

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

Samuel M. Goodman, Dan Kim and John VerWey

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 competitiveness 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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Introduction

In July 2019, the Japanese government imposed export restrictions on various goods to South Korea (referred to as “Korea” throughout this paper), including key chemical materials and machinery used for semiconductor production.¹ The global semiconductor industry has publicly expressed concerns and called for efforts to reduce the potential “regulatory uncertainty, potential supply chain disruptions, and delays in shipments that may result from this ongoing dispute.”² Understanding the implications of the recent trade tensions between Japan (a highly competitive supplier of semiconductor machinery and materials) and Korea (a highly competitive producer of semiconductors) requires an examination of the semiconductor industry supply chain, which is simultaneously globalized in its production flow and concentrated among a few leading firms for various inputs.

Low international trade costs have significantly contributed to making the semiconductor industry’s supply chain globally expansive.³ In the past three decades, global and regional trade policies have generally encouraged tariff and non-tariff related trade costs related to the semiconductor supply chain to remain low and predictable. For example, the 1996 World Trade Organization (WTO) Information Technology Agreement (ITA) effectively zeroed out tariffs for 97 percent of world trade in information technology products, including most semiconductors.⁴ Recent analysis by the U.S. International Trade Commission found that the tariff elimination by the ITA significantly expanded U.S. exports of covered products.⁵ Relatedly, the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) and the United States, Mexico, and Canada Trade Agreement (USMCA) include provisions that prohibit restrictions of imports on commercial cryptography products, which include semiconductors.⁶

Meanwhile, primarily due to increasingly high fixed costs and specialization, semiconductor related industries have consolidated significantly in the past 30 years.⁷ For example, most of the global market for photolithography equipment was supplied by three leading firms (from the Netherlands and Japan) in 2018.⁸ Further in the supply chain, about 10 DRAM memory chip producers accounted for 80 percent of global production in 1995. By 2014, three producers (two from Korea and one from the United States) accounted for more than 90 percent of global market share.⁹ These two trends of supply chain globalization and industry consolidation have led to more concentrated groups of upstream suppliers

¹ Maizland, Lindsay, August 2019. [“The Japan-South Korea Trade Dispute: What to Know.”](#)

² Multi-association letter, July 23, 2019, [Letter to Japanese and Korean governments.](#)

³ United States International Trade Commission (USITC), “The Economic effects of Significant U.S. Import Restraints,” September 2017, 9.

⁴ WTO, “Information Technology Agreement” (accessed August 29, 2019).

⁵ Econometric estimates suggests export expansion of about 56 percent (\$34.4 billion) by 2010 relative to the baseline of no ITA. USITC, “Economic Impacts of Trade Agreements Implemented Under Trade Authorities Procedures,” June 2016, 148.

⁶ [Government of Canada, “Consolidated TPP Text – Chapter 2 – National Treatment and Market Access for Goods,” June 28, 2018](#) (accessed August 29, 2019); [Office of the United States Trade Representative, “Agreement between the United States of America, the United Mexican States, and Canada 05/30/19 Text,” November 30, 2018](#) (accessed August 29, 2019).

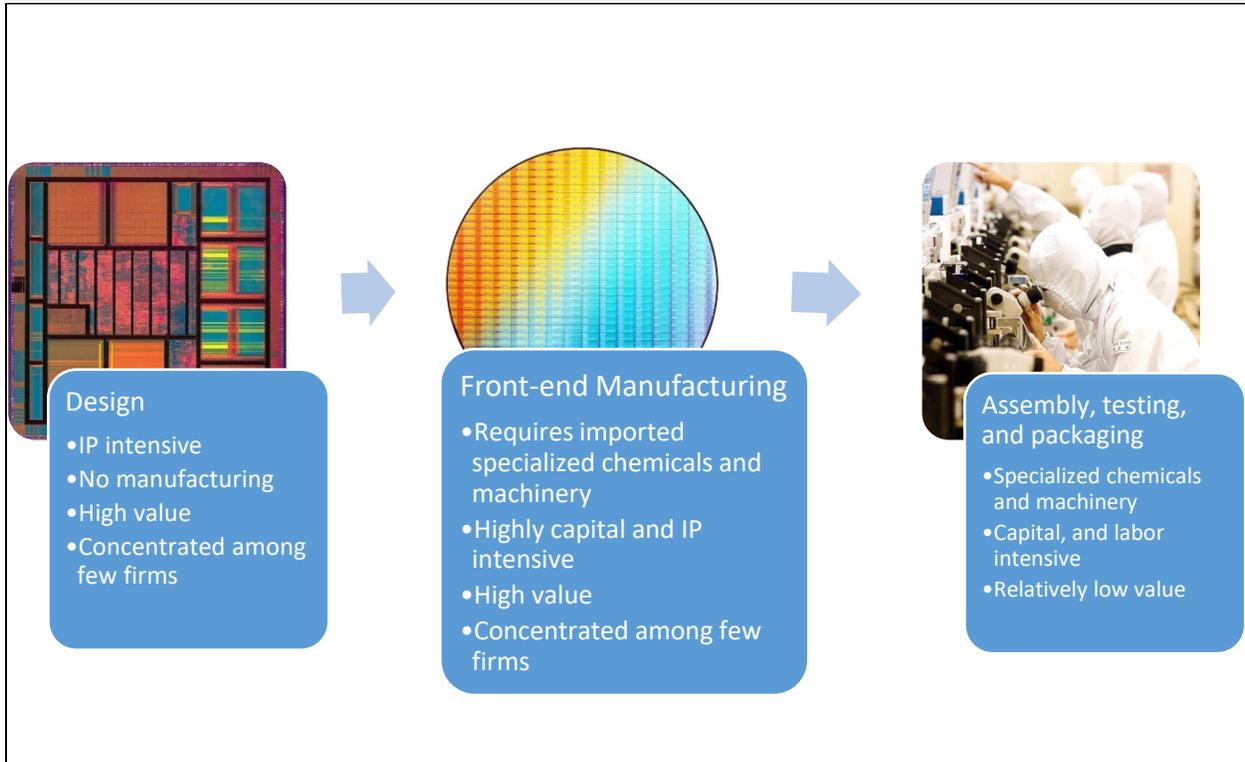
⁷ Only a few firms can afford to keep up with these costs. A new fabrication facility is estimated to cost at least \$10 billion.

⁸ VerWey, “Health and Competitiveness of the U.S. Semiconductor Manufacturing Equipment Industry,” July 2019.

⁹ Bauer, H., et al, “Memory: Are Challenges Ahead?,” March 2016 (accessed August 29, 2019).

(equipment and materials) selling to more concentrated groups of customers (chip producers), relying on internationally sourced goods and intellectual property (figure 1).

Figure 1: Semiconductor production flow



Source: figure by authors based on SIA 2016, “Beyond Borders,” 4–6.

Because the semiconductor industry is concentrated and globally dispersed, disruptions to the supply chains are felt acutely, as firms do not have easily replaceable suppliers in the short-term and long-term solutions are costly to implement (see Box 1). This supply chain risk became apparent in 2011, when a major earthquake and tsunami off the coast of Japan significantly affected the production of vehicles by Toyota, Nissan, and Honda for several months. Analysis of this disruption showed that the most vulnerable portion of the Japanese automotive supply chain was the production of automotive semiconductors, which analysts suggest were effectively single-sourced from Renesas (Japan).¹⁰ When Renesas’ production capacity became severely limited after the earthquake, switching to other production sources took several months.¹¹ This experience showed how reliant downstream producers—in this case, Japanese auto producers—are on single-sourced semiconductor suppliers. However, the benefits of these seemingly exclusive supplier-customer relationships appear to have outweighed the risks, partly because these risks were limited to unexpected events like natural

¹⁰ Matsuo, “Implications of the Tohoku Earthquake for Toyota’s Coordination Mechanism: Supply Chain Disruption of Automotive Semiconductors,” March 2015.

¹¹ Matsuo, “Implications of the Tohoku Earthquake for Toyota’s Coordination Mechanism: Supply Chain Disruption of Automotive Semiconductors,” March 2015.

disasters. Renesas remains the key supplier of automotive processors for Toyota, exhibiting an extraordinarily strong supplier to customer relationship.¹²

Box 1: Example of Semiconductor materials supply disruptions

Supply chain risks due to political tensions between major supplying countries is an unfamiliar situation for this industry, though there is a useful comparison to a recent unexpected supply chain disruption as an outcome of a military conflict. The supply of highly purified Neon gas (necessary for semiconductor lithography) was severely impacted due to the Russia-Ukraine conflict in 2014. The price of Neon increased by 600 percent with the impending shortage, as most of the global supply was sourced from a few firms located in Ukraine. Industry analysts estimated that adding new capacity would require costly investments that take years to complete. Firms had little choice but to pay the higher costs of inputs and adjust their production processes to recycle as much Neon gas as possible. The price of Neon has since stabilized, but semiconductor producers were forced to recognize and adapt to this unexpected supply chain vulnerability with no easy solutions.

The key difference between the Neon shortage and recent tensions between Japan and Korea is that the industry's supply chain was not deliberately targeted in the case of Neon. That is, the Neon shortage could be interpreted as a one-time disruption as a result of a larger geopolitical event. The recent trade actions by Japan poses a fundamentally different risk for firms. The targeting of specialized materials between two countries with highly integrated supply chains have been interpreted by the industry as a signal of a willingness to expose supply chain vulnerabilities for what industry representatives view to be unrelated bilateral political disputes.

Sources: Schaeffer, 2015; Dorsch, 2015; Fukuda, et al. 2016; industry representatives, July 2019.

In this context, this paper aims to examine the implications of Japan's export controls for the semiconductor industry. Japan's export control actions and the resulting trade tensions have introduced supply chain risks due to trade policy. Firms along the semiconductor supply chain may take into account supply chain disruptions due to unexpected single events (like an earthquake) in their investment and sourcing decisions, but supply chain disruptions and risks due to trade policy among major producing countries is largely uncharted territory for the industry.¹³

This paper examines the implications of such risks by placing these trade tensions in context, with a deep dive into three specialized chemicals and their role in the supply chain. The paper is organized as follows. First, we summarize the Japanese export controls on sales of semiconductor machinery and materials to Korea.¹⁴ Second, we explore the factors behind Japan's competitiveness in semiconductor's materials and equipment industries, and Korea's competitiveness in semiconductor manufacturing. Third,

¹² For example, Renesas' partnership with Toyota to supply MCUs for autonomous-driving vehicles. Renesas, "Renesas, Toyota, and Denso Bring Autonomous-Driving Vehicles to Market Faster," October 31, 2017 (accessed August 29, 2019).

¹³ With the notable exception of industry concerns with China's investment plans. VerWey, "Chinese Semiconductor Industrial Policy: Past and Present," July 2019; VerWey, "The Health and Competitiveness of the U.S. Semiconductor Manufacturing Equipment Industry," July 2019.

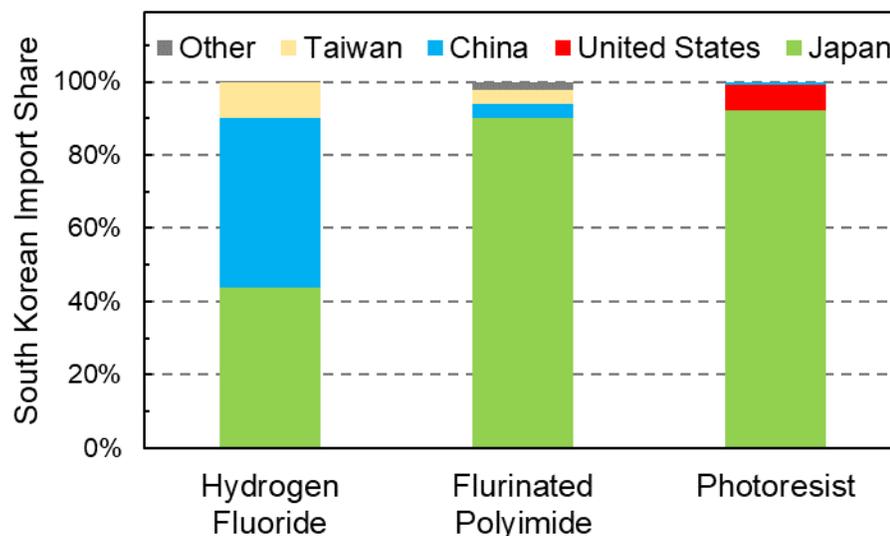
¹⁴ Although the Japanese government has disputed this is an "export control" action, its announcements indicate amendments to its exports controls regulations, as explained below. We do not examine the political merits of this dispute.

we examine the chemicals involved in these trade actions, their uses in the supply chain, and why it may be difficult to find substitute inputs for semiconductor producers. And fourth, we examine the short and long-term implications of sustained supply chain risks for this particular supply chain. We conclude by examining the potentially increasing role of political risks in this industry’s global supply chain.

Background on Japan’s Export Controls

On July 1, 2019, Japan announced that it would restrict exports of certain key semiconductor manufacturing materials to Korea. These materials—hydrogen fluoride, fluorinated polyimides, and photoresist/resist, “and their relevant technologies”—are important inputs for Korea’s semiconductor industry.¹⁵ The Korea International Trade Association (KITA) estimates that for all three types of semiconductor related chemicals, Japan is a major or leading supplier of these chemicals for Korea (figure 2).¹⁶ Analysts have traced the origins of these actions as a part of a longstanding dispute between the two countries concerning reparations for forced Korean labor during Japan’s colonial-WWII period.¹⁷ This paper makes no commentary on the merits the dispute between these two countries.

Figure 2: Sources of Semiconductor Related Chemicals Imports for Korea, by source (percent of total) from January to May 2019



Source: Korea International Trade Association, communication to authors, August 23, 2019.

¹⁵ The cited release is on the Japanese Ministry of Economy, Trade, and Industry’s (METI) English language website and does not contain the full details of the action. The full text of the order is in Japanese, and an accurate English translation is not, to our knowledge, currently available. METI, “Update of METI’s Licensing Policies and Procedures on Exports of Controlled Items to the Republic of Korea,” July 1, 2019 (accessed August 1, 2019).

¹⁶ The role of these chemicals are described in more detail in sections below.

¹⁷ See for example, Maizland, August 2019; Smith, July 2019; and Snyder, August 2019.

The export controls mean Japanese companies must apply for a license for each shipment of exports of these listed items.¹⁸ It is worth noting that during the public comments period for this export controls amendment in Japan, several objections were filed citing the potentially negative impact on the Japanese industry supplying these chemicals to Korea.¹⁹

Japan also removed Korea from its “white list” countries, potentially requiring additional export licensing procedures for all exported products to Korea.²⁰ KITA estimates that Korean imports from Japan of these listed products account for 12.6 percent of Korea’s global imports.²¹ Because the items impacted in this additional action are beyond the semiconductor industry, we do not address its wider impacts in this paper.

The impact of these export controls of these specialized chemicals on Korea’s semiconductor industry stands to be significant, placing unwanted risks for both supplying and purchasing firms in the supply chain. When the announcements were made, industry sources speculated that it might take upwards of three months to acquire such export licenses, which could lead to a supply shutdown during the interim for Korean firms that make use of these Japanese-origin materials.²²

Tensions declined somewhat in August 2019 as sales of some photoresists and hydrogen fluoride were approved by the Japanese government.²³ However, industry representatives noted that, even if licenses were initially granted, importing Korean firms would be highly uncomfortable with a continuous dependence on uncertain licensing procedures that may fluctuate with political tensions. In September 2019, the South Korean Government has initiated a WTO dispute.²⁴

¹⁸ Hydrogen fluoride and fluorinated polyimides are captured under Category 5 (Advanced Materials) of Japan’s export control list (sections 1 and 3, respectively), while photoresists fall within Category 7 (Electronics, section 19). The U.S. Department of Commerce also has these items on the Commerce Control List: hydrogen fluoride (1C350.d.10), fluorinated polyimide (1C009.b), photoresists (3C002, 3C992, etc.). The manufacturing equipment aspect is less clear, as it may also fall under Category 7 (section 16) or elsewhere. CISTEC, “Overview of Japan’s Export Controls (4th Edition),” June 2015; 15 C.F.R. § 774 supplement.

¹⁹ Public comments were solicited from July 1–24 and METI reports receiving 40,666 responses, of which 95 percent were in agreement with the proposed action. Cited numbers based on translated version of the posted summary of comments. Comments disagreeing cite a variety of reasons, including a negative impact on Japanese industry. Japan e-Gov, “Public Comment: Result Notice Item Details for Proposal number 595119079,” (accessed August 2, 2019).

²⁰ METI, “The Cabinet Approved partial Amendment to the Export Trade Control Order,” August 2, 2019 (accessed August 2, 2019); Sugihara, Junichi, “Japan officially ousts South Korea from export whitelist.” (accessed October 7, 2019).

²¹ The requirement to license such exports is found in sections 25 and 48 of the Japanese Foreign Exchange and Foreign Trade Law. Trade data provided by KITA, communication to authors, August 23, 2019.

²² Industry representative, telephone interview by USITC staff, July 23, 2019.

²³ Jiji Press, “Japan OKs Exports of Some Chip Materials to S. Korea,” August 8, 2019 (accessed August 8, 2019); Reuters, “South Korea Holds off Plan to Drop Japan from ‘White List’: Trade Ministry Officials,” August 8, 2019 (accessed August 8, 2019); Cho, “Japan Approves Second Material for Samsung Export: Report,” August 30, 2019 (accessed August 30, 2019).

²⁴ WTO, [“Japan-Measures related to the exportation of products and technology to Korea.”](#) September 2019.

Box 2: Background on the Semiconductor Industry

Semiconductors are the enabling hardware for all information technology. Also referred to as integrated circuits (ICs) or “chips,” semiconductors are found in everything from smartphones and computers to automobiles and medical devices. The semiconductor fabrication process is among the most complicated, knowledge-intensive manufacturing processes known. Large multinational companies regularly invest upwards of 20 percent of their annual profits in research and development (R&D) budgets. At the same time, they are coordinating up to 16,000 suppliers to organize the intellectual and physical property needed to produce chips that are nearing atomic feature sizes in heavily automated factories that cost \$10 billion or more and that feature class one cleanrooms.

The semiconductor industry is increasingly mature, with most segments dominated by a small number of large firms that are concentrated in Europe, the United States, Korea, Japan, Taiwan, and China. The barriers to entry in the semiconductor industry are high and stem from many sources, including first mover advantages, economies of scale, brand recognition, stickiness and customer loyalty, intellectual property (IP), and most importantly, high and fixed capital expenditures.

High capital expenditures increasingly stem from the cost of semiconductor manufacturing equipment, the machines that physically fabricate chips. This fabrication process is accomplished by depositing film layers that act as conductors, semiconductors, or insulators to create circuit patterns on wafers, removing select portions, repeating these steps, and then performing heat treatment, measurement, and inspection. The entire process can require over 300 steps utilizing over 50 different types of semiconductor manufacturing equipment. Chemicals are used intensively in all stages of semiconductor manufacturing, from high purity neon to advanced photoresists.

The Competitiveness of Japan and Korea in the Semiconductor Supply Chain

The Japanese Semiconductor Industry's Competitiveness

Japan's semiconductor and semiconductor manufacturing equipment industries developed in tandem. Beginning in the 1960s, Japan's semiconductor industry engaged in license agreements with then-leading U.S. firms, which resulted in a transfer of intellectual property and key technologies. In 1965, Tokyo Electron Laboratories (now known as “TEL,” Japan's largest semiconductor manufacturing equipment (SME) firm) partnered with Fairchild Semiconductor (United States) to act as Fairchild's distributor of testing systems in Japan and later partnered with Lam Research (United States) in the 1980s.²⁵ At the same time, the Japanese government engaged in policies preventing leading U.S. semiconductor firms from directly investing in Japan, protecting nascent Japanese semiconductor firms from competition.²⁶ Japanese firms leveraged knowledge spillovers derived from international partnerships and a favored position in the domestic market in the 1980s to develop dynamic random-

²⁵ TEL, “Milestones” (accessed August 29, 2019).

²⁶ Irwin and Klenow, “Learning-by-Doing Spillovers in the Semiconductor Industry,” 1994, 1206.

access memory (DRAM), with Japanese firm market share increasing from less than 30 percent to nearly 75 percent between 1978 and 1986.²⁷

Japanese firms' investments in process innovation and increasing wafer yields (the number of operable chips per wafer), at a time when the U.S. industry was focused on product innovation, were also bolstered by increasing domestic demand.²⁸ These firms were able to develop semiconductors targeting well-defined end uses (such as consumer electronics), given that many companies that entered the semiconductor business were telecommunications firms (e.g., NEC and Fujitsu), industrial conglomerates (e.g., Hitachi and Toshiba), and consumer electronic companies (e.g., Sharp). This allowed Japanese chipmakers to focus on developing products in response to internal company demand, which in turn provided a test market for a given chip, enabling fast feedback loops.²⁹ It also meant that much of the equipment used to produce semiconductors was produced by Japanese firms, which were also substantial consumers of those semiconductors, allowing them to leverage gains from vertical integration. Though several leading Japanese SME firms are standalone companies, this operating model persists to date. For example, Screen Semiconductor and Hitachi High Tech, which are two of the leading SME firms in the world, are subsidiaries of large Japanese-headquartered industrial conglomerates.

Despite its historic successes, Japan's semiconductor and SME industries have experienced a precipitous loss of market share in the past 15 years (figure 3). Between 2005 and 2017, Japanese semiconductor firms saw their worldwide market share decline from 19 to 9 percent, while Japanese SME firms' worldwide market share was reduced from 25 to 11 percent over the same time period. Semiconductor companies in Japan developed products designed to appeal to Japanese consumers and as the domestic consumer market has declined, demand for semiconductors and the equipment that makes semiconductors declined.³⁰ The Great Recession in 2009 and the 2011 Fukushima Earthquake both accelerated these declines, from which Japan's semiconductor and SME industries have yet to recover.

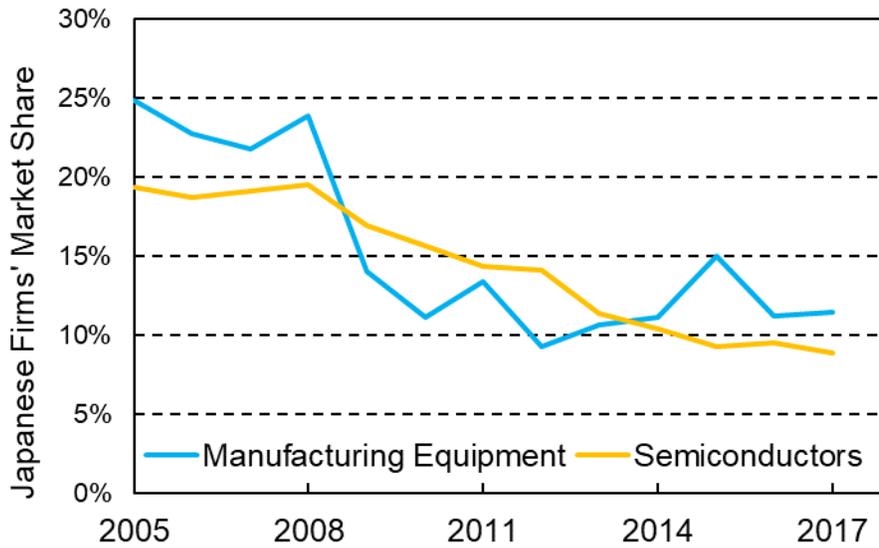
²⁷ Irwin, "The U.S.-Japan Semiconductor Trade Conflict," 1996, 7.

²⁸ Langlois and Steinmueller, "Strategy and Circumstance: the Response of American Firms to Japanese Competition in Semiconductors, 1980-1995," 1999, 1167.

²⁹ Cho, Kim, and Rhee, "Latecomer Strategies: Evidence from the Semiconductor Industry in Japan and Korea," 1998, 493-496.

³⁰<https://ihsmarkit.com/research-analysis/japanese-semiconductor-companies-continue-to-struggle-in-a-very-tough-semiconductor-market.html>

Figure 3: Japanese Semiconductor and SME Firm Worldwide Billings, 2005–17

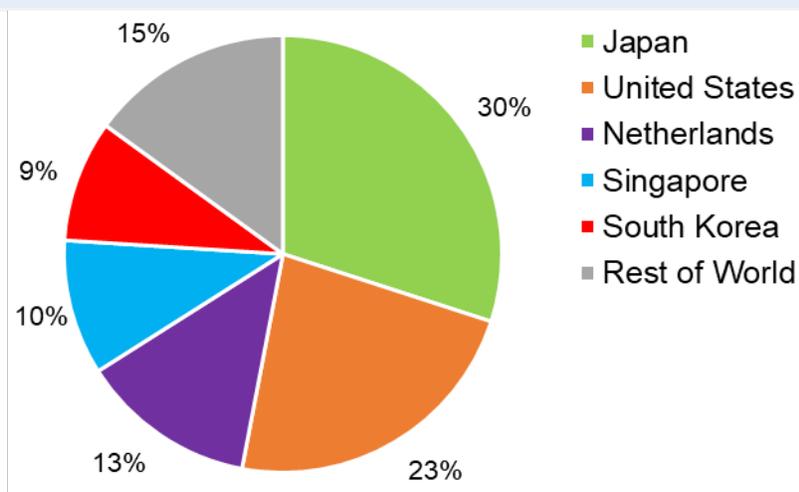


Source: Semiconductor Equipment Association of Japan, “World Wide Semiconductor Equipment Manufacturing Statistics (Billings)”; World Semiconductor Trade Statistics, “Historical Billings Report,” 2019.

Japanese exports of semiconductor manufacturing equipment remain globally competitive despite this decline, and several Japanese firms retain considerable market share due to the maturity of the global industry and high barriers to entry. Japan, the United States, the Netherlands, Singapore, and Korea were the largest exporters of SME from 2014-18 (figure 4). Worldwide exports of SME increased from \$46.8 billion in 2014 to \$83 billion in 2018 and, for that five-year period, total worldwide exports were approximately \$310 billion. In fact, the country that experienced the largest increase in exports by value was Japan, with a cumulative increase in exports from 2014-2018 of \$11.7 billion.³¹

³¹ VerWey, “The Health and Competitiveness of the U.S. Semiconductor Manufacturing Equipment Industry,” July 2019.

Figure 4: Top Five Exporters of Semiconductor Manufacturing Equipment, 2014–18



Source: IHS Markit, Global Trade Atlas Database for HTS heading 8486 (accessed April 24, 2019).

The juxtaposition of overall Japanese firm market share declining while Japanese exports continue to lead reflects the high barriers to entry in this industry, which have allowed Japanese companies to retain market share. In 2018, three Japanese firms—TEL, Screen, and Hitachi High Tech—were among the top ten SME firms worldwide (table 1). This is a decline from 2005 however, when five Japanese-headquartered firms—TEL, Advantest, Nikon, Hitachi High Tech, and Canon—were among the top ten semiconductor manufacturing equipment firms worldwide by revenue.³²

Table.1: Global Market Share Held by SME Firms in 2018 (percent of total).

Firm	Headquarters	2018 Market Share
Applied Materials	United States	17.7
Tokyo Electron	Japan	15.0
Lam Research	United States	14.0
ASML	Netherlands	12.1
KLA-Tencor	United States	04.4
Screen Semiconductor	Japan	02.2
Hitachi High Tech	Japan	01.8
ASM International	Netherlands	00.6
Rudolph Technology	United States	00.4
Nova Measuring	Israel	00.3
Nanometrics	United States	00.3
Others		31.1
Top Ten Total		69.1

Source: Statista, “Global Market Share Held by Semiconductor Equipment Manufacturers in 1Q’17 and 1Q’18,” 2018.

A qualitative look at the state of the worldwide SME industry demonstrates both the consolidation and the relatively dominant position that Japanese firms have retained. A 2006 USITC report observed

³² United States International Trade Commission, “Industry and Trade Summary: Semiconductor Manufacturing Equipment,” June 2006, 14.

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.

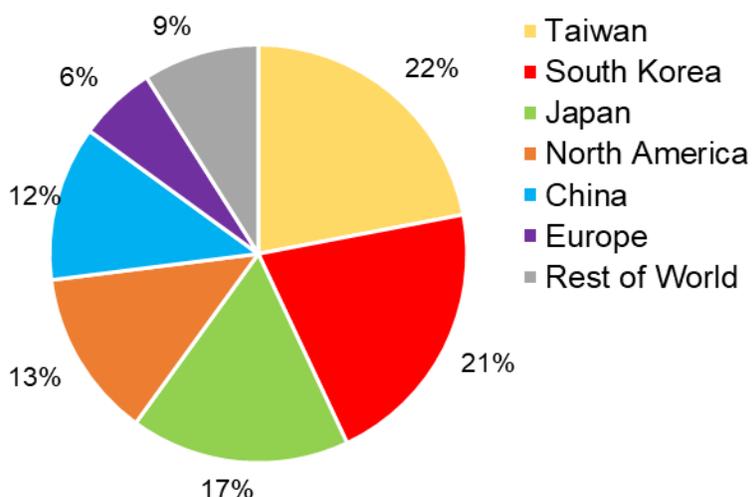
³⁵ Amsden, *Asia's Next Giant*, 1989, 82–83.

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.

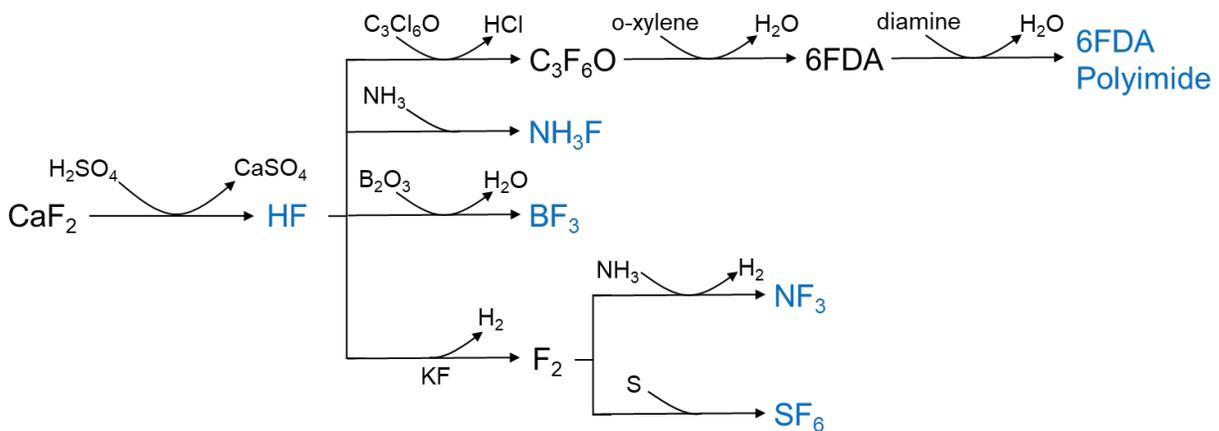
percent decline in year-over-year sales, Samsung and SK Hynix remain in leading positions and are two of only five firms capable of commercial production of today's most advanced chips.⁴²

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 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

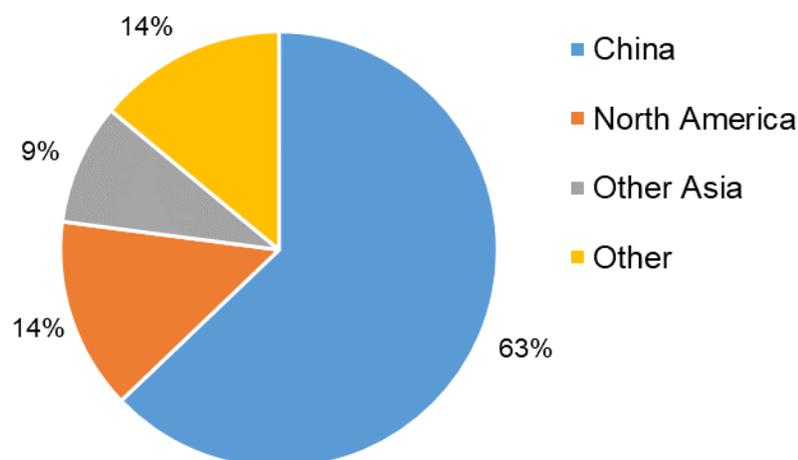
⁴² Han, "Samsung to Apply EUV to 1z DRAM Mass Production for First Time," June 13, 2019.

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,

Exporter	Imports (\$ Million)				
	China	Japan	Korea	Taiwan	United States
China	(c)	27.1	8.0	3.3	00.2
Japan	(a)	(c)	(b)	(b)	00.3
United States	(a)	(b)	(a)	(b)	(c)
Mexico	09.3	(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).

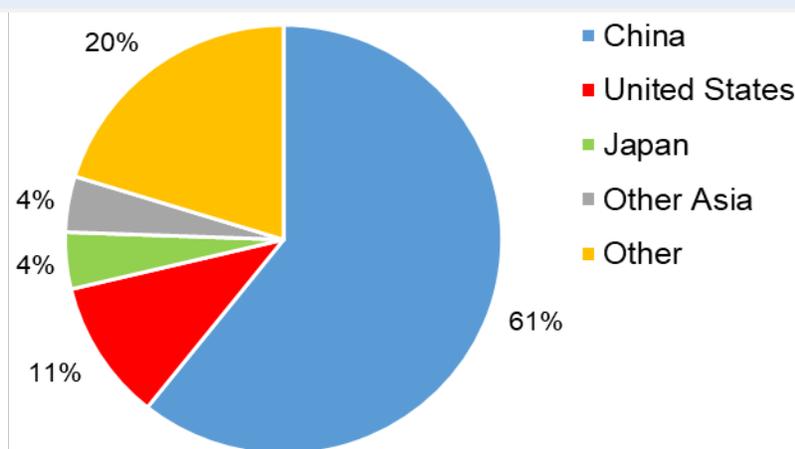
⁴⁶ Wietlisbach, Gao, and Funada, “Fluorspar and Inorganic Fluorine Compounds,” January 2016, 51.

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 (H₂SO₄) to produce HF and calcium sulfate (gypsum, CaSO₄) 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 region, 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 (HSO₃F). Wietlisbach, Gao, and Funada, “Fluorspar and Inorganic Fluorine Compounds,” January 2016, 17–18.

⁵⁰ For example, fluorosulfuric acid (HSO₃F). 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).

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

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

Exporter	Imports (\$ Million)				
	China	Japan	Korea	Taiwan	United States
China	(c)	229.8	083.0	87.0	003.2
Japan	02.1	(c)	066.9	01.1	003.8
Korea	11.7	(b)	(c)	(b)	001.8
Taiwan	11.8	000.4	009.1	(c)	001.2
United States	00.8	(b)	000.5	02.3	(c)
Mexico	(b)	(a)	(b)	(b)	165.0
Other	04.7	000.1	000.1	05.6	008.7

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).

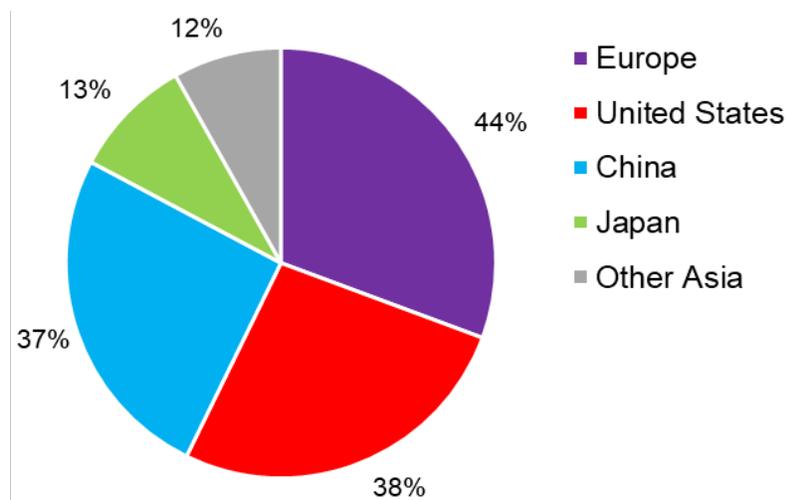
⁶⁰ Formosa Daikin Advanced Chemicals Co., "Company Profile" (accessed July 26, 2019).

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 R₁-(C=O)-O-(C=O)-R₂. A diamine is a chemical that contains two amine groups, taking the form H₂N-R-NH₂.

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.

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

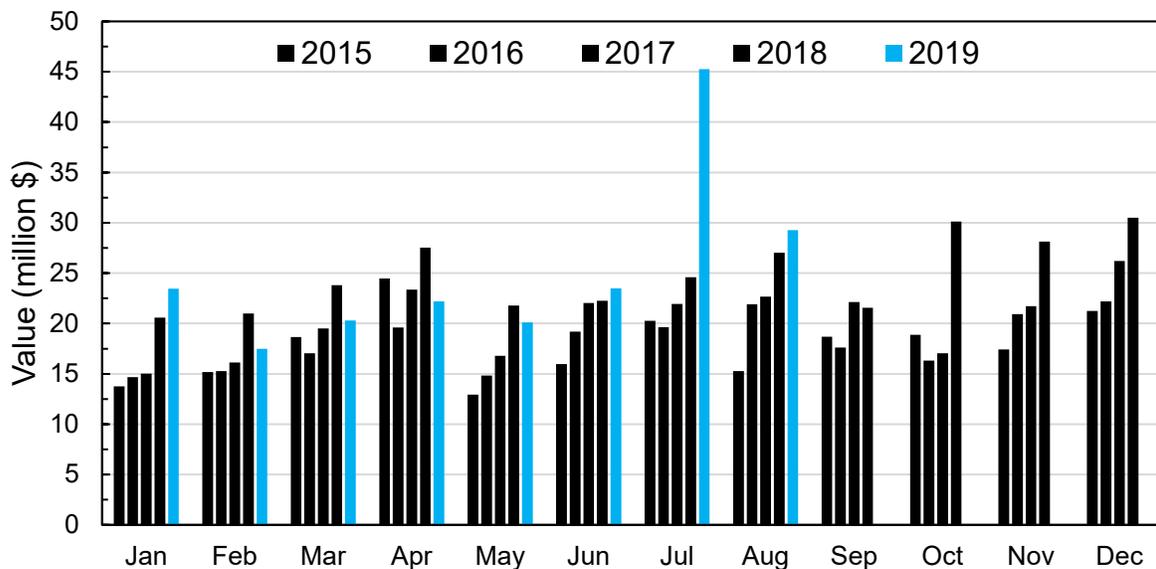
In the short-term, while Japanese chemicals exporters potentially face reduced exports to Korea, in comparison Korean semiconductor producers face a much larger magnitude of production/export losses. On a monthly average, Korea imported \$33.6 million value of related chemicals, while exporting \$8.4 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.

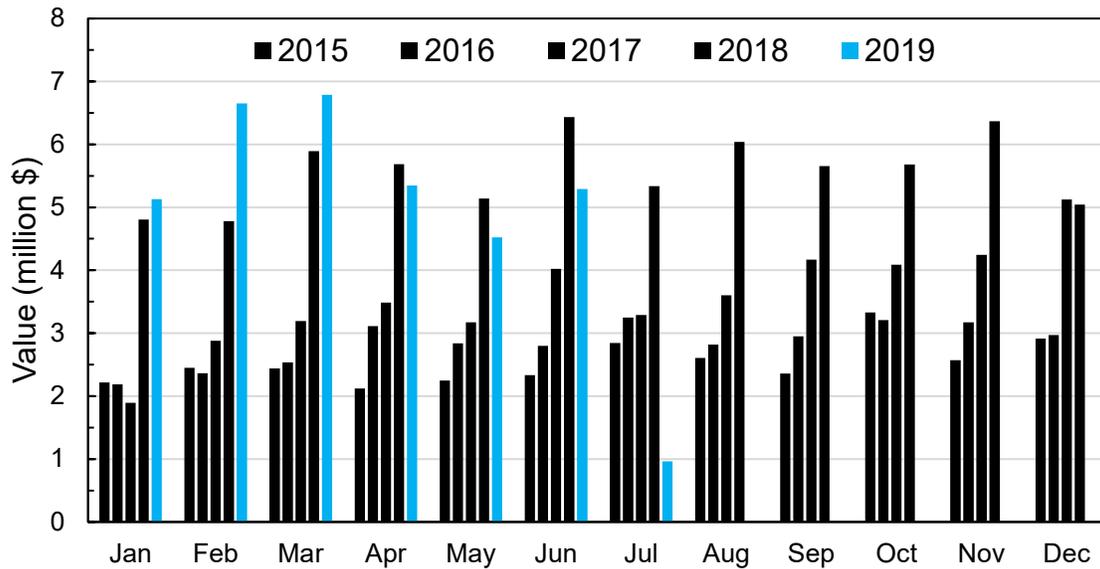
Figure 10: Korea’s monthly imports of photoresist chemicals from Japan (\$M)



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.

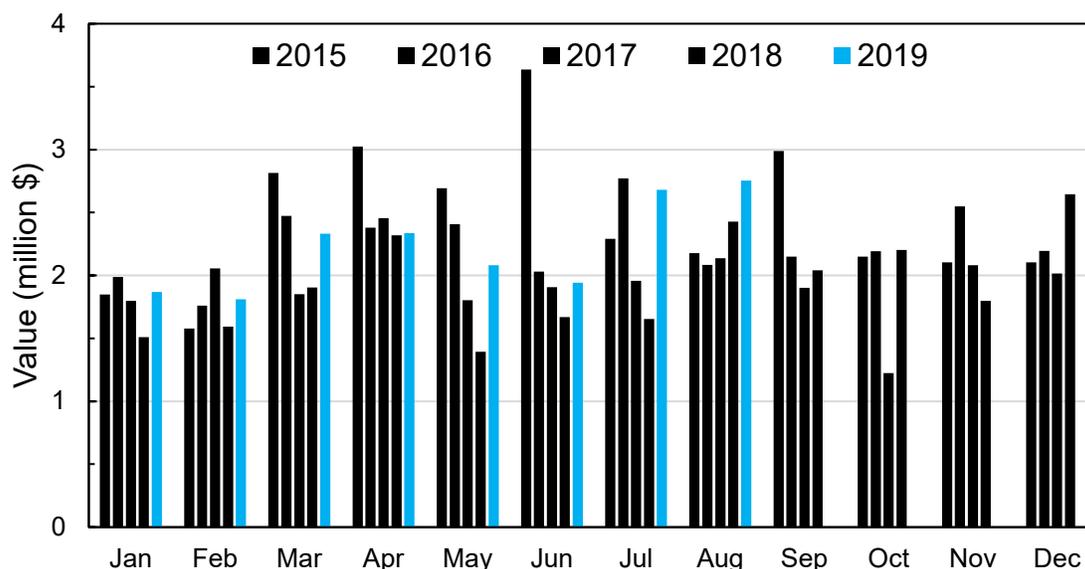
Figure 11: Korea’s monthly imports of hydrogen fluoride from Japan (\$M)



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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