Office of Industries
Working Paper ID-062
October 2019

The South Korea-Japan Trade Dispute in Context: Semiconductor Manufacturing, Chemicals, and Concentrated Supply Chains

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Abstract

The semiconductor production supply chain is among the most globally integrated. Japan's recently announced export control actions have introduced supply chain risks for semiconductor and electronics manufacturers, particularly in Japan and Korea. This paper provides context and examines the potential implications of such risks. We identify the factors behind Japan's competitiveness in the semiconductor materials and equipment industries, focusing on specialized chemicals, and South Korea's competiveness in semiconductor manufacturing. We explore the short and long-term implications of sustained supply chain risks for this particular supply chain and find that there are strong supplier-customer relationships between materials and equipment suppliers and semiconductor manufacturers, due to specialization and high fixed costs throughout the supply chain. In the short-term, Japanese chemical providers and Korean semiconductor producers face potential disruptions in their production and exports, though the magnitude of potential losses for Korean chipmakers are likely much larger than Japanese chemicals suppliers. In the long-term, these actions create incentives for Korean chipmakers to significantly lessen their sourcing from Japanese suppliers, not only in specialized chemicals, but throughout the entire semiconductor supply chain.

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The authors are staff with the Office of Industries of the U.S. International Trade Commission (USITC). Office of Industries working papers are the result of the ongoing professional research of USITC staff. Working papers are circulated to promote the active exchange of ideas between USITC staff and recognized experts outside the USITC, and to promote professional development of office staff by encouraging outside professional critique of staff research.

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Authors would like to thank Heidi Colby-Oizumi, John Fry, Tamar Khachaturian, Linda Linkins, Bill Powers, and James Stamps for their helpful comments. Authors are also grateful for Dennis Hahm for providing and checking Korea specific trade statistics. Authors also acknowledge with gratitude various representatives in the chemicals and semiconductor industries for their feedback. Lastly, authors thank Trina Chambers and Monica Sanders for administrative assistance.

concentration in photolithography, with ASML (The Netherlands), Canon (Japan), and Nikon (Japan) responsible for 40, 30, and 30 percent of market share in 2004, respectively.[33] The SME market's current concentration is apparent when broken down by key semiconductor fabrication process and related equipment:[34]

- chemical vapor deposition equipment—Applied Materials (USA) has slightly more than 50 -percent of global market share, followed by Lam Research (USA) and TEL (Japan);
- photolithography—ASML (Netherlands) maintains roughly 75 percent market share, followed by Canon (Japan) and Nikon (Japan);
- etch equipment—Lam Research (USA) has roughly 60 percent market share, followed by TEL (Japan) and Applied Materials (USA); and
- quality and process control equipment—KLA-Tencor (USA) has roughly 55 percent market share.

A wide variety of chemicals are used in semiconductor manufacturing equipment during each of the aforementioned stages of the semiconductor fabrication process. For example, photolithography equipment makes use of photoresists, while etch equipment makes extensive use of hydrogen fluoride. The use of these chemicals in semiconductor manufacturing equipment is discussed at length in the following section.

The Korean Semiconductor Industry's Competitiveness

The development of the Korean semiconductor industry began in the 1960s and 1970s when large multinational corporations established semiconductor assembly facilities, seeking to use low-cost Korean labor for relatively low-value added work. By the 1980s, as wages and skill levels increased, the large industrial conglomerates Samsung and Hyundai emerged as serious competitors in the DRAM market. The Korean government supported the nascent industry through the establishment of industrial estates for semiconductor production, housed state-sponsored research institutes (such as the Electronics and Telecommunication Research Institute) on these estates, used import restrictions to protect the market share of domestic firms, and limited foreign direct investment (except for joint ventures).[35] In spite of a worldwide recession in 1985, Korean firms were able to continue to invest in their manufacturing facilities, allowing them to remain competitive during a downward cycle in the market.[36]

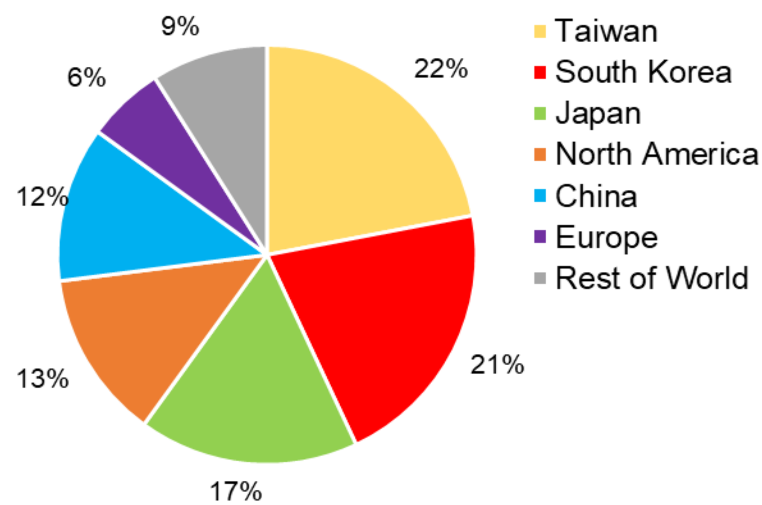
Unlike Japanese firms, Korean firms were not able to rely on within-company or domestic demand to inform product development and instead invested heavily in advanced manufacturing processes to enter new markets. Intense competition among the leading firms (Samsung, Hyundai, and LG)

[33] United States International Trade Commission, "Industry and Trade Summary: Semiconductor Manufacturing Equipment," June 2006, 9.
[34] Hall, "Overview of the Semiconductor Capital Equipment Industry," January 15, 2019.
[35] Amsden, *Asia's Next Giant*, 1989, 82–83.
[36] Cho, Kim, and Rhee, "Latecomer Strategies: Evidence from the Semiconductor Industry in Japan and Korea," 1998, 499.

throughout the 1980s and 1990s precipitated expansion and upgrading.[37] Over time, the Korean government provided preferred interest rates, offered subsidies for research and development, and sponsored pre-competitive research that led to breakthroughs. The Korean industry also directly benefited from the memory chip dispute between Japan and the United States.[38] In the late 1980s and early 1990s, as Japanese firms reduced their worldwide production in accordance with the negotiated settlement with the United States, Korean firms expanded to fill part of that demand.[39]

The Korean semiconductor industry today is a global leader, with overall fabrication capacity second only to that of Taiwan (as of 2018, figure 5). In particular, Samsung and SK Hynix (formerly known as Hyundai Electronics) have emerged as the second and fourth largest suppliers of semiconductors in the world, and for much of 2018, Samsung led Intel in the race to be the largest semiconductor company in the world.[40]

Figure 5 Global wafer capacity as of December 2018, share by region (monthly installed capacity in 200 mm wafer equivalents)



Source: IC Insights, “Taiwan Maintains the Largest Share of Global IC Wafer Fab Capacity,” February 14, 2019.

Korean firms are particularly competitive in certain sub-segments of the semiconductor market. For example, the top two Korean memory chip manufacturers, Samsung and SK Hynix, accounted for a combined 74.7 percent of the global DRAM market in Q42017.[41] Though there has been a significant price decline in the overall memory market in 2019, with the three leading firms all reporting a 30-plus

[37] Cho, Kim, and Rhee, “Latecomer Strategies: Evidence from the Semiconductor Industry in Japan and Korea,” 1998, 499–500.
[38] For more on this conflict, see Irwin, “The U.S.-Japan Semiconductor Trade Conflict,” 1996.
[39] Cho, Kim, and Rhee, “Latecomer Strategies: Evidence from the Semiconductor Industry in Japan and Korea,” 1998, 500.
[40] IC Insights, “Top-15 Semiconductor Suppliers’ Sales Fall by 18% in 1H19,” August 20, 2019.
[41] Wu, “DRAM Revenue Grew by 76% YoY in 2017, and is Expected to Increase Further by More than 30% in 2018, Says TrendForce,” February 13, 2018.

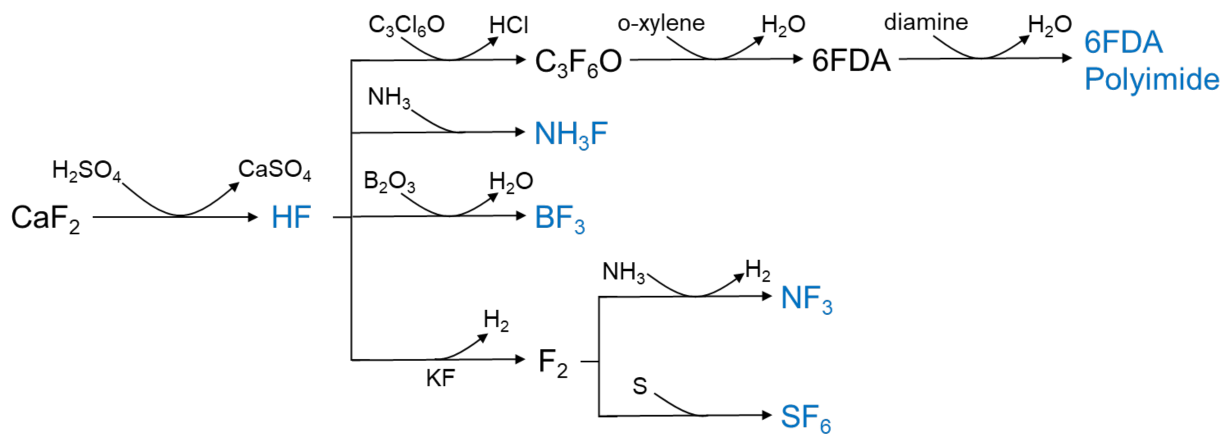
percent decline in year-over-year sales, Samsung and SK Hynix remain in leading positions and are two of only five firms capable of commercial production of today's most advanced chips.[42]

Semiconductor Manufacturing and Chemicals

Hydrogen Fluoride

The semiconductor industry uses hydrogen fluoride (HF) in many applications.[43] On its own or in aqueous solution as hydrofluoric acid, it is a powerful etchant for stripping layers from a wafer during processing. It is also used as a feedstock to produce other chemicals (figure 6).

Figure 6 Semiconductor processing chemicals derived from hydrogen fluoride



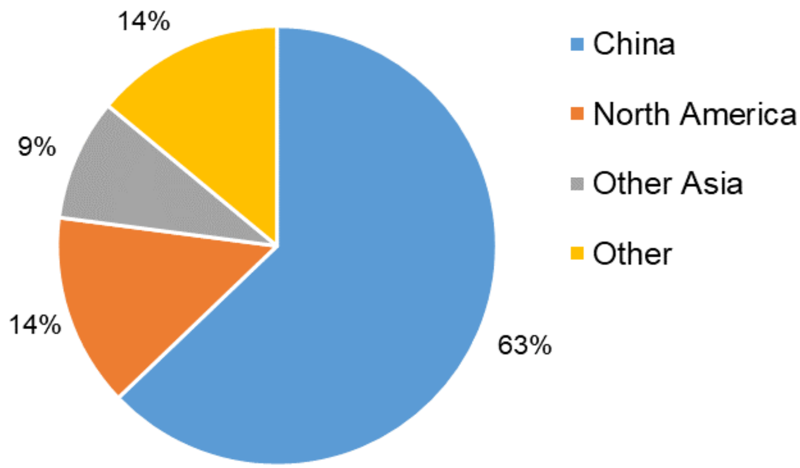
Source: USITC Staff.
Note: Stoichiometry is omitted for clarity. Blue-highlighted chemicals are used in semiconductor processing. Specifically, reacting HF with ammonia (NH_3) yields ammonium fluoride (NH_3F, used in etching solutions); reacting HF with boron oxide (B_2O_3) makes trifluoroboron (BF_3, used for doping); reacting HF with sulfur to creates sulfur hexafluoride (SF_6, used for etching); and reacting HF with chlorocarbons makes fluorocarbons (used for plasma etching and as polymer precursors). HF is also used to produce fluorine gas (F_2), which is used to make other fluorine chemicals, like nitrogen trifluoride (NF_3), another etchant.

The value chain for HF begins with mining its parent ore, fluorspar (or fluorite, calcium fluoride, CaF_2). Fluorspar used to produce HF is sold as acid grade, which is defined as material composed of at least 97 percent calcium fluoride.[44] China is the largest overall producer of acid grade fluorspar, accounting

[42] Han, "Samsung to Apply EUV to 1z DRAM Mass Production for First Time," June 13, 2019.
[43] HF is included on export control lists because it can be used in the manufacture weapons of mass destruction. U.S. Department of Commerce, "Commerce Control List," 15 C.F.R. § 774 Supplement No. 1, heading 1C350 (Chemicals that may be used as precursors for toxic chemical agents).
[44] Less concentrated fluorspar is used as ceramic or metallurgical grades. About 2.2 kg of fluorspar produces 1 kg of HF. Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 17–18.

for over half of global production (figure 7). Neither Japan nor Korea appears to mine it. The United States does produce some fluorspar, and multiple states possess deposits.[45]

Figure 7 Acid Grade Fluorspar production share by source



Source: Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 11, 54.
Note: Does not include other grades of fluorspar. Data for 2015.

Both Japan's and Korea's needs for fluorspar are met by imports, primarily from China (table 2).[46] Similarly, U.S. production of fluorspar relies on imports, predominantly from Mexico (table 2), and the U.S. Department of the Interior has identified fluorspar as a critical mineral dependent on foreign sources.[47]

Table 2 2018 Trade in Acid Grade Fluorspar

	Imports ($ Million)				
Exporter	**China**	**Japan**	**Korea**	**Taiwan**	**United States**
China	(c)	27.1	8.0	3.3	0.2
Japan	(a)	(c)	(b)	(b)	0.3
United States	(a)	(b)	(a)	(b)	(c)
Mexico	9.3	(b)	(b)	(b)	60.5
Other	17.9	10.7	0.3	(a)	44.2

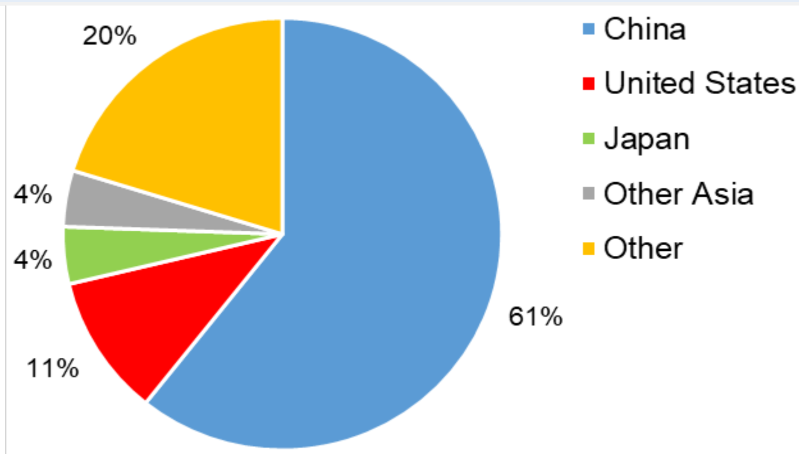
Source: IHS Markit, Global Trade Atlas database for HTS subheading 2529.22 (accessed July 17, 2019).
(a) Less than $100,000.
(b) No trade in 2018.
(c) Not Applicable.

[45] Most deposits are not currently economical to mine. One firm recovers and sells some fluorspar in Illinois, and stockpiles the mineral at another mine in Kentucky. Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 23; USGS, "Fluorspar," February 2019; Mindat.org, "Minerva No. 1 Mine," "Rosiclare Mine," "Klondike Mine," (accessed July 25, 2019).
[46] Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 51.
[47] Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 28; 82 Fed. Reg. 60835; 83 Fed. Reg. 23295.

Producing HF from fluorspar is relatively straightforward. The acid grade mineral is reacted with sulfuric acid (H_2SO_4) to produce HF and calcium sulfate (gypsum, $CaSO_4$) as a byproduct.[48] However, crude HF can contain impurities from the mineral—such as arsenic, phosphorous, and silicon—or undesired side products with sulfuric acid.[49] Further processing is necessary to remove these impurities before HF can be used for semiconductor manufacturing. The presence of even minute quantities of other elements can lead to inadvertent doping of the semiconductor material during processing, which degrades the function of the resulting component or prevents it from operating.

While China leads overall production of HF (including unrefined HF, figure 8), Japan is the global leader in highly purified HF used in semiconductor production. Most of China's HF production is used domestically, with less than 25 percent exported.[50] While Japan produces less than five percent of global HF, it imports substantial quantities from China.[51] Japanese firms have increasingly imported and consumed Chinese HF rather than fluorspar over the past decade.[52] However, Chinese HF is too crude to be used in advanced semiconductor manufacturing. The Japanese companies have developed process technology for purifying and homogenizing lower grade HF.[53] Because of the time and resources required to develop and qualify a replacement source in this industry, those firms have a competitive advantage, as it takes consumers time and money to test the usability of other firms' HF. Japanese media reports that Japan produces 70 percent of the HF used for etching globally.[54]

Figure 8 Unrefined Hydrogen Fluoride production share by reegion, 2016



Source: Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 12.

[48] Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 18.
[49] For example, fluorosulfuric acid (HSO_3F). Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 17–18.
[50] For example, fluorosulfuric acid (HSO_3F). Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 95–96.
[51] Examples of Japanese HF producers for the semiconductor industry include Central Glass (anhydrous and aqueous grades) and Daikin (aqueous grades). Central Glass, "Hydrofluoric Acid," (accessed July 26, 2019); Daikin, "Semicon Etching Agents," (accessed July 26, 2019).
[52] Wietlisbach, Gao, and Funada, "Fluorspar and Inorganic Fluorine Compounds," January 2016, 62.
[53] Industry representative, telephone interview by USITC staff, July 23, 2019.
[54] Reuters, "Factbox: the High-Tech Materials at the Heart of a Japan-South Korea Row," July 2, 2019 (accessed July 30, 2019).

Note: this figure shows shares of production of all HF, including unrefined HF, of which China is the leading producer. Data for 2015.

Korea sources the majority of its HF from China and Japan (table 3). There may be only one firm that produces it domestically, the Foosung Co.[55] The company currently supplies Korean manufacturers like Samsung and SK Hynix, and it has reportedly received requests to increase production in response to the Japanese trade actions as those consumers test replacements.[56]

Table 3 2018 Trade in Hydrogen Fluoride

	Imports ($ Million)				
Exporter	**China**	**Japan**	**Korea**	**Taiwan**	**United States**
China	(c)	229.8	83.0	87.0	3.2
Japan	2.1	(c)	66.9	1.1	3.8
Korea	11.7	(b)	(c)	(b)	1.8
Taiwan	11.8	0.4	9.1	(c)	1.2
United States	0.8	(b)	0.5	2.3	(c)
Mexico	(b)	(a)	(b)	(b)	165.0
Other	4.7	0.1	0.1	5.6	8.7

Source: IHS Markit, Global Trade Atlas database for HTS subheading 2811.11 (accessed July 17, 2019); Trade data provided by KITA for HSK 2811.11.1000, communication to authors, August 23, 2019.
(a) Less than $100,000.
(b) No trade in 2018.
(c) Not Applicable.

Taiwan, in contrast, does not source large quantities of HF from Japan, instead being almost wholly reliant on Chinese imports (see table 3). It also possesses its own hydrofluoric acid production capability, although less than other producers.[57] Taiwanese firms may use a similar model as Japan, where imported crude HF from China is refined for use in domestic semiconductor manufacturing.[58] Korean manufacturer LG Display is reportedly testing Taiwanese HF as a replacement for Japanese product.[59] At least one HF producer in Taiwan appears to be affiliated with or is a subsidiary of a Japanese firm, and it is unclear what the trade restrictions would have on its operations or potential sales to Korea.[60]

Fluorinated Polyimides

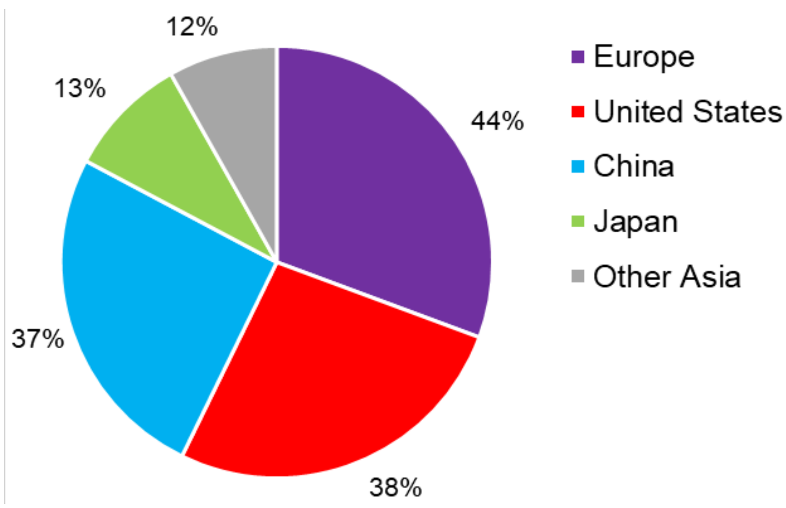
Polyimides are a group of specialty polymers that provide physical strength and heat resistance for demanding applications. The general structure of a polyimide typically contains two monomers, a dianhydride and a diamine, which are chosen to impart desired properties.[61] Fluorinated polyimides are a sub-class where part of the polymers is composed of a fluorocarbon group, which imparts greater

[55] Foosung, “Chemical/Environment” (accessed July 26, 2019); Wietlisbach, Gao, and Funada, “Fluorspar and Inorganic Fluorine Compounds,” January 2016, 101.
[56] Yang and Park, “Samsung, SK Hynix Ask Korean Firm to Boost Chemicals Supply Amid Japanese Curbs,” July 16, 2019 (accessed July 26, 2019); Bhayana, “Foosung Co Gets Big Orders for Hydrogen Fluoride from South Korean Electronics Giants,” July 18, 2019 (accessed July 26, 2019).
[57] Wietlisbach, Gao, and Funada, “Fluorspar and Inorganic Fluorine Compounds,” January 2016, 102.
[58] Taiwan imported circa 38.6 kt, exported 5.9 kt, and produced 60 kt of HF in 2015,
[59] Herh, “LG Display Testing Taiwanese and Chinese Hydrofluoric Acid,” July 10, 2019 (accessed July 26, 2019).
[60] Formosa Daikin Advanced Chemicals Co., “Company Profile” (accessed July 26, 2019).
[61] A dianhydride is a chemical that contains two anhydride groups. An anhydride group is formed by the dehydration, that is, removal of water, and linkage of two carboxylic acid groups and takes the general form of R_1-(C=O)-O-(C=O)-R_2. A diamine is a chemical that contains two amine groups, taking the form H_2N-R-NH_2.

stability.[62] The properties of polyimides make them suitable for a variety of applications. Electronics manufacturers use them in end-uses including electrical insulation, flexible substrates, and displays.[63] Fluorinated polyimides under consideration here find substantial use in organic light-emitting diodes (OLEDs), displays, and printed circuits, and they can be deposited on a substrate and patterned much like other microelectronics layers.[64] They are desirable for these applications because they can replace glass screens and allow flexible and lightweight electronics.

Trade and production data on fluorinated polyimides and their monomers are limited. Overall consumption of polyimides is led by the Europe, the United States, and China; however, those figures include all polyimides, not just the fluorinated polyimides used in semiconductor fabrication (see figure 9). The majority of polyimide manufacturers do not appear to produce fluorinated polyimides.[65]

Figure 9 Polyimide consumption by region, 2017



Source: Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 6, 69–71.
Note: Data for 2017. Includes both fluorinated polyimides and out of scope polyimides. Other Asia includes Korea, Taiwan, Malaysia, and India, which is dominated by Korea (5 percent of world total) and Taiwan (3 percent of world total).

Producers of polyimides for electronics applications appear to be globally distributed, although there remains a cluster of producers in East Asia.[66] Known manufacturers of relevant monomers include

[62] A prototypical example is a polyimide based on 6FDA, whose synthesis is outlined in figure 5. The fluorocarbon in this case is hexafluoropropanone (per- or hexafluoroacetone), which reacts with two equivalents of ortho-xylene and is then oxidized to form a dianhydride monomer. Polymerizing with a diamine yields the final fluorinated polyimide. Either the dianhydride or the diamine can have a fluorocarbon group, and both are commercially available. Science Direct, "Fluorinated Polyimides" (accessed July 30, 2019); Daikin Chemicals, "6FDA, Others" (accessed July 30, 2019).
[63] Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 8–10.
[64] Industry representative, telephone interview by USITC staff, July 23, 2019.
[65] Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 24–25, 54–55.
[66] Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 7.

DuPont (United States) and Daikin Chemical (Japan), both of which have a global presence.[67] DuPont also produces polyimides in Japan through various joint ventures that, along with Japanese producers like Kaneka Asahi Kasei, and Fujifilm, accounts for a substantial share of world production for these applications.[68] Korea is also home to one of the largest manufacturers, in addition to joint ventures between Japanese and Korean firms for displays.[69] Taiwan rounds out the East Asian market with one of the largest producers, Taimide Technology.[70]

It is unclear what fraction of these firms' business is devoted to fluorinated polyimides. Japanese media reports that about 90 percent of these polymers are produced in Japan; however, that value could not be independently verified.[71] According to KITA, Japan supplied 93.7 percent of Korea's fluorinated polyimide imports between January and May 2019.[72]

Photoresists

The role of photoresists in semiconductor processing is to provide the patterns used to build the micro-circuitry. The resist is applied to the surface of a wafer and exposed to light through a photomask that has the desired pattern. The light makes portions of the resist susceptible to certain chemicals, which remove those parts of the resist during a subsequent development step. What's left is the desired pattern for building part of the microelectronic component.

Choosing the proper resist is a complex process requiring several months of work before full-scale production is feasible.[73] When a firm is starting-up a semiconductor manufacturing process, they typically provide documentation of their needs to a resist manufacturer and request samples that could meet their needs. The firm then screens the samples to determine which have the greatest potential and asks the manufacturer for refinement, a process that can take weeks or months. If one of the refined samples works, full-scale production can take several additional months to ensure quality and consistency. It is unclear if the Japanese export restrictions would require a license for each individual resist test sample, which could add significant amounts of time and effort to the process.

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[67] Other companies are listed in market analysis reports, but current availability of offerings is not apparent from their websites. Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 19; Daikin Chemicals, "6FDA, Others" (accessed July 30, 2019); DuPont, "6-FDA Technical Information," October 26, 2006.
[68] HD MicoSystems, "Liquid Polyimides & PBO Precursors" (accessed July 30, 2019); Asahi Kasei, "Photosensitive Polyimide/PBO PIMEL" (accessed July 30, 2019); Fujifilm, "Polyimides and PBO's" (accessed July 30, 2019); Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 7, 54–55.
[69] SKC Kolon has an estimated total capacity of circa 3,300 metric tons per year between two manufacturing sites. Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 7, 69.
[70] Taimide Technology, "Product List" (accessed July 30, 2019); Linak et al, "Polyimides and Imide Polymers," December 14, 2018, 7, 69.
[71] Reuters, "Factbox: the High-Tech Materials at the Heart of a Japan-South Korea Row," July 2, 2019 (accessed July 30, 2019).
[72] This fraction is larger than the overall share of Japanese exports of fluorinated polymers to Korea, which were 22 percent for powder and 85 percent for film. Trade data provided by KITA for HSK 3911.90.9000 (powder) and 3920.99.9010 (film), communication to authors, August 23, 2019.
[73] Industry representative, telephone interview by USITC staff, July 26, 2019.

A disruption in the resist supply chain has the potential to fundamentally alter a manufacturer's process.[74] The firm would rely on any stockpiles it has, which are typically minimal given the shelf life of the resist chemicals and the small quantities in which they are typically purchased; industry analysts estimate the shelf life of these chemicals to be between 3 and 6 months.[75] Samsung has reportedly asked its vendors to stockpile enough chemicals to last three months in response to the current situation.[76] Once those run out, production would cease until a replacement is found. Capital depreciates rapidly within this industry, where high volumes and constant uptime are required for profitability at state-of-the-art manufacturers. Replacing a resist with a different product from another supplier, even if nominally the same formulation, requires additional months of process qualification that starts from scratch. They need to be proven to meet the technical needs of the process, and the new production needs to demonstrate an ability to scale their production while maintaining quality. This would cause significant problems, as alternatives to Japanese resists are uncommon.

An extreme ultraviolet (EUV) photoresist performs the same function as any other; however, it operates under much tighter tolerances due to the size of the features being built and the energy of the light used for patterning.[77] EUV lithography equipment is currently used in commercial production of semiconductors that contain transistors at 7 nanometers (nm) in width, enabling the industry's most advanced devices.[78] Several Korean semiconductor manufacturers, including Samsung and SK Hynix, make use of EUV equipment that relies on these specialized photoresists to fabricate some of the most advanced commercially available semiconductor devices. The level of complexity and precision required to produce feature sizes at this scale necessitates highly specialized chemicals that have undergone rigorous qualification, and few firms are able to meet these demands.

Japanese media reports that Japan produces approximately 90 percent of global photoresists, and over 90 percent of 2018 Korean photoresist imports originated from Japan.[79] There are less than five Japanese resist manufacturers currently supplying the industry or that could potentially enter the EUV space.[80] Like HF, Japan has refined technology and high-quality manufacturing systems since firms continue to invest in this space.[81] JSR Corporation offers EUV photoresists alongside less advanced

[74] Industry representative, telephone interview by USITC staff, July 26, 2019.
[75] 10–100 kg batches. Industry representative, telephone interview by USITC staff, July 26, 2019.
[76] Obe and Jaewon, "Inside the Lose-Lose Trade Fight between Japan and South Korea," August 4, 2019 (accessed August 13, 2019).
[77] The EUV photoresist is a mixture of complex polymers with tightly controlled structure and photoacid generators that assist with the development process. The precise formulation is highly specific for a given customer, application, and manufacturing process and changes depending on the type of semiconductor being manufactured. Photoacid describes a system where acid molecules are released within the photomask upon exposure to light. Those acid molecules then further react with the polymers in the resist and increase the light's area of effect within the resist.
[78] One nanometer is equal to one billionth of a meter.
[79] Reuters, "Factbox: the High-Tech Materials at the Heart of a Japan-South Korea Row," July 2, 2019 (accessed July 30, 2019); trade data provided by KITA for HSK 3707.90.1010, communication to authors, August 23, 2019.
[80] According to Global Market Insights, four firms account for more than 75 percent of the global photoresist market, two of which are based in Japan: Tokyo Ohka Kogyo Co, and JSR Corporation. According to industry representatives, Fujifilm Electronic Materials is also likely providing EUV materials, and Sumitomo Chemical Co. has market entry potential. Pulidindi and Chakraborty, "Photoresist and Photoresist Ancillaries Market Size… 2017–2024," May 2017; Industry representative, telephone interview by USITC staff, July 26, 2019.
[81] Industry representative, telephone interview by USITC staff, July 26, 2019.

technologies, as does Tokyo Ohka Kogyo Company (TOK).[82] Both companies have a manufacturing presence outside of Japan as well, which can more rapidly meet local demand. JSR has semiconductor production sites in the United States, Korea, Taiwan, and Europe.[83] The facility in Europe is a joint venture with IMEC in Belgium, which is dedicated to developing and manufacturing EUV photoresists.[84] TOK manufactures photoresists, but not necessarily EUV photoresists, in Taiwan, the United States, Korea, and the Netherlands.[85] Fujifilm, Shin-Etsu Chemical Company, and Sumitomo Chemical are all manufacturers of older photoresists in Japan, but they do not advertise EUV technologies among their offerings.[86]

Photoresist manufacturers in Korea are reportedly less advanced and serve older manufacturing nodes. These include Dongjin Semiconductor Company, which manufactures resists at one facility in Balan; Dongwoo Fine Chemicals—a subsidiary of Sumitomo—which operates one facility in Sinheung to supply DRAM and flash memory photoresists; and DuPont Electronic Solutions, which maintains three sites in Hwaseong and Cheonan with Rohm and Haas Electronic Materials Korea LTD.[87]

Firms outside of Asia have, for the most part, ceased developing EUV photoresist technology due to the high capital and R&D costs required to bring a product to market. DuPont stopped R&D on EUV photoresists several years ago, staying at the 193 nm node. EMD Performance Materials, a subsidiary of Merck headquartered in Darmstadt, Germany, also stopped development to focus on other market sectors.[88] Firms like these would require several years to restart R&D and bring production online to meet the needs of the most advanced consumers. There is one alternative in the United States, a startup based in Portland called Inpria that uses tin oxide nanomaterials instead of polymers as the photoresist.[89] The company has received attention and funding from manufacturing equipment and semiconductor firms, although any switch to the technology would have the same qualification and time requirements of switching to a different polymer photoresist.[90]

[82] JSR Corporation, "Electronic Materials" (accessed July 30, 2019); JSR Corporation, "JSR EUV Lithography Materials"; TOK, "Semiconductor Manufacturing Field" (accessed July 30, 2019).
[83] JSR Corporation, "Materials Innovation Corporate Profile."
[84] IMEC, "JSR and imec Formalize Joint Venture for EUV Lithography Resist Solutions," February 22, 2016 (accessed July 30, 2019); JSR Corporation, "EUV Resist Manufacturing Facility Completed," February 2, 2017 (accessed July 30, 2019).
[85] TOK, "Sites Overseas" (accessed July 30, 2019).
[86] Industry representative, telephone interview by USITC staff, July 26, 2019; Fujifilm, "Photoresists" (accessed July 30, 2019); Shin-Etsu, "Lithography" (accessed July 30, 2019); Sumitomo Chemical, "Semiconductor Photoresists and Functional Cleaning Solutions" (accessed July 30, 2019).
[87] Dongjin also has several manufacturing locations in China and Taiwan. Tremblay, "South Korea Is Catching up in Electronics Materials," February 22, 2016; Dongjin, "Materials for Semiconductor" and "Domestic" (accessed July 30, 2019); Dongwoo, "Top Partner in 3E"; DuPont, "Photoresists" and "Global Locations" (accessed July 30, 2019).
[88] Industry representative, telephone interview by USITC staff, July 26, 2019; EMD Group, "Photresists for Optimized Patterning Processes" and "Merck KGaA, Darmstadt, Germany Presents New Material Advancements for Next Generation Lithography" (accessed July 30, 2019).
[89] Inpria, "Inpria" (accessed July 30, 2019); McCoy, "Inpria," October 31, 2016.
[90] Merritt, "ASML Invests $1.9B in Next-Gen EUV," November 3, 2016 (accessed July 30, 2019); Inpria, "EUV Photoresist Pioneer Inpria Raises $23.5 Million in Series B Funding Led by Samsung Ventures," July 10, 2017 (accessed July 30, 2019).

Short and Long-term Implications of Japan's export control actions

Industry representatives expect that Japan's export control actions on semiconductor equipment and material can have substantial impacts on Korea's semiconductor industry in the near and medium term.[91] The degree of the impact partly depends on the predictability with which the Japanese companies are able to acquire export licenses. The minimal disruption case is if export licenses are rapidly approved, which will deter production shutdowns. In a scenario where there are licensing delays and production lines have to temporarily mothballed, the Korean industry are likely to seek alternative suppliers, the qualification of which will take several months.[92] The potential overall impact can be significant on the Korean semiconductor firms' bottom lines given the high capital costs of the industry that can ill-afford low process utilization.

Direct Production and Trade impacts for Korea

The direct impact on Korea's semiconductor production and exports depends on the length of the potential shortage of imported chemicals needed for production of semiconductors and display panels. Because a significant portion of semiconductors products are exported to markets outside of Korea, exports figures provide adequate approximations of potential sales losses for Korean producers in case of a production delays or stoppage. In the past year, Korea recorded monthly exports of approximately $7.7 billion of integrated circuits, and $0.8 billion in display parts (which accounts for LED and OLED – Table 1). Together, the potential short-term upper-bound monthly impact on Korea's production and exports (assuming a complete production disruption) is about $8.4 billion.

Table 4 Korea's exports of potentially impacted products ($ million)

Export Code	Product description	Monthly average	Quarterly average
854231	Processors And Controllers, Electronic Integrated Circuits	$1,746.7	$5,240.1
854232	Memories, Electronic Integrated Circuits	$5,525.0	$16,575.0
854233	Amplifiers, Electronic Integrated Circuits	$4.5	$13.5
854239	Electronic Integrated Circuits, Nesoi	$381.4	$1,144.1
854290	Parts For Electronic Integrated Circuits And Microassemblies	$21.1	$63.2
(a)	Display parts	$752.9	$2,258.6
	Total	$8,431.5	$25,294.5

Source: Global Trade Atlas.
Notes: Monthly average based from 12-month data ranging from August 2018 and August 2019 (latest data available). Quarterly average is the monthly average multiplied by 3.
(a) We estimate that display parts are included under the following Korea's export codes: 8517701023, 8517701029, and 8517701090.

Of these products, processors and controllers (HS 854131) and memories (HS 854232) are integrated circuits (IC) likely most directly impacted by a potential shortage of specialized chemicals, which account for 95 percent of Korea's IC exports.

[91] Industry representative, telephone interviews by USITC staff, July 23, July 26, and October 7, 2019.
[92] Industry representative, telephone interview by USITC staff, July 23, July 26, and October 7, 2019.

Even in the best-case scenario with minimal delays, this action will likely spur long-term changes in Korea.[93] As semiconductors encompass a significant portion of Korean exports (about 19 percent of total Korean exports), this type of supply chain vulnerability will not be tolerated in the long-term.[94] It is likely that there will be increased investment in moving or building some of the capacity for these chemicals to Korea (or seek other import sources) as firms work to ensure they are not in this situation again, although that process could take years to complete.[95] That would, eventually, lead to a major shift in the supply chain as Korean firms may be unlikely to switch back to Japanese suppliers if they are forced to look elsewhere for the necessary products. The Korean government has taken some steps to encourage on-shoring of chemical manufacturing capacity recently by relaxing regulatory requirements for replacements of previously imported substances.[96]

Direct Production and Trade impacts for Japan

The impact on Japanese exporters also depends on the potential length of delays due to export control licensing procedures. Korea imported on average about $33.6 million monthly in the listed chemicals related to semiconductor manufacturing from Japan in the past year (Table 5). This figure provides an approximate upper-bound monthly impact on Japanese exporters for disruptions in their exports. Unlike semiconductor producers in Korea where production could suffer acutely by a potential lack of necessary inputs, chemical producers in Japan could potentially redirect their exports to other consuming markets, including China, Taiwan, and the United States.

Table 5 Korea's imports of potentially impacted chemicals from Japan ($ million)

Import code	Tariff Line Description	Monthly average	Quarterly average
2811111000	Hydrogen Flouride	$5.3	$15.9
3707901010	Photoresist	$26.1	$78.2
3911909000	Flourinated Polyimides - Powder	$2.2	$6.7
3920999010	Polyimides Film, For Manufacturing Printed Circuit Board With The Function Of Lead Frame	$2.2	$6.7
	Total	$33.6	$100.7

Source: Global Trade Atlas; KITA.
Note: Monthly average is based on August 2018 to August 2019 data (latest available); Quarterly average is the monthly average times three.

How quickly Japanese exporters can find alternative buyers depends on the level of customization associated with individual chemical products and the demand outside of Korea. For some highly customized products, particularly photoresist for EUV applications, alternative buyers in the short-term may not exist. At the very least, assuming that alternative buyers are available outside of Korea, Japanese exporters are likely to face some price declines due to temporary over-supply.

[93] Industry representative, telephone interview by USITC staff, July 23, July 26, and October 7, 2019.
[94] According to Global Trade Atlas, Korea's exports of products under HS8541 and HS8542 accounted for $115.8 in 2018. Korea exported $604.9 billion for all products in 2018. Industry representative, telephone interview by USITC staff, October 7, 2019.
[95] Industry representative, telephone interview by USITC staff, July 23, 2019; Tremblay, "South Korea Is Catching up in Electronics Materials," February 22, 2016.
[96] Kang, "How to Comply with K-REACH Strategically?" September 4, 2019; Song, "South Korea Groups See Supply Chain Boost in Trade War With Japan." September 24, 2019.

Short and Long-term Adjustments

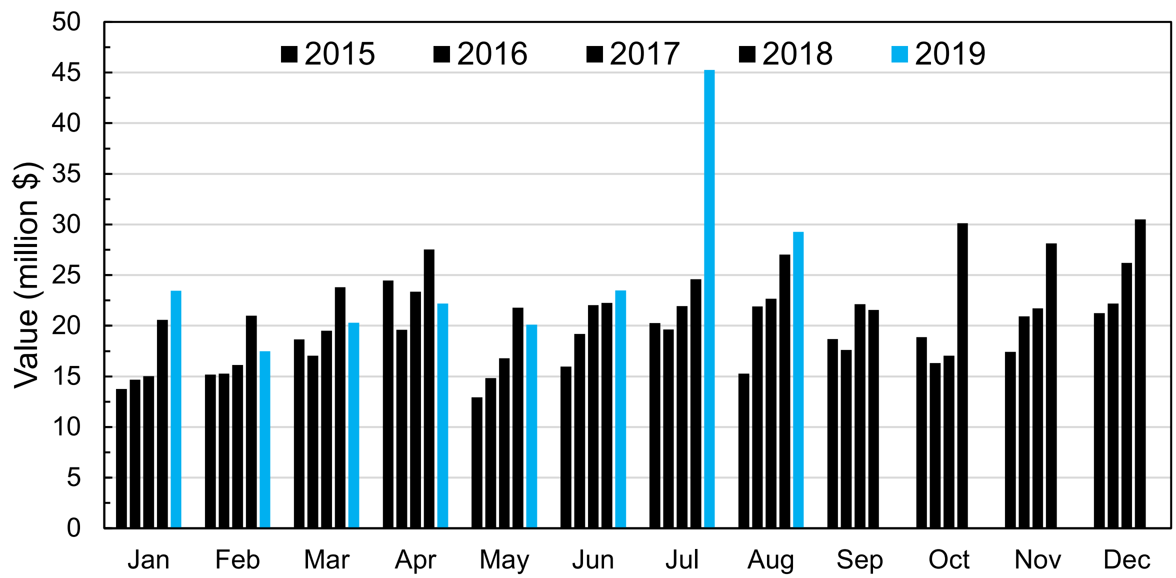
In the short-term, while Japanese chemicals exporters potentially face reduced exports to Korea, in comparison Korean semiconductor producers face a much larger magnitude of production/export losses. On a monthly average, Korea imported $33.6 million value of related chemicals, while exporting $8.4 billion value of semiconductor and display parts that rely on these imported chemicals for their production. If supply disruptions were to occur, the short-term export loss for Korean semiconductor producers are approximately 250 times that of Japanese chemical exporters.

In the long-term however, because Korean semiconductor producers face incentives to reduce supply chain risks by diversifying their chemical supplies with domestic and non-Japanese suppliers, Japanese chemical producers could lose out on the Korean export market, which is among the leading and fastest growing semiconductor producing countries.

Short term Trade Trends

Because trade data is limited to only two months since the announcement of Japan's actions, we do not attempt to identify or isolate definitive impacts of Japan's trade actions with trade data. However, some unusual trends in Korea's monthly imports of from Japan can be observed. Korea's monthly imports of photoresist from Japan averaged $25 million in 2018, but imports almost doubled in July 2019 to $45 million before decreasing to $29 million in August 2019 (figure 10). The average import prices (value/quantity) stayed relatively stable during July and August 2019. This spike in July imports suggest a possibility that importing firms are stockpiling Japanese photoresist chemicals due to uncertainty about future supply.

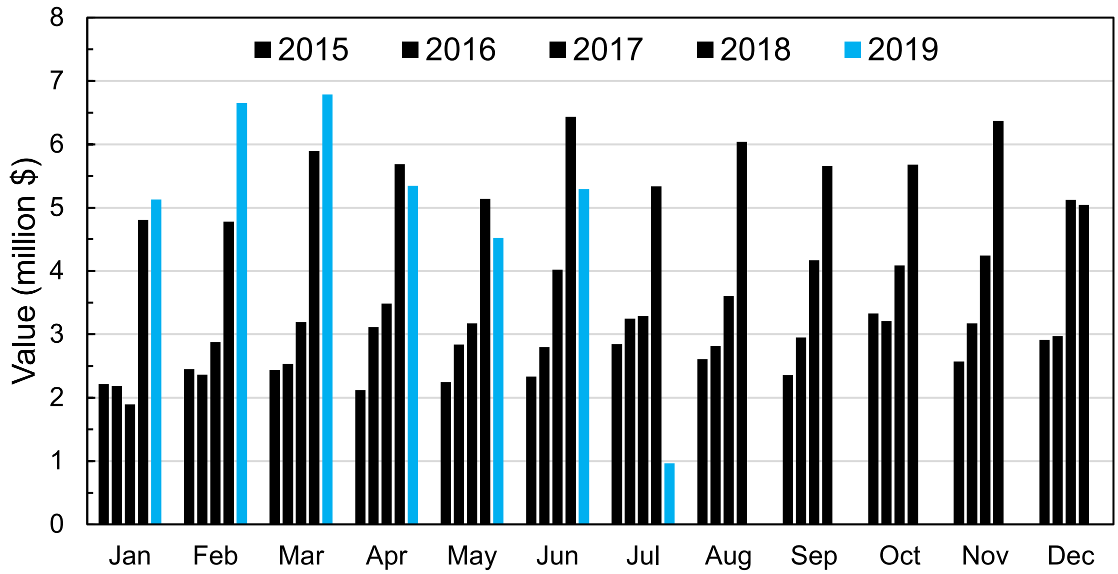
Figure 10 Korea's monthly imports of photoresist chemicals from Japan ($M)



Source: Global Trade Atlas.

Korea's imports of hydrogen fluoride from Japan showed an opposite trend, as imports from Japan dropped from a monthly average of $5.6 million in 2018 to slightly less than $1.0 million in July 2019 and $0.0 million in August 2019 (figure 11). This immediate monthly drop in imports from Japan was only partially offset by a modest increase of imports from Taiwan, which increased from $0.4 million in June 2019 to $1.1 million in July and $2.6 million in August. Overall, Korean imports of hydrogen fluoride decreased substantially in July and August 2019, suggesting a potential combination of consumption of existing stockpiles, increased consumption of domestically produced chemicals, or decreased overall consumption.

Figure 11 Korea's monthly imports of hydrogen fluoride from Japan ($M)

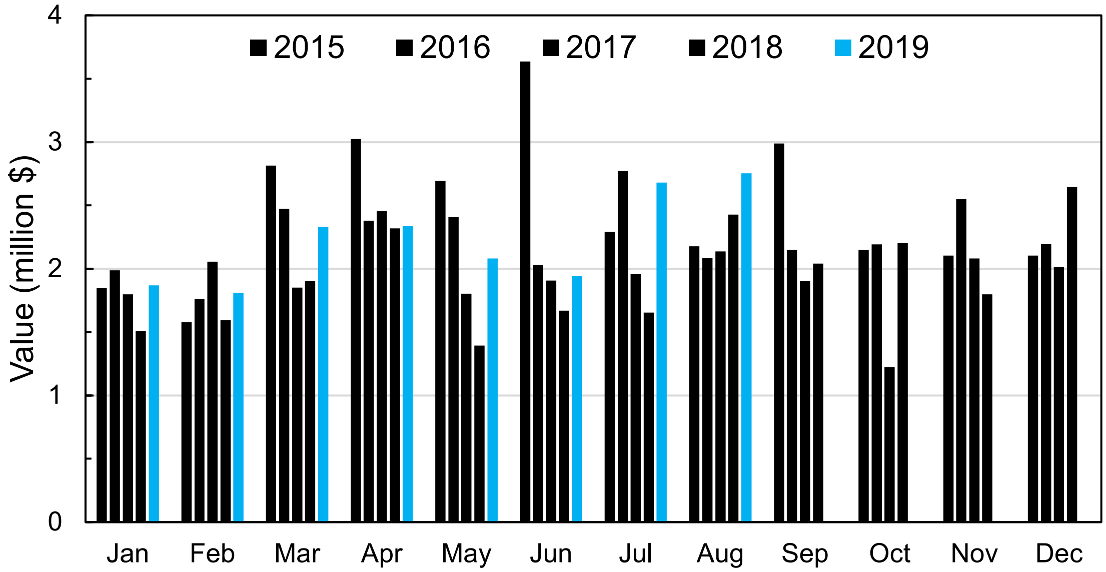


Source: Global Trade Atlas.

The pattern of Korea's monthly imports of fluorinated polyimides from Japan remained relatively stable in July and August 2019 compared to previous years (Figure 12).[97] The different patterns of short-term trade among the three chemicals categories is likely a reflection of substitutability, relative reliance on Japanese imports, and storage capacity of these chemicals for importing firms in Korea.

[97] The import code for fluorinated polyimides captures a broader basket category, potentially muting the immediate trade patterns compared to the other two chemicals categories analyzed in this section.

Figure 12 Korea's monthly imports of fluorinated polyimides from Japan ($M)



Source: Global Trade Atlas.

Impacts on Other the United States and Countries

Japan's export controls on semiconductor materials and equipment are likely to affect other countries as well, either directly or indirectly. Some firms would likely benefit from a shutdown of Korean capacity, namely TSMC (Taiwan) and Intel (United States), which would still have access to the Japanese EUV photoresists to produce the most advanced chips. Producers that compete with Korean chipmakers, like Micron (United States), are likely to benefit from at least some short-term price and demand increases in specific semiconductor products. Similarly, foundries that compete with Korean chipmakers (particularly TSMC) could potentially benefit from increased demand for their foundry services. Companies like Apple (United States) which manufactures its chips exclusively in Taiwan, would be unaffected.

However, companies like Nvidia (United States) that partner with a Korean foundry to produce chips, and all of the downstream producers that use Korea-made chips in their products—including cell phones, displays, and TVs—could be in a crunch as their supply chains are disrupted. They would have to find alternate sources so they can continue to build products, a process that would, again, take a substantial amount of time (months to years depending on the product) to ensure the replacements meet specification.

In the short-term, China is unlikely to be able to capitalize on the dispute to gain further foothold in the global microelectronics value chain because its chemicals industry is not likely to be able to produce the kind of high-quality inputs required by state-of-the-art chip production.[98] It would, however, provide

[98] According to industry sources, firms are reluctant to build state-of-the-art chemical facilities in China due to fears of intellectual property theft. Industry representative, telephone interview by USITC staff, July 23, 2019.

additional incentives to their already stated goals of self-sufficiency in their domestic semiconductor production.

The Japanese export controls may also create additional challenges in identifying potential bottlenecks within the semiconductor supply chain for the global industry, including in the United States. While there have been publicly expressed discussions and concerns within the U.S. government about chip manufacturing, comparatively little attention has been given to the chemical supply chains.[99] For example, the U.S. Department of the Interior assembled a list of critical minerals and cited the use of some in electronics as an important consideration.[100] While fluorspar is on that list, the fact that the majority of semiconductor grade HF comes from a handful of firms in one country poses challenging considerations regarding finished chemical products in addition to sourcing raw materials. The fact that Japan's export controls have the potential to shut down substantial production in another country emphasizes the risks involved in dealing with such a concentrated grouping of critical chemicals suppliers. The semiconductor industry and related policy makers may now be required to consider the full chemical supply chains for potential disruptions, whether policy driven or the result of natural disasters.

Conclusion: A new type of risk in semiconductor supply chains

The semiconductor industry of the past three decades has been characterized by its globalized production processes with fewer firms specialized in their portions of the supply chain. For the most part, the industry has relied on predictable and low trade costs to maintain supply chain efficiencies. The recent trade tensions between Japan and Korea pose unique challenges as it risks the availability of specialized and necessary chemicals that are not easily substitutable without imports.

Our paper argued that these risks are likely to force firms in the industry to make investment and sourcing decisions related to specialized chemicals that are otherwise counter-intuitive. There are no clear winners, and strong supplier-customer relationships face an uncertain future. Japanese firms with clear competitiveness in the manufacturing of these chemicals risk losing customers in a market where there are currently no obvious alternative buyers. Korean firms with clear competitiveness in semiconductor manufacturing may be forced to invest in or source from alternative sources that are inferior to their current sources. New firms that may enter the market as alternative chemicals suppliers face uncertain investment decisions in a highly capital intensive industry. These political tensions may last months, while several years may be necessary for them to catch up to the level of incumbents' manufacturing efficiency and quality.[101]

These actions have the potential to become an ongoing risk in the semiconductor supply chain for Japan and Korea, with consequences for the global semiconductor industry, industries that supply to

[99] The U.S. Department of Defense has been engaged in this area for the past several years due to concerns over the source of components and intellectual property theft, but with a focus on manufacturing chips, not chemicals. United States Department of Defense, "Trusted and Assured Microelectronics" (accessed August 2, 2019).
[100] United States Geological Survey, "Interior Releases 2018's Final List of 35 Minerals Deemed Critical to U.S. National Security and the Economy," May 18, 2018 (accessed August 2, 2019).
[101] Song, Jung-a, "South Korea Groups See Supply Chain Boost in Trade War with Japan." September 24, 2019.

semiconductor manufacturers, and wider electronics industries that rely on semiconductors as inputs.[102] If these supply chain risks stemming from seemingly unresolved and unrelated bilateral political tensions continue, difficult and costly trade and investment decisions may be unavoidable.

[102] One analyst suggests a "potential decoupling of the two countries in the semiconductor industry..." Park, June. "Semiconductor tech war underlies the Japan-South Trade Dispute," East Asia Forum, September 24, 2019.

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