Depreciation rate	δ	0.013	Alessandria et al. (2010) and Carreras-Valle (2021)		
Demand elasticity	σ_d	1.50	Alessandria et al. (2010) and Carreras-Valle (2021)		
Interest rate	β	$0.99^{1/24}$	Bank of Korea		

Table 2: Baseline Calibration

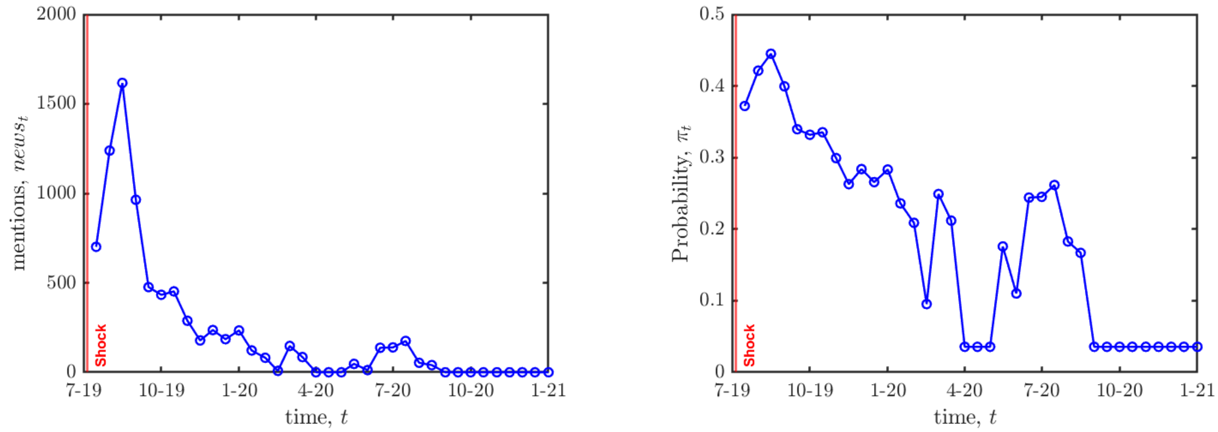
Notes: $\omega_{U,post}$ for each chemical is calibrated to match the changes in the US share in Korean imports before and after the US-Korea FTA enactment. It is assumed that $\omega_{J,post}$ increased by the same degree as $\omega_{U,post}$, thus calibrating accordingly. Both $\omega_{U,pre}$ and $\omega_{J,pre}$ are normalized to 1. The bi-weekly setting for both δ and β reflects the typical two-week delivery time due to air shipment and Korea's geographical proximity to its source countries.

Japan, $\pi(b|a)$. Since the shock occurred, firms have been faced with the probability, which motivates them to stockpile Japanese inputs more than usual before the export controls are realized. However, the challenge lies in the fact that the probability perceived by the firms is unobservable. To address this, I parameterize the probability using the number of news articles that mention the Korea-Japan dispute as follows:

$$\pi_t = \Phi\Big(\alpha_0 + \alpha_1 \times log(news_t + 1)\Big) \tag{7}$$

$news_t$ represents the number of news articles mentioning the dispute at time t after the shock happened. α_0 and α_1 are parameters to be calibrated, where α_0 sets the baseline level of the probability when $news_t = 0$, and α_1 scales the impact of $news_t$ on the probability. $\Phi(\cdot)$ is the cumulative distribution function of the normal distribution. Thus, the probability, π_t, is a linear function of the number of news articles, $news_t$, transformed by $\Phi(\cdot)$ to fall within the range [0,1]. α_0 and α_1 are calibrated to match the post-shock data; I select six moments in total, with two distinct moments for each of the targeted chemicals. The first moment is change in Japan's share in Korea's imports by each targeted chemical, assessed by comparing the periods before and after the shock. The second moment is change in the standard deviation of Korea's imports by each targeted chemical, determined by comparing before and after the shock. The calibration of α_0 and α_1 is performed such that the sum of the percentage differences between each moment generated by the model and its corresponding moment in the observed data is minimized. This procedure ensures an accurate estimation of the probability of import denial across the targeted chemicals. Note that π_t is the only parameter calibrated on post-shock data, while the other parameters, as previously shown, are calibrated on pre-shock data. Moreover, the same π_t is used for all three targeted chemicals in the simulations, indicating a homogeneous calibrated probability of the export controls across these chemicals in each period.

The calibration results are presented in Panel D of Table 2, and illustrated in Figure 2. The highest probability of import denial, standing at 0.4450, occurs in the first half of August 2019, a month after the announcement of the export controls. This corresponds to the peak in news mentions with 1,617 articles. A gradual decline from this peak is observed in the calibrated probabilities, reflecting the dispute's dwindling presence in the media, which in turn influenced firms' perception of import denial risk. The lowest probability, 0.0356, is noted during the periods with zero news mentions of the Korea-Japan dispute, from mid-August 2020 to the end of 2020. This positive value, albeit low, is plausible given that the Japanese government had not lifted its export controls yet,



(A) Number of News Articles

(B) Calibrated Probability π_t

Figure 2: Calibration of Probability of Import Denial

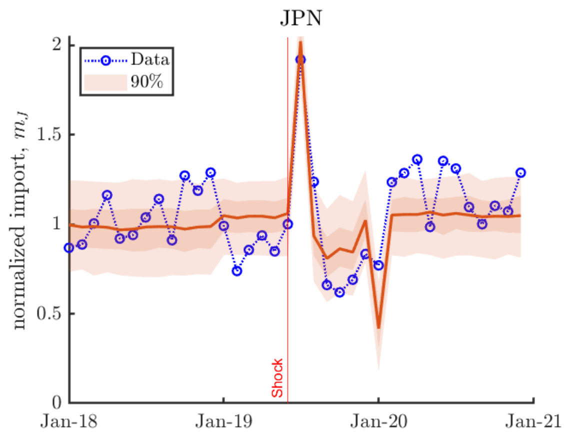
Notes: The x-axis interval represents a two-week period, which corresponds to the model's length of a period and shipping lag.
Source: News Based Statistics Search from Statistics Korea (2019-2020)

suggesting that the firms still perceived, although extremely small, risk of import denial. Moreover, from the perspective of the model, this value is merely around 3%, thereby not acting as a significant driver of changes in the firms' responses. The detailed calibration results are presented in Table A1. See the Appendix B for details.

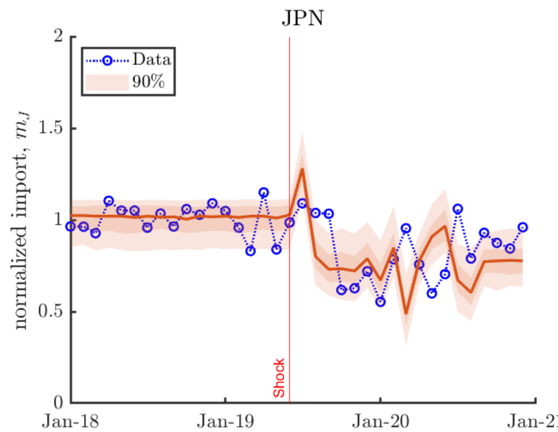
4.3 Simulation Results

For each targeted chemical, I perform 500 separate simulations, incorporating a random demand shock into the model in every period, using the calibrated parameters. This demand shock, as presented in equation (3), follows an independent and identically distributed normal distribution. Thus, each simulation enables us to observe the trade policy shock's effects under varying demand conditions. The simulation results align well with the observed data, demonstrating consistency not only with the heterogeneous shifts in shares of the three targeted chemicals after the shock, but also with the heterogeneous responses of these three chemicals at the onset of the event. These results are both illustrated in Figure 3 and tabulated in Table 3, which compare the model-generated outcomes with the observed data.

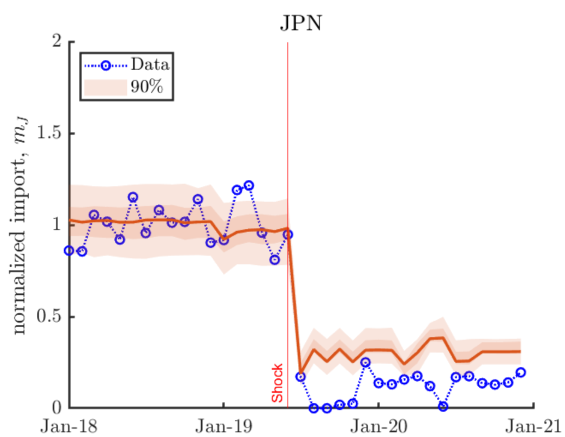
Photoresist (PR). The results successfully capture two distinct patterns for PR observed in the data as described in Section 3: i) a two-fold increase in the import values in July 2019, the month when the event started, and ii) a slight increase in Japan's share in the



(A) PR



(B) FP



(C) HF

Figure 3: Results of Baseline Simulations

Notes: For each targeted chemical, 500 simulations are conducted, each incorporating a random demand shock into the model in every period, using the calibrated parameters. The y-axis represents import values of each chemical, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. Note that unlike the other two chemicals, the shock to photoresist has dissipated since January 2020 to reflect the fact that Japan eased the export controls on photoresist at the end of December 2019. For the results of simulations for another source, see Figure A4 in the Appendix C.
Source: Korea Customs Service (2018-2020)

Korean imports during post-shock period (18 months after the shock). In Panel A of Figure 3, the blue dotted line represents the PR data, while the red solid line signifies the mean of the PR simulations. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. In July 2019, the month of the export controls announcement, the simulations also peak, mirroring approximately twice the value compared to the pre-shock period, similar to the observed data. Furthermore, the majority of the observed data (indicated by the blue line in Panel A) lie within the distribution bands, suggesting that the simulations can successfully replicate the patterns of the observed data. These patterns are also well-documented in Panel A of Table 3, where the right side of each column represents the mean of the simulations. Notably, the model also exhibits the increase in Japan's share in Korean imports of photoresist during the post-shock period. This is evident in Table 3, Panel A, Column (4), where both the mean of the simulations and the observed data show an identical value of 94.0% for Japan's share. In sum, the PR simulations through the calibrated model depict the underlying stockpiling mechanisms exhibited by Korean importing firms, responsible for the observed changes in PR imports in response to the Japanese export controls.

Fluorinated Polyimide (FP). The results successfully capture two distinct patterns for FP observed in the data, as described in Section 3. Firstly, the import values modestly increased in July 2019, the month when the vent started, followed by a decrease for the remainder of the post-shock period in 2019 (from July through December). Secondly, there was a decline exceeding 5% points in Japan's share of the Korean imports during the 18-month post-shock period. In Panel B of Figure 3, the blue dotted line represents the FP data, while the red solid line signifies the mean of the FP simulations. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. In July 2019, the month of the announcement, the simulations show a 29% increase, followed by a decline that persists for the rest of 2019, mirroring the observed data. Moreover, the majority of the observed data (indicated by the blue line in Panel B) lies within the distribution bands, suggesting that the model accurately replicates the observed data patterns. These patterns are also well-documented in Panel B of Table 3, where the right side of each column represents the mean of the simulations. The simulations also capture a modest decline in Japan's share in the Korean imports during the post-shock period, 18 months after the shock. This is evident in Table 3, Panel B, Column (4), where both the mean of the simulations and the observed data demonstrate a decline in Japan's share by approximately 8% points

	(1) Pre (2018m1-2019m6)		(2) Onset (2019m7)		(3) Post 1 (2019m7-2019m12)		(4) Post 2 (2019m7-2020m12)	
	Data	Model	Data	Model	Data	Model	Data	Model
Panel A. PR								
Value	1.00	1.00	1.92	2.02	0.99	1.09	1.10	1.03
Share	93.8	93.8	96.0	96.8	92.6	94.2	94.0	94.0
Panel B. FP								
Value	1.00	1.00	1.09	1.29	0.85	0.85	0.83	0.79
Share	44.6	44.9	45.7	47.5	41.4	38.1	39.9	36.3
Panel C. HF								
Value	1.00	1.00	0.17	0.20	0.08	0.29	0.12	0.31
Share	42.8	42.7	12.1	18.8	7.0	22.4	10.9	23.0

Table 3: Results of Baseline Simulations

Notes: For each column, the left and right sides represent the observed data and the mean of simulations, respectively. The import values of each chemical are normalized by the average import values during the pre-shock period. Each chemical's import share is calculated by dividing its imports from Japan by its total imports. Column (1) corresponds to the pre-shock period, spanning from January 2018 to June 2019, a total of 18 months before the shock. Column (2) signifies the onset of the shock, July 2019. Column (3) covers the post-shock period in 2019, starting from July and ending in December 2019, effectively six months after the shock. Lastly, Column (4) covers an extended post-shock period, from July 2019 through December 2020, comprising 18 months subsequent to the shock.
Source: Korea Customs Service (2018-2020)

and 5% points, respectively. In sum, the FP simulations performed using the calibrated model effectively illustrate that two different mechanisms are at play simultaneously in the response of Korean importing firms to the Japanese export controls: i) stockpiling of Japanese FP in July 2019, the month of the announcement, albeit to a lesser extent than PR, and ii) a gradual partial substitution away from Japanese FP over the course of 18 months following the shock.

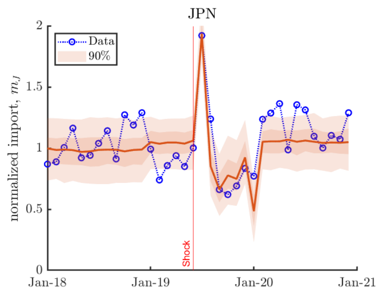
Hydrogen Fluoride (HF). The results successfully capture two distinct patterns for HF observed in the data, as described in Section 3. Firstly, there is a considerable decline in the import values in July 2019, the month when the event started. Secondly, this decreased level persists throughout the 18-month post-shock period following the shock. In Panel C of Figure 3, the blue dotted line represents the HF data, while the red solid line signifies the mean of the HF simulations. The dark red shaded area and the light red shaded area display the 50% and 90% distribution bands of the simulations, respectively.

In July 2019, the month of the export controls announcement, the simulations show a notable drop, reflecting approximately an 80% decrease compared to the pre-shock period, similar to the observed data. The simulations also successfully replicate the patterns observed in the data, exhibiting persistent declines in imports from Japan over the rest of the event period, though to a slightly lesser extent than the data. These patterns are also well-documented in Panel C of Table 3, where the right side of each column represents the mean of the simulations. In Column (4), both the mean of the simulations and the observed data display a decrease in Japan's share by approximately 20% points and 30% points, respectively. In sum, the HF simulations performed using the calibrated model effectively illustrate the rapid substitution mechanisms exerted by Korean importing firms in response to the export controls. This response is observed both in the short and long term, leading to significant and continued decreases in Japan's share in the Korean markets following the announcement of the export controls.

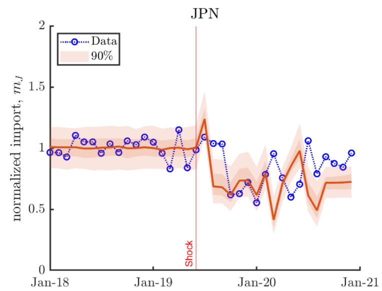
4.4 Robustness

In this section, I examine the robustness of the baseline results to incorporating homogeneity across the three targeted chemicals. In Section 4.3, heterogeneity is introduced across the chemicals in terms of both the increase in non-tariff barriers following the export controls (transitioning from $\omega_{J,pre}$ to $\omega_{J,post}$) and the elasticity of substitution, ρ. This is done to align with observed changes in each chemical's share from 2010 to 2014 after the implementation of the US-Korea FTA, and to adhere to the estimates from Broda and Weinstein (2006). The results remain robust, despite assuming homogeneity across the chemicals, suggesting the model successfully illustrates the response mechanisms to the imposition of the export controls.

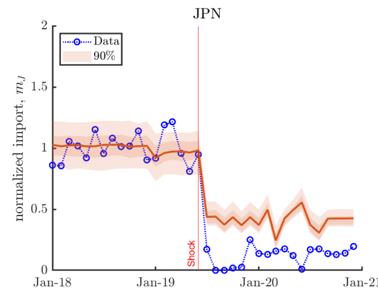
Case 1: Homogeneity in non-tariff barriers. This case incorporates homogeneity in non-tariff barriers across the three targeted chemicals. Specifically, the post-shock non-tariff barrier level for all chemicals, $\omega_{J,post}$, is set to 1.13, the average of the values used in the baseline simulations. Heterogeneity in the elasticity of substitution, ρ, across chemicals remains as in the baseline. All other parameters are calibrated in line with the baseline. For PR, the model still captures two distinct patterns. As depicted in Panel 1A of Figure 4, a significant surge in the simulations occurs in July 2019, the month of the export control announcement. Table 4, Panel A, Column (1) shows a slight rise in Japan's share in Korean PR imports during the post-shock period; the model's mean is 93.8%, closely matching the actual figure of 94.0%. For FP, two distinct patterns in the data are



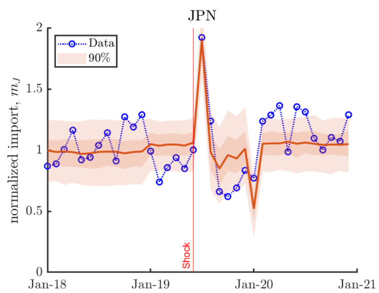
(1A) PR



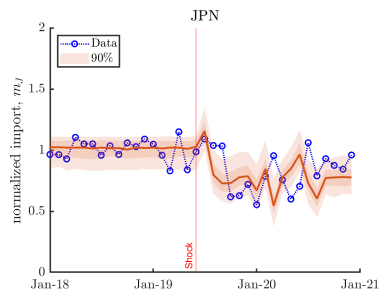
(1B) FP



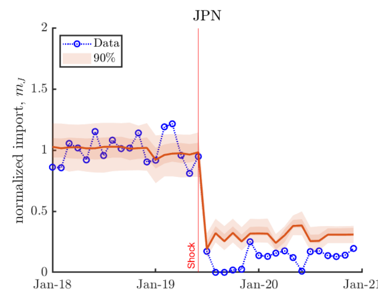
(1C) HF



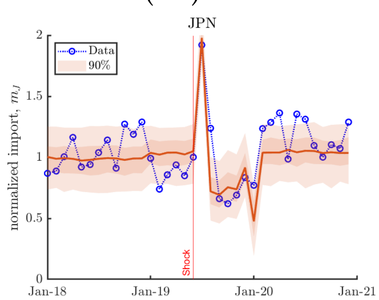
(2A) PR



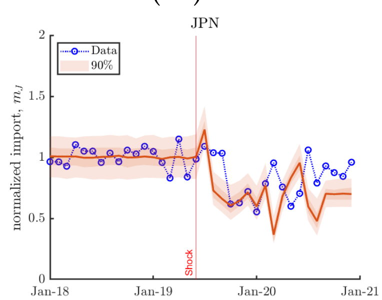
(2B) FP



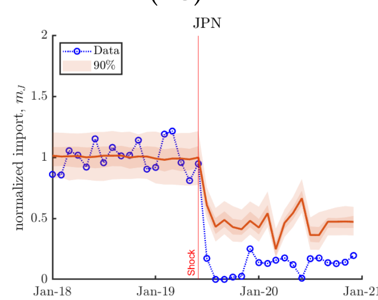
(2C) HF



(3A) PR



(3B) FP



(3C) HF

Figure 4: Robustness of the Baseline Results

Notes: For each panel, 500 simulations are conducted, incorporating a random demand shock into the model in every period. The y-axis represents import values from Japan, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. The first, second, and third set of panels correspond to the results of Case 1—homogeneity in non-tariff barriers, Case 2—homogeneity in elasticity of substitution, and Case 3—homogeneity in both non-tariff barriers and elasticity of substitution, respectively. Note that unlike the other two chemicals, the shock to photoresist has dissipated since January 2020 to reflect the fact that Japan eased the export controls on photoresist at the end of December 2019. For the results of simulations for another source, see Figure A5 in the Appendix D.
Source: Korea Customs Service (2018-2020)

	(1) Case 1	(2) Case 2	(3) Case 3	(4) Baseline	(5) Data
Panel A. PR					
Parameters					
Non-tariff barriers, $\omega_{J,post}$	1.13	1.02	1.14	1.08	-
Elasticity of sub., ρ	2.16	3.63	3.63	2.16	-
Results					
Value in July 2019	1.94	1.89	1.98	2.02	1.92
Share in post period	93.8	94.2	93.4	94.0	94.0
Panel B. FP					
Parameters					
Non-tariff barriers, $\omega_{J,post}$	1.13	1.12	1.14	1.12	-
Elasticity of sub., ρ	3.61	3.63	3.63	3.61	-
Results					
Value in July 2019	1.25	1.16	1.23	1.29	1.09
Share in post period	34.6	36.3	33.4	36.3	39.9
Panel C. HF					
Parameters					
Non-tariff barriers, $\omega_{J,post}$	1.13	1.28	1.14	1.20	-
Elasticity of sub., ρ	5.12	3.63	3.63	5.12	-
Results					
Value in July 2019	0.44	0.21	0.61	0.20	0.17
Share in post period	28.2	23.1	32.6	23.0	10.9

Table 4: Robustness of the Baseline Results

Notes: Columns (1), (2), and (3) represent the parameter values utilized and the results from Case 1 (homogeneity in non-tariff barriers), Case 2 (homogeneity in elasticity of substitution), and Case 3 (homogeneity in both non-tariff barriers and elasticity of substitution), respectively. Columns (4) and (5) correspond to the baseline simulations and the actual data, respectively. The 'Results' part displays the respective outcomes for each case, which include 'Value in July 2019' and 'Share in post period.' 'Value in July 2019' corresponds to the average of the simulated import values from Japan in July 2019, the month of the export controls announcement. 'Share in post period' signifies the average of Japan's import share, computed from the simulations, during the post-shock period that spans from July 2019 to December 2020.
Source: Korea Customs Service (2018-2020)

still replicated. As displayed in Panel 1B of Figure 4, the import values peak slightly, followed by a decreases for the remainder of 2019. Table 4, Panel B, Column (1) shows a decline in Japan's share in Korean FP imports during the post-shock period, albeit to a greater extent than the baseline and the data in Columns (4) and (5). For HF, the results align with the baseline. As illustrated in Panel 1C of Figure 4, there is a noticeable decrease in the import values in July 2019, followed by persistent declines throughout the entire post-shock period. However, as shown in Table 4, Panel C, Column (1), the extent of the decrease is slightly less pronounced than in the baseline and the data for both the value in July 2019 and the post-shock share.

Case 2: Homogeneity in elasticity of substitution. This case introduces homogeneity in the elasticity of substitution across the three targeted chemicals. Specifically, the elasticity of substitution for all chemicals, ρ, is set to 3.63, the average of the values used in the baseline simulations. Heterogeneity in the non-tariff barriers, $\omega_{J,post}$, across chemicals remains as in the baseline. All other parameters are calibrated in accordance with the baseline. For PR, the results represents two key features as in the observed data. As depicted in Panel 2A of Figure 4, a significant spike in the simulations occurs in July 2019. Table 4, Panel A, Column (2), also shows an increase in Japan's share of Korean PR imports during the post-shock period, with the model's mean at 94.2%, closely matching the actual data of 94.0%. For FP, the results replicate two distinct patterns in the data. As displayed in Panel 2B of Figure 4, the import values surge slightly, followed by a decrease throughout 2019. Table 4, Panel B, Column (2) reflects a decline in Japan's share of Korean FP imports during the post-shock period, which is identical to the baseline, 36.3%. For HF, the results closely align with the baseline. Panel 2C of Figure 4 depicts a sharp decrease in import values in July 2019, persisting throughout the post-shock period. As shown in Table 4, Panel C, Column (2), Japan's share decreases by approximately 20%, identical to the baseline results.

Case 3: Homogeneity in both non-tariff barriers and elasticity of substitution. This case assumes homogeneity in both non-tariff barriers and the elasticity of substitution across the three targeted chemicals. Specifically, for all chemicals, the post-shock non-tariff barriers, $\omega_{J,post}$, and the elasticity of substitution, ρ, are set to 1.14 and 3.63, respectively, reflecting the averages of the values used in the baseline simulations. Thus, heterogeneity across chemicals is retained only in their weight, θ, and the standard deviation of their demand shocks, σ_v. For PR, as illustrated in Panel 3A of Figure 4, the results indicate a noticeable spike in the import values in July 2019. However, as shown in Table 4, Panel A, Column (3), a decrease in Japan's share of Korean PR imports is observed during the post-shock period, with the model's share falling from 93.8% to 93.4%, whereas the data shows a rise from 93.8% to 94.0%. This suggests that, in this case of homogeneity across chemicals, PR importing firms initially respond to the shock by stockpiling Japanese PR. Over a longer period, they begin to substitute Japanese PR, albeit with a slight extent. For FP, the model continues to reflect two distinct patterns observed in the data. As exhibited in Panel 3B of Figure 4, there is a minor surge in the import values, followed by a decline throughout 2019. Table 4, Panel B, Column (3) presents a decrease in Japan's share of Korean FP imports during the post-shock period, though a greater extent than both the baseline and the data displayed in Columns (4) and (5). For HF, the results still capture two distinct patterns observed in the data, albeit a lesser extent than the baseline. Panel 3C of Figure 4 illustrates a substantial decrease in the import values in July 2019, a trend that persists throughout the post-shock period. Table 4, Panel C, Column (3) also presents a decrease in Japan's share, by approximately 10%.

5 Scenario: Export Control Extensions

In this section, I investigate the hypothetical scenario where the Japanese government had extended export controls to other intermediates essential for semiconductor production. This analysis aims to provide policy implications to the Korean government, enabling a proactive response to any potential broadening of export controls. Understanding how Korean producers might response allows the government to strategize ways to mitigate negative repercussions.

Potential targets selection. I select potential target intermediates using two primary sources from the Korean Customs Service. Firstly, I employ the HS-Korea classification, specifically focusing on items whose descriptions include "for making semiconductors." Secondly, I refer to the "Semiconductor HS-Korea Standard Interpretation Guidelines (Korea Customs Service (2023))," which provides guidance on classifying materials, parts, and equipment used in manufacturing semiconductors based on the HS-Korea classification. Given that the targeted intermediates—photoresist, fluorinated polyimide, and hydrogen fluoride—are chemicals, my selection concentrate on chemical intermediates for semiconductor production. Specifically, I select items in these sources with HS codes starting from HS28 to HS39, as these codes correspond to chemicals. In total, 12 potential target chemicals are identified. See the Appendix E for the detailed process and the full list.

Calibration. I use the same model that incorporates inventorying and sourcing decisions, as described in Section 4, to explore the hypothetical scenario where the export controls had been imposed on the potential target chemicals. I refrain from recalibrating parameters associated with non-tariff barriers, elasticity of substitution, and probability of import denial for each potential target. Therefore, I adopt the calibrated parameter values from Case 3 in Section 4.4, where homogeneity is applied across all items. Heterogeneity across potential targets only lies in their weight to reflect the relative Japanese share for each chemical, and the standard deviation of their demand shocks, consistent with Case 3 in Section 4.4. See Table A3 in the Appendix E for the detailed calibration results.

Simulation results. For each of the potential targets, I conduct 500 separate simulations, integrating a random demand shock in every period to observe the effect of the hypothetical shock under varying demand conditions. In July 2019, the onset of the event, six out of the twelve potential targets exhibit an increase in import values by more than 50% compared to their pre-dispute levels, as detailed in Column (2) of Table 5. This trend mirrors that of photoresist, which was actually targeted by the Japanese government. Compared to these six, the other four items of the potential targets display a substantially smaller increase in imports, which aligns closely with the pattern observed in fluorinated polyimide, one of the actual targeted chemicals. The remaining two items show a trend similar to hydrogen fluoride, indicating a decline in the initial phase of the dispute. Additionally, Column (3) of Table 5 depicts Japan's share in each chemical's import during the post-event period from July 2019 to December 2020. The six items that mirrored the sharp rise of photoresist at the onset of the event exhibit less than a 5% point decrease in Japan's share relative to their pre-dispute levels. The other chemicals, which either followed the pattern of fluorinated polyimide's increase or hydrogen fluoride decline at the onset of the event, display a significant 10 to 15% points drop from their pre-dispute levels.

Policy implications. The simulation results suggest that the initial share of Japanese intermediates might serve as a reliable predictor for how Korean producers would respond if the same export controls were extended to other crucial chemicals. As illustrated in Table 5, potential targets with the Japan's initial share exceeding 70% exhibit pronounced stockpiling patterns, akin to the behavior observed in photoresist. Conversely, potential

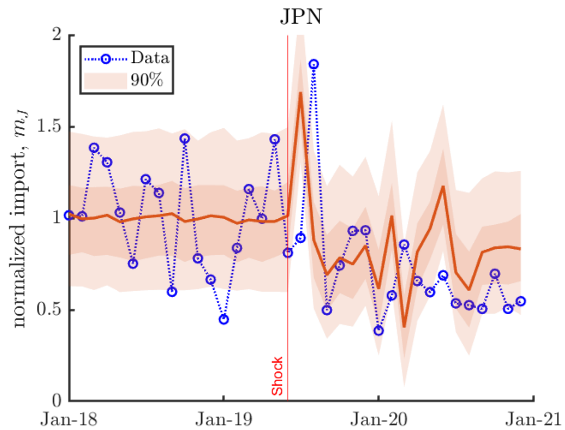
Item		(1) Pre (2018m1-2019m6)	(2) Onset (2019m7)	(3) Post (2019m7-2020m12)	(4) Type
Phosphoric Acid	Value	1.00	1.70	-	PR
	Share	96.6	-	95.0	
Sulphur Chlorides	Value	1.00	1.09	-	FP
	Share	62.0	-	51.1	
Sulphur Hexafluoride	Value	1.00	0.94	-	HF
	Share	33.4	-	24.4	
Varnishes	Value	1.00	1.82	-	PR
	Share	93.8	-	91.6	
Scouring Pastes	Value	1.00	1.56	-	PR
	Share	87.5	-	83.0	
Photographic Plates	Value	1.00	1.58	-	PR
(Unexposed)	Share	84.9	-	78.9	
Photographic Plates	Value	1.00	1.25	-	FP
(Exposed)	Share	70.6	-	60.7	
Chemical Elements	Value	1.00	1.19	-	FP
Doped for Use in Electronics	Share	52.7	-	41.7	
Prepared Binders	Value	1.00	1.52	-	PR
	Share	78.7	-	70.9	
Epoxide Resins	Value	1.00	1.63	-	PR
	Share	87.2	-	82.8	
Self-adhesive Plates	Value	1.00	1.35	-	FP
	Share	56.7	-	45.8	
Plastic Parts	Value	1.00	0.93	-	HF
for Use in Machinery	Share	23.6	-	15.7	

Table 5: Results of Scenario Simulations

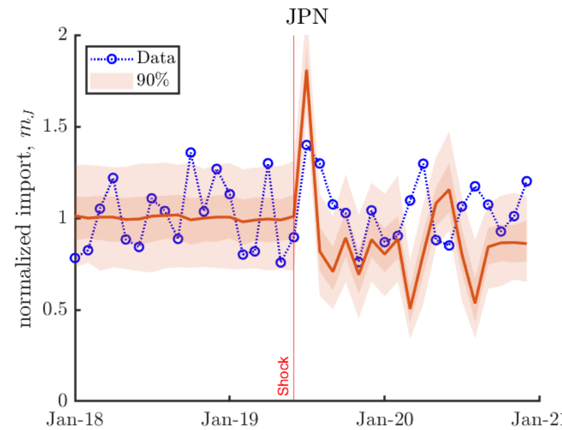
Notes: Each potential target is classified under the corresponding HSK code. See Table A2 in the Appendix E for the detailed list. The import values of each chemical are normalized by the average import values during the pre-shock period. Each chemical's import share is calculated by dividing its imports from Japan by its total imports. Column (1) corresponds to the pre-shock period, spanning from January 2018 to June 2019. Column (2) signifies the onset of the shock, July 2019. Column (3) covers the post-shock period, from July 2019 through December 2020. Column (4) classifies each potential target based on its similarity to one of the three actual targets: photoresist (PR), fluorinated polyimide (FP), or hydrogen fluoride (HF).
Source: Korea Customs Service (2018-2020)

targets with the Japan's initial share between 50% and 70% display moderate stockpiling and substitution patterns, reminiscent of the trend seen in fluorinated polyimide. Notably, for the targets where the Japan's initial share falls below 50%, there is a marked shift away from Japan immediately following the announcement of export controls. Consequently, an early warning system based on each chemical's initial share of Japan can be a viable strategy to address potential disruptions in the semiconductor supply chain. Intermediates with a higher Japanese share indicate a challenge in finding substitutes in the short run. In such cases, the government should consider proactively facilitating imports to buffer against possible export controls. On the other hand, those with a lower Japanese share suggest relatively easier substitution by other sources. For these, the government can guide firms towards identifying alternative suppliers, potentially by collaborating with overseas branches of multinational semiconductor manufacturers or leveraging public trade support agencies.

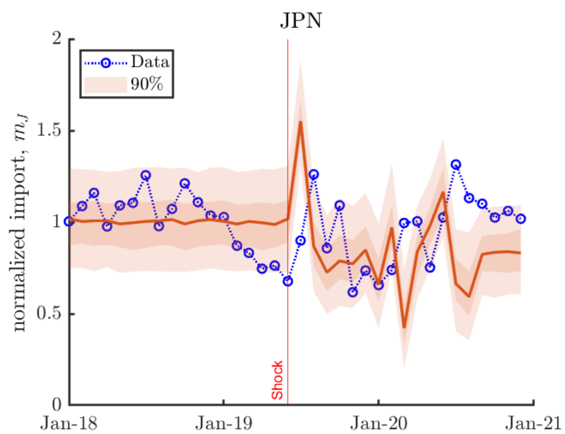
Comparison with the data. A comparison between the simulation results and actual data also yields interesting implications. The simulation results of some potential targets align closely with their actual data, even in the absence of export controls directed at these potential targets. Figure 5 illustrates the comparison between the observed data and the simulation results for four potential targets. These potential targets simulations display stockpiling of imports from Japan, reflecting the pattern of photoresist. The blue dotted line, which represents the actual import data, exhibits a significant spike in the months following Japan's announcement of export controls on photoresist, fluorinated polyimide, and hydrogen fluoride. This trend is consistent with the red solid line and shaded area that represent the simulation results. Moreover, the blue dots are mostly located within the red shaded area during the post-event period. With regard to the change in Japan's share, the simulation results for some potential targets match the corresponding data, as shown in Table A4. Notably, the simulation accurately forecasts the actual change in Japan's share for unexposed photographic plates and epoxide resins, even without calibrating its key parameters to match their specific moments. Thus, the comparison between the simulated scenarios and the observed data suggests that Korean semiconductor producers responded to the export controls even for non-targeted chemicals. They stockpiled Japanese chemicals or diversified away from Japan, anticipating that Japan might extend the export controls to other key intermediates.



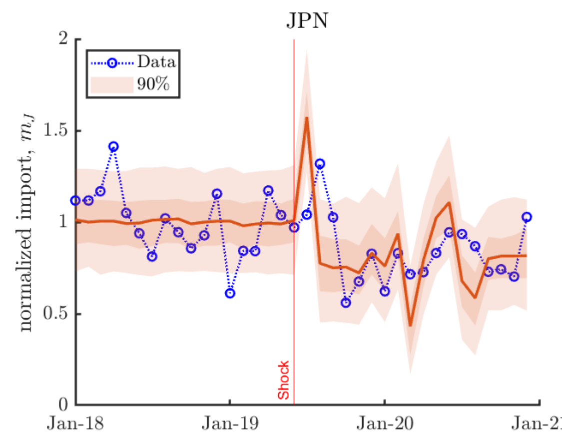
(A) Phosphoric Acid



(B) Varnishes



(C) Scouring Pastes



(D) Photographic Plates (Unexposed)

Figure 5: Results of Scenario Simulations - PR Type

Notes: For each potential target, 500 simulations are conducted, each incorporating a random demand shock into the model in every period. The y-axis represents import values of each potential target, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. For the results of simulations for other potential targets, see Table A6 in the Appendix E.
Source: Korea Customs Service (2018-2020)

6 Conclusion

This paper examines responses of semiconductor producers to supply chain disruptions, specifically focusing on the Korea-Japan trade dispute of 2019. The unprecedented announcement by the Japanese government to impose export controls on crucial chemicals for semiconductor manufacturing lead Korean semiconductor producers to make adjustments in their sourcing, revealed in either stockpiling or substitution behaviors.

The calibrated model, which incorporates inventory and sourcing decisions, successfully captures the disparate responses—stockpiling and substitution—of Korean producers to the threat of the export controls. The results highlight the influence of three drivers for these sourcing adjustments: initial share of sources, elasticity of substitution, and the extent of non-tariff barriers. Moreover, the model's simulations align closely with the observed data, further attesting its validity. Its robustness is also evident when introducing homogeneity in parameters such as elasticity of substitution and levels of non-tariff barriers across targeted chemicals.

This paper also studies a hypothetical scenario where Japan had extended its export controls to other key intermediates. Two main implications arise from this analysis. First, the initial share of Japanese intermediates serve as a reliable predictor for firm responses: higher shares suggest potential stockpiling, while lower shares indicate substitution. Therefore, an early warning system based on the initial share could be an effective way to mitigate potential disruptions in the semiconductor supply chain. Second, even for items not directly targeted by the export controls, Korean firms exhibit anticipatory behaviors in the form of stockpiling and substitution, suggesting proactive sourcing strategies. As countries increasingly leverage trade policies in geopolitical disputes, understanding these supply chain responses in the semiconductor industry is essential for both policymakers and semiconductor producers.

References

Aizcorbe, Ana and Samuel Kortum, "Moore's Law and the Semiconductor Industry: A Vintage Model," *The Scandinavian Journal of Economics*, 2005, *107* (4), 603–630.

Alessandria, George, Joseph P Kaboski, and Virgiliu Midrigan, "Inventories, Lumpy Trade, and Large Devaluations," *American Economic Review*, 2010, *100* (5), 2304–2339.

_, Shafaat Khan, and Armen Khederlarian, "Taking Stock of Trade Policy Uncertainty: Evidence from China's Pre-WTO Accession," *NBER Working Paper 25965*, 2019.

Amiti, Mary, Stephen J. Redding, and David E. Weinstein, "The Impact of the 2018 Tariffs on Prices and Welfare," *Journal of Economic Perspectives*, November 2019, *33* (4), 187–210.

Antràs, Pol and Elhanan Helpman, "Global Sourcing," *Journal of Political Economy*, 2004, *112* (3), 552–580.

_, Teresa C. Fort, and Felix Tintelnot, "The Margins of Global Sourcing: Theory and Evidence from US Firms," *American Economic Review*, 2017, *107* (9), 2514–2564.

Asmat, Danial, "Collusion Along the Learning Curve: Theory and Evidence From the Semiconductor Industry*," *The Journal of Industrial Economics*, 2021, *69* (1), 83–108.

Bekes, Gabor, Lionel Fontagne, Balazs Murakozy, and Vincent Vicard, "Shipment frequency of exporters and demand uncertainty," *Review of World Economics*, 2017, *153* (4), 779–807.

Blaum, Joaquin, Claire Lelarge, and Michael Peters, "The Gains from Input Trade with Heterogeneous Importers," *American Economic Journal: Macroeconomics*, October 2018, *10* (4), 77–127.

Broda, Christian and David E. Weinstein, "Globalization and the Gains From Variety," *The Quarterly Journal of Economics*, May 2006, *121* (2), 541–585.

Cabral, Ricardo and Michael J. Leiblein, "Adoption of a Process Innovation with Learning-by-Doing: Evidence from the Semiconductor Industry," *The Journal of Industrial Economics*, 2001, *49* (3), 269–280.

Carreras-Valle, Maria-Jose, "Increasing Inventories: The Role of Delivery Times," *Unpublished manuscript*, 2021.

Crowley, Meredith, Ning Meng, and Huasheng Song, "Tariff scares: Trade policy uncertainty and foreign market entry by Chinese firms," *Journal of International Economics*, 2018, *114*, 96–115.

Fajgelbaum, Pablo D. and Amit K. Khandelwal, "The Economic Impacts of the US–China Trade War," *Annual Review of Economics*, 2022, *14* (1), 205–228.

Fajgelbaum, Pablo D, Pinelopi K Goldberg, Patrick J Kennedy, and Amit K Khandelwal, "The Return to Protectionism," *The Quarterly Journal of Economics*, 2020, *135* (1), 1–55.

Feng, Ling, Zhiyuan Li, and Deborah L. Swenson, "Trade policy uncertainty and exports: Evidence from China's WTO accession," *Journal of International Economics*, 2017, *106*, 20–36.

Halpern, László, Miklós Koren, and Adam Szeidl, "Imported Inputs and Productivity," *American Economic Review*, December 2015, *105* (12), 3660–3703.

Handley, Kyle and Nuno Limao, "Trade and Investment under Policy Uncertainty: Theory and Firm Evidence," *American Economic Journal: Economic Policy*, 2015, *7* (4), 189–222.

_ , _ , Rodney Ludema, and Zhi Yu, "Firm Input Choice under Trade Policy Uncertainty," *NBER Working Paper 27910*, 2020.

Irwin, Douglas A. and Peter J. Klenow, "Learning-by-Doing Spillovers in the Semiconductor Industry," *Journal of Political Economy*, 1994, *102* (6), 1200–1227.

Itskhoki, Oleg and Dmitry Mukhin, "Sanctions and the Exchange Rate," *NBER Working Paper 30009*, 2022.

Khan, Aubhik and Julia K Thomas, "Inventories and the Business Cycle: An Equilibrium Analysis of (S, s) Policies," *American Economic Review*, 2007, *97* (4).

Korea Customs Service, "Semiconductor Harmonized System (HS) Standard Interpretation Guidelines Issued," *Press Releases*, April 24 2023. https://www.customs.go.kr/kcs/na/ntt/selectNttList.do?mi=2891&bbsId=1362.

Lorenzoni, Guido and Ivan Werning, "A Minimalist Model for the Ruble During the Russian Invasion of Ukraine," *NBER Working Paper 29929*, 2022.

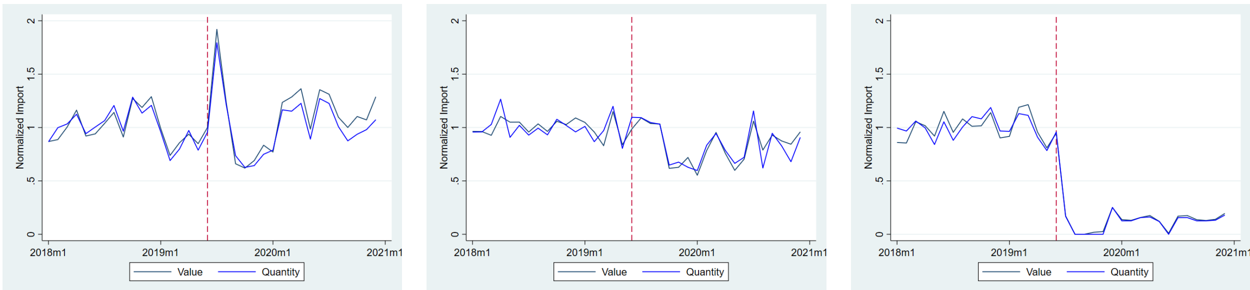
Ministry of Economy and Finance, Korea, "Results of the second public-private meeting on the Japanese export controls.," *Press Releases*, August 14 2019. https://www.moef.go.kr/nw/nes/detailNesDtaView.do?searchBbsId1=MOSFBBS_000000000028&searchNttId1=MOSF_000000000029444&menuNo=4010100.

Pierce, Justin R. and Peter K. Schott, "The Surprisingly Swift Decline of US Manufacturing Employment," *American Economic Review*, 2016, *106* (7), 1632–1662.

Pillai, Unni, "A Model of Technological Progress in the Microprocessor Industry," *The Journal of Industrial Economics*, 2013, *61* (4), 877–912.

Siebert, Ralph B., "Estimating Differential Dynamic Merger Effects on Market Structure and Entry in Related Markets," *Review of Industrial Organization*, 2019, *55* (3), 431–458.

A Appendix to Section 3

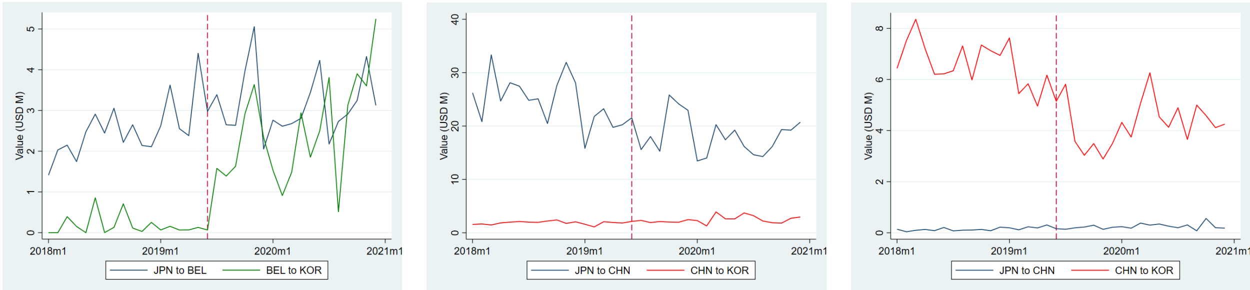


(A) PR (B) FP (C) HF

Figure A1: Korea's Monthly Imports - Values and Quantities

Notes: PR is classified under HSK 3707901010. FP is classified under HSK 3906909000. HF is classified under HSK 2811111000. The import values and the import quantities for each chemical are normalized by their respective average imports during the pre-shock period (18 months prior to the shock).
Source: Korea Customs Service (2018-2020).

Import quantities. Figure A1 illustrates the import quantities of the three target chemicals, while Section 3 examines the import values of these chemicals. In each panel, the navy line represents the import values, and the blue line represents the import quantities. The observed patterns for both values and quantities across all three chemicals are almost identical. This implies that the changes in the import values of the three chemicals are entirely driven by the changes in their import quantities, suggesting no evident changes in the import prices of the three chemicals.



(A) PR (B) FP (C) HF

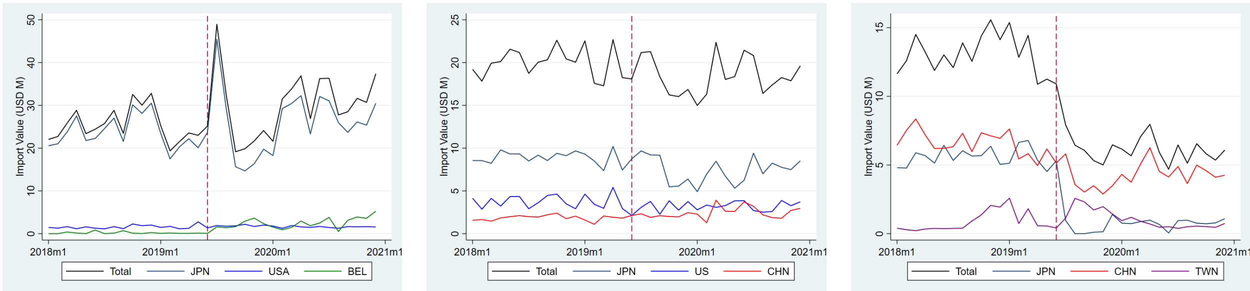
Figure A2: Japan's Exports and Korea's Imports

Notes: Japan's PR export to Belgium and Korea's PR import from Belgium are classified under HSJ 370790000 and HSK 3707901010, respectively. Japan's FP export to China and Korea's FP import from China are classified under HSJ 390690100 and HSK 3906909000, respectively. Japan's HF export to China and Korea's HF import from China are classified under HSJ 281111000 and HSK 2811111000, respectively. Source: Ministry of Finance Japan (2018-2020) and Korea Customs Service (2018-2020).

Possible circumvention. It is important to note that Japanese export firms and Korean import firms may be able to circumvent the export controls. Specifically, chemicals produced in Japan could be shipped to other countries and then exported to South Korea. To check whether this circumvention has occurred, I compare Japan's exports to a specific country with Korea's imports from that country. For each chemical, I select a country with the largest increase in import share in the Korean market: Belgium for PR, and China for FP and HF.[7] Panel A of Figure A2 illustrates the values of Japanese PR exports to Belgium (navy line in Panel A) and Korea's PR imports from Belgium (green line in Panel A). The movement of the former was coincident with that of the latter after the announcement of the export controls. Furthermore, Japan's PR exports to Belgium increased by approximately 24% points compared to the pre-shock period. However, for the other two chemicals, their Japanese export patterns were not consistent with their Korean import patterns at all, as depicted in Panel B and C of Figure A2. This can be suggestive evidence that Japanese and Korean firms utilized a third location to evade the Japanese export restrictions. In fact, Samsung Electronics, the largest memory chip manufacturer in the world, purchased more than six months' worth of PR from a Belgium supplier owned by a Japanese chemical company named JSR. [8]

[7]The shares of Belgian PR, Chinese FP, and Chinese HF in the Korean market increased by 7% points, 21% points and 4% points, respectively, compared to the pre-shock period (January 2018 to June 2019).

[8]A news article from Nikkei Asia on August 14, 2019, "Samsung Secures Key Chip Supply in Belgium as Tokyo Curbs Exports." (https://asia.nikkei.com/Spotlight/Japan-South-Korea-rift/Samsung-secures-key-chip-supply-in-Belgium-as-Tokyo-curbs-exports)



(A) PR (B) FP (C) HF

Figure A3: Korea's Monthly Imports

Notes: PR is classified under HSK 3707901010. FP is classified under HSK 3906909000. HF is classified under HSK 2811111000.
Source: Korea Customs Service (2018-2020)

Korea's total imports. Figure A3 illustrates the changes in Korea's total imports of three target chemicals and their import values from the main trading partners. Notably, the total HF imports (black line in Panel C) decreased by around 53% compared to the pre-shock period. Furthermore, the significant decline was observed not only in Japanese HF (navy line in Panel C), but also in Chinese HF (red line in Panel C). The import values from Japan and China decreased by approximately 88% and 35%, respectively. The contemporaneous declines in both sources could be explained by the case in which Korean firms that used to import HF are substantially souring this chemical domestically. In contrast, the total PR imports (black line in Panel A) even increased, and the total FP imports (black line in Panel B) fell slightly: around 19% increase and 7% decrease, respectively. It is suggestive that PR and FP imports have not being substituted by domestic chemicals, unlike HF.

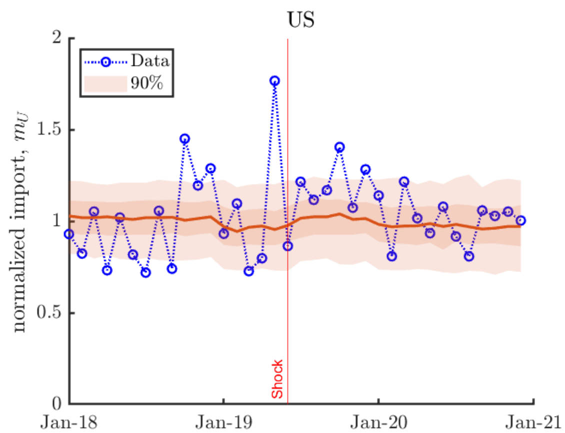
B Appendix to Section 4.2

Start Date	End Date	News Articles	Calibrated Probability
07-01-2019	07-15-2019	701	0.3720
07-16-2019	07-31-2019	1239	0.4214
08-01-2019	08-15-2019	1617	0.4450
08-16-2019	08-31-2019	964	0.3995
09-01-2019	09-15-2019	476	0.3396
09-16-2019	09-30-2019	433	0.3318
10-01-2019	10-15-2019	452	0.3353
10-16-2019	10-31-2019	288	0.2992
11-01-2019	11-15-2019	178	0.2628
11-16-2019	11-30-2019	236	0.2839
12-01-2019	12-15-2019	185	0.2657
12-16-2019	12-31-2019	234	0.2832
01-01-2020	01-15-2020	122	0.2360
01-16-2020	01-31-2020	81	0.2088
02-01-2020	02-15-2020	8	0.0953
02-16-2020	02-29-2020	147	0.2490
03-01-2020	03-15-2020	85	0.2119
03-16-2020	03-31-2020	0	0.0356
04-01-2020	04-15-2020	0	0.0356
04-16-2020	04-30-2020	0	0.0356
05-01-2020	05-15-2020	47	0.1758
05-16-2020	05-31-2020	12	0.1101
06-01-2020	06-15-2020	137	0.2441
06-16-2020	06-30-2020	139	0.2451
07-01-2020	07-15-2020	175	0.2616
07-16-2020	07-31-2020	53	0.1828
08-01-2020	08-15-2020	40	0.1668
08-16-2020	08-31-2020	0	0.0356
09-01-2020	09-15-2020	0	0.0356
09-16-2020	09-30-2020	0	0.0356
10-01-2020	10-15-2020	0	0.0356
10-16-2020	10-31-2020	0	0.0356
11-01-2020	11-15-2020	0	0.0356
11-16-2020	11-30-2020	0	0.0356
12-01-2020	12-15-2020	0	0.0356
12-16-2020	12-31-2020	0	0.0356

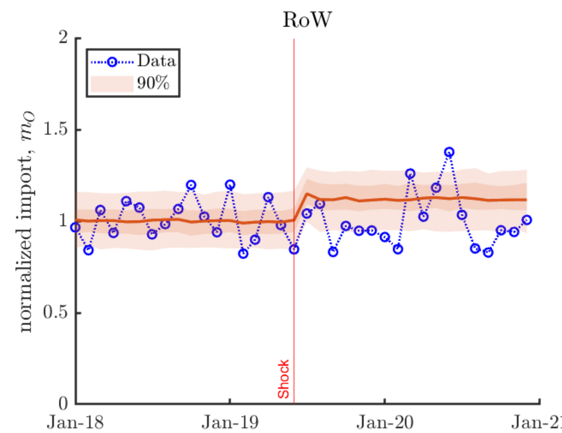
Table A1: Calibration of Probability of Import Denial

Notes: Each period defined by the start date and end date spans two weeks.
Source: News Based Statistics Search from Statistics Korea (2019-2020)

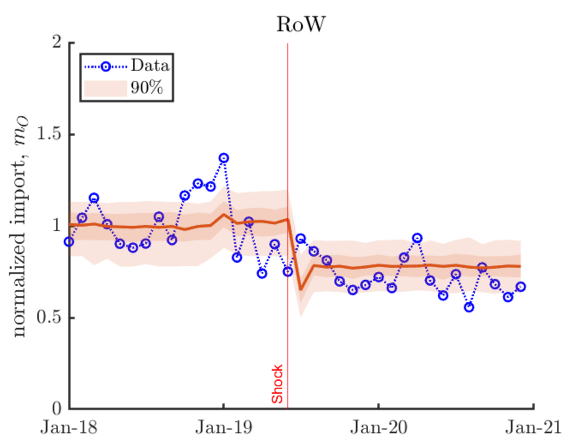
C Appendix to Section 4.3



(A) PR



(B) FP



(C) HF

Figure A4: Results of Baseline Simulations - Imports from Another Source

Notes: For each targeted chemical, 500 simulations are conducted, each incorporating a random demand shock into the model in every period, using the calibrated parameters. The y-axis represents import values of each chemical, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. Note that unlike the other two chemicals, the shock to photoresist has dissipated since January 2020 to reflect the fact that Japan eased the export controls on photoresist at the end of December 2019.
Source: Korea Customs Service (2018-2020)

D Appendix to Section 4.4

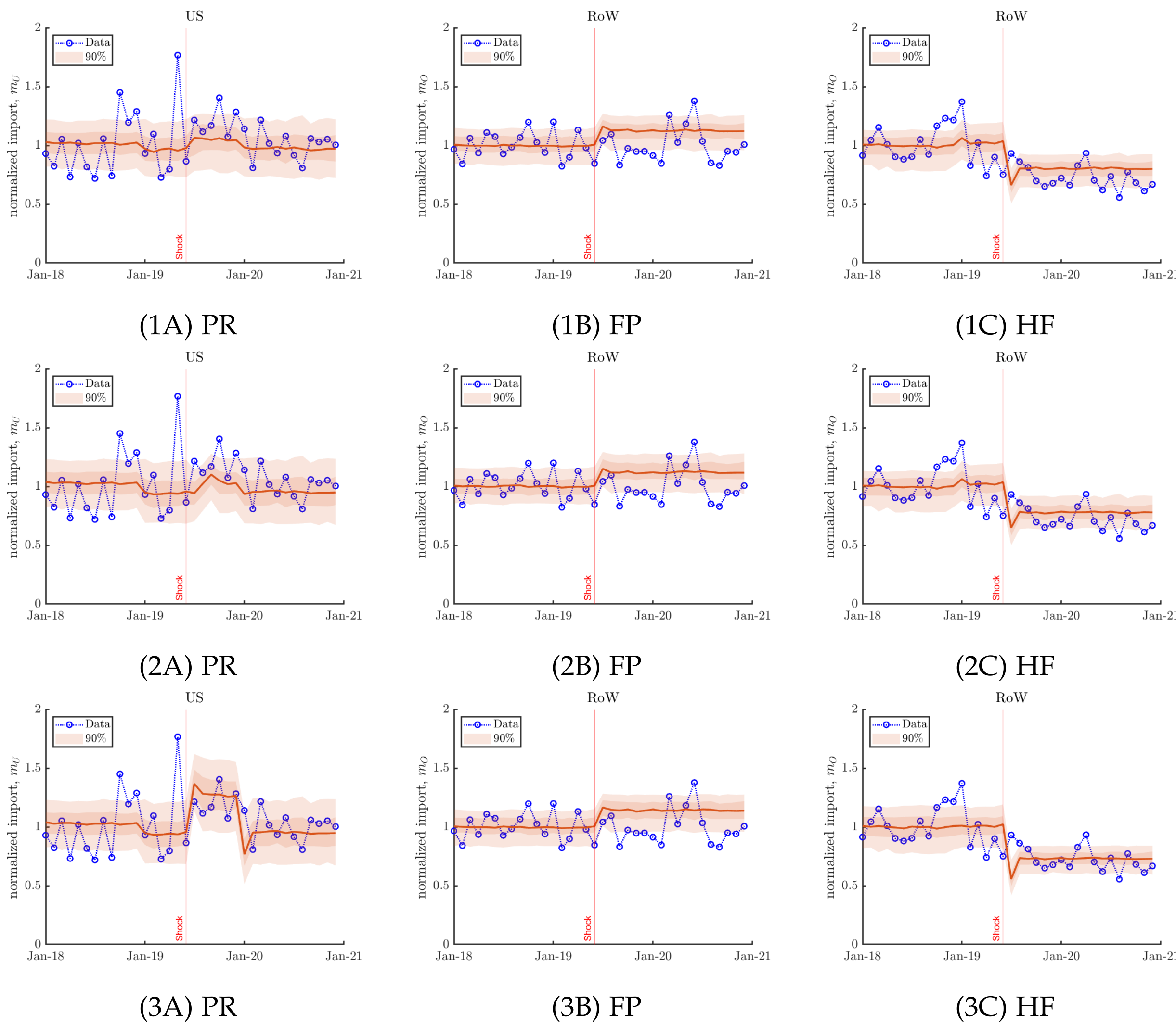


Figure A5: Robustness of the Baseline Results - Imports from Another Source

Notes: For each panel, 500 simulations are conducted, incorporating a random demand shock into the model in every period. The y-axis represents import values from Japan, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively. The first, second, and third set of panels correspond to the results of Case 1—homogeneity in non-tariff barriers, Case 2—homogeneity in elasticity of substitution, and Case 3—homogeneity in both non-tariff barriers and elasticity of substitution, respectively. Note that unlike the other two chemicals, the shock to photoresist has dissipated since January 2020 to reflect the fact that Japan eased the export controls on photoresist at the end of December 2019.
Source: Korea Customs Service (2018-2020)

E Appendix to Section 5

(1) Item	(2) HSK Code	(3) Imports from Japan Value (USD)	(4) Share	(5) Source
Phosphoric Acid	2809201010	17,183,921	0.96	Description
Sulphur Chlorides	2812190000	9,590,610	0.65	Guideline
Sulphur Hexafluoride	2812902000	2,986,068	0.37	Guideline
Varnishes	3208201030	95,281,098	0.94	Guideline
Scouring Pastes	3405400000	136,847,373	0.81	Guideline
Photographic Plates (Unexposed)	3701991000	49,217,265	0.85	Description
Photographic Plates (Exposed)	3705009010	36,147,333	0.77	Description
Chemical Elements Doped for Use in Electronics	3818001000	848,703,827	0.53	Guideline
Prepared Binders	3824997100	181,831,264	0.80	Guideline
Epoxide Resins	3907301000	52,073,628	0.87	Description
Self-adhesive Plates	3919900000	261,817,287	0.59	Guideline
Plastic Parts for Use in Machinery	3926901000	53,164,388	0.24	Guideline

Table A2: List of Potential Target Items

Notes: Column (1) lists the items as referenced in the primary sources. Column (2) provides the HS-Korea classification code for each item. Column (3) shows the value of Korea's imports from Japan in 2018, expressed in U.S. Dollars. Column (4) denotes Japan's share in the Korean imports in 2018 for each item. Column (5) indicates the source used to identify each item, whether from the HS-Korea description or the Semiconductor HS-Korea Standard Interpretation Guidelines.
Source: Korea Customs Service

Potential target items. I select potential target intermediates based on two primary sources from the Korean Customs Service: the HS-Korea description and the Semiconductor HS-Korea Standard Interpretation Guidelines (Korea Customs Service (2023)). Focusing on chemicals, which are identified by HS codes ranging from 28 to 39, I choose items from the first source whose descriptions include "for making semiconductors." and all relevant items from the second source. From the gathered data, a total of 29 items are identified: 17 items from the first source and 12 from the second. The next step is to refine the selection. I eliminate items with weak ties to Japan: those not imported from Japan, those where Korea's exports to Japan exceed its imports from Japan, and those where Japan's share in Korea's market is below 10%. After this thorough filtering process, I finalize a list of 12 key chemicals used for semiconductor production. These items stand out as potential targets for export controls by the Japanese government. Table A2 lists the potential target items.

Panel A. Calibrated Parameters

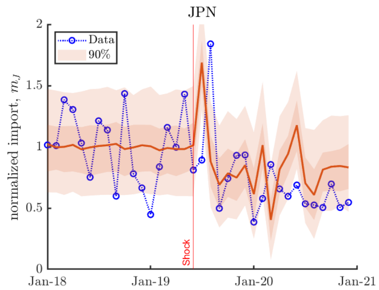
	Parameter	Value	Moment	Data	Model
Phosphoric Acid					
Weight	θ	0.97	JPN share in pre-shock period	0.97	0.97
S.D. of demand shocks	σ_v	0.45	S.D. of total imports in pre-period	0.29	0.26
Sulphur Chlorides					
Weight	θ	0.66	JPN share in pre-shock period	0.62	0.62
S.D. of demand shocks	σ_v	0.50	S.D. of total imports in pre-period	0.30	0.28
Sulphur Hexafluoride					
Weight	θ	0.37	JPN share in pre-shock period	0.33	0.33
S.D. of demand shocks	σ_v	0.50	S.D. of total imports in pre-period	0.33	0.27
Varnishes					
Weight	θ	0.95	JPN share in pre-shock period	0.94	0.94
S.D. of demand shocks	σ_v	0.29	S.D. of total imports in pre-period	0.19	0.17
Scouring Pastes					
Weight	θ	0.94	JPN share in pre-shock period	0.88	0.87
S.D. of demand shocks	σ_v	0.30	S.D. of total imports in pre-period	0.17	0.17
Photographic Plates (Unexposed)					
Weight	θ	0.85	JPN share in pre-shock period	0.85	0.85
S.D. of demand shocks	σ_v	0.30	S.D. of total imports in pre-period	0.17	0.17
Photographic Plates (Exposed)					
Weight	θ	0.73	JPN share in pre-shock period	0.71	0.71
S.D. of demand shocks	σ_v	0.50	S.D. of total imports in pre-period	0.38	0.28
Chemical Elements Doped					
Weight	θ	0.57	JPN share in pre-shock period	0.53	0.53
S.D. of demand shocks	σ_v	0.24	S.D. of total imports in pre-period	0.13	0.12
Prepared Binders					
Weight	θ	0.84	JPN share in pre-shock period	0.79	0.79
S.D. of demand shocks	σ_v	0.16	S.D. of total imports in pre-period	0.07	0.08
Epoxide Resins					
Weight	θ	0.90	JPN share in pre-shock period	0.87	0.87
S.D. of demand shocks	σ_v	0.27	S.D. of total imports in pre-period	0.14	0.14
Self-adhesive Plates					
Weight	θ	0.58	JPN share in pre-shock period	0.57	0.57
S.D. of demand shocks	σ_v	0.22	S.D. of total imports in pre-period	0.12	0.11
Plastic Parts for Use in Machinery					
Weight	θ	0.27	JPN share in pre-shock period	0.23	0.24
S.D. of demand shocks	σ_v	0.16	S.D. of total imports in pre-period	0.09	0.09

Panel B. Common Parameters

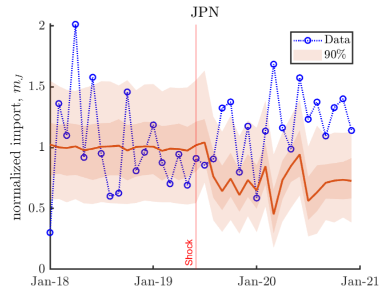
	Parameter	Value	Source
Non-tariff barriers	$\omega_{J,post}$	1.14	Case 3 in Section 4.4
Elasticity of substitution	ρ	3.63	Case 3 in Section 4.4
Probability of import denial	α_0	-1.804	Baseline in Section 4.3
	α_1	0.226	
Depreciation rate	δ	0.013	Alessandria et al. (2010), Carreras-Valle (2021)
Demand elasticity	σ_d	1.50	Alessandria et al. (2010), Carreras-Valle (2021)
Interest rate	β	$0.99^{1/24}$	Bank of Korea

Table A3: Calibration: Export Controls Extension

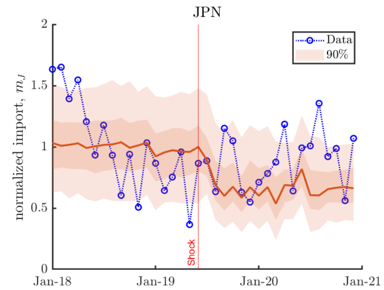
Notes: For each chemical, the weight, θ, is calibrated to match its relative Japanese share, and the standard deviation of demand shocks, σ_v, is calibrated to match the standard deviation of total imports in Korea. All other parameters are homogeneous across all potential targets.



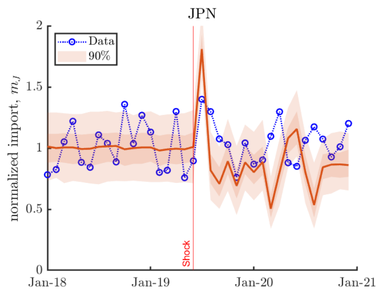
(A) Phosphoric Acid



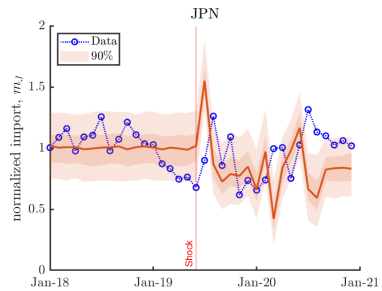
(B) Sulphur Chlorides



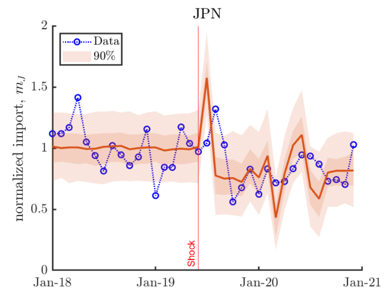
(C) Sulphur Hexafluoride



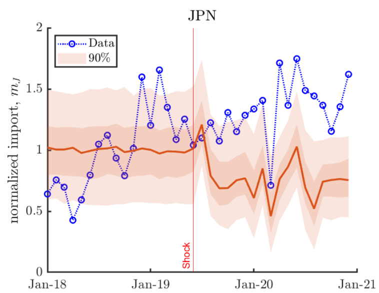
(D) Varnishes



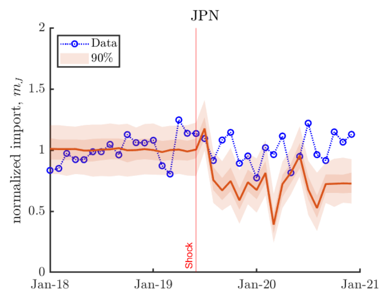
(E) Scouring Pastes



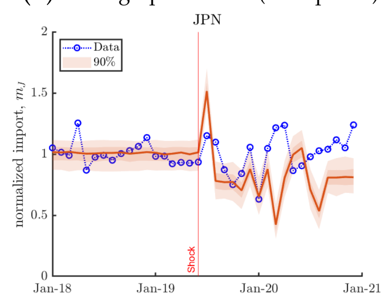
(F) Photographic Plates (Unexposed)



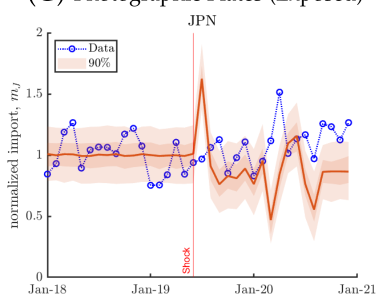
(G) Photographic Plates (Exposed)



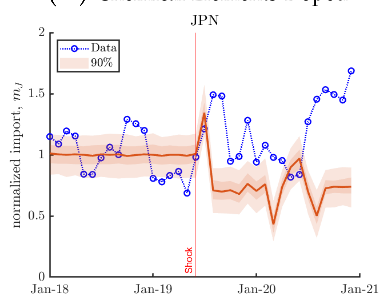
(H) Chemical Elements Doped



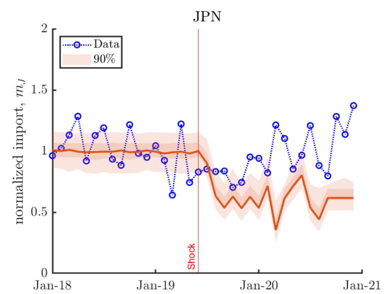
(I) Prepared Binders



(J) Epoxide Resins



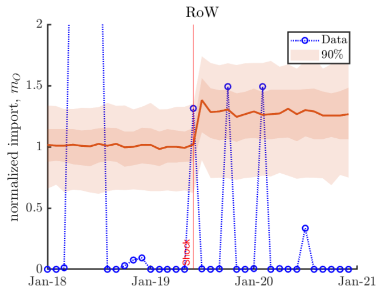
(K) Self-adhesive Plates



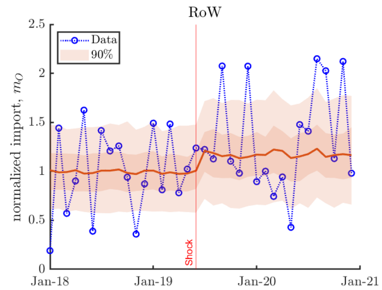
(L) Plastic Parts for Use in Machinery

Figure A6: Results of Scenario Simulations

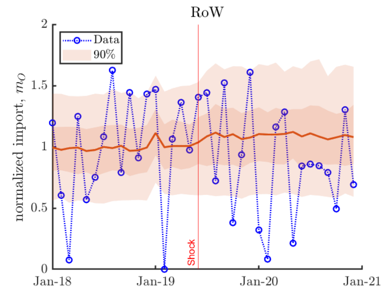
Notes: For each potential target, 500 simulations are conducted, each incorporating a random demand shock into the model in every period. The y-axis represents import values of each potential target, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively.
Source: Korea Customs Service (2018-2020)



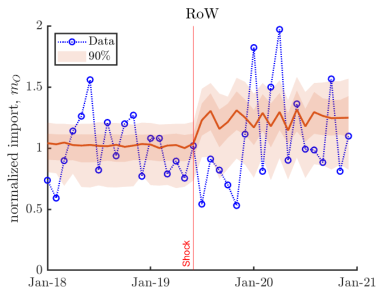
(A) Phosphoric Acid



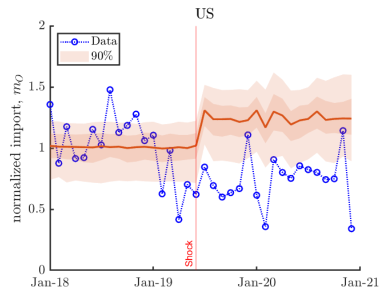
(B) Sulphur Chlorides



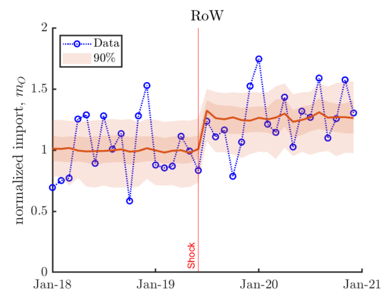
(C) Sulphur Hexafluoride



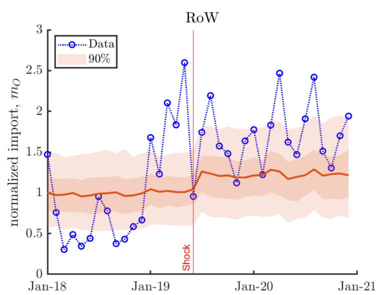
(D) Varnishes



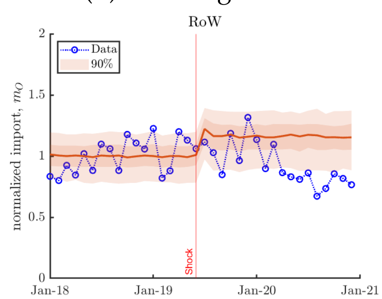
(E) Scouring Pastes



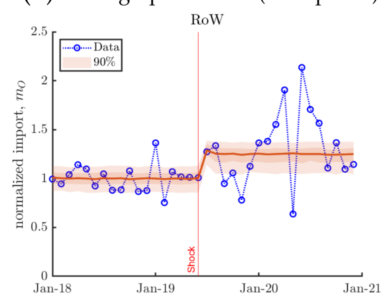
(F) Photographic Plates (Unexposed)



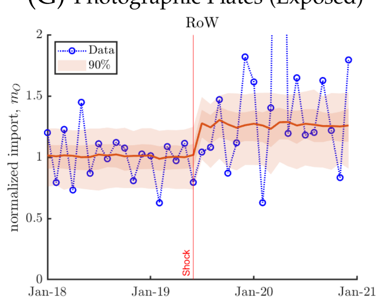
(G) Photographic Plates (Exposed)



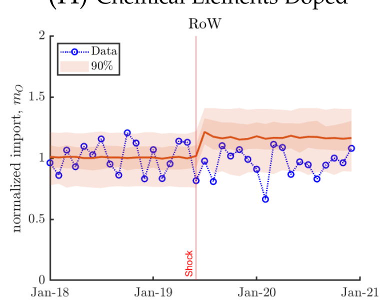
(H) Chemical Elements Doped



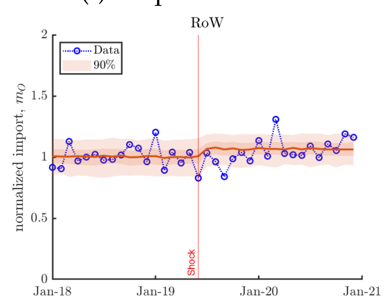
(I) Prepared Binders



(J) Epoxide Resins



(K) Self-adhesive Plates



(L) Plastic Parts for Use in Machinery

Figure A7: Results of Scenario Simulations - Imports from Another Source

Notes: For each potential target, 500 simulations are conducted, each incorporating a random demand shock into the model in every period. The y-axis represents import values of each potential target, normalized to the average import values during the pre-shock period (18 months prior to the shock). In each panel, the red solid line represents the mean of the simulations while the blue dotted line signifies the corresponding data. The dark red shaded area and the light red shaded area illustrate the 50% and 90% distribution bands of the simulations, respectively.
Source: Korea Customs Service (2018-2020)

Item		(1) Pre (2018m1-2019m6)		(2) Post (2019m7-2020m12)	
		Data	Simulation	Data	Simulation
Phosphoric Acid	Share	97.0	96.6	99.2	95.0
Sulphur Chlorides	Share	62.0	62.0	59.1	51.1
Sulphur Hexafluoride	Share	33.4	33.4	34.2	24.4
Varnishes	Share	94.1	93.8	94.0	91.6
Scouring Pastes	Share	87.8	87.5	90.2	83.0
Photographic Plates (Unexposed)	Share	85.1	84.9	79.0	78.9
Photographic Plates (Exposed)	Share	70.6	70.6	64.9	60.7
Chemical Elements Doped for Use in Electronics	Share	52.7	52.7	54.7	41.7
Prepared Binders	Share	79.0	78.7	74.4	70.9
Epoxide Resins	Share	87.1	87.2	82.6	82.8
Self-adhesive Plates	Share	56.7	56.7	62.3	45.8
Plastic Parts for Use in Machinery	Share	23.6	23.6	21.6	15.7

Table A4: Comparison between Data and Scenario Simulations

Notes: Each potential target is classified under the corresponding HSK code. See Table A2 for the detailed list. Each chemical's import share is calculated by dividing its imports from Japan by its total imports. Column (1) corresponds to the pre-shock period, spanning from January 2018 to June 2019. Column (2) covers the post-shock period, from July 2019 through December 2020.
Source: Korea Customs Service (2018-2020)