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The Impact of US Export Controls on Korean Semiconductor Exports†

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This study empirically investigates the impact of recent US export controls on China on South Korea's semiconductor exports. We analyze South Korean export data to shed light on the repercussions of US export restrictions on a third country. Our findings reveal a significant decline in Korean semiconductor exports following the October 2022 imposition of US controls. This decline was most pronounced in the memory, discrete devices, and discrete device components subsectors of the semiconductor industry. In addition, we observed a decrease in unit prices, especially for memory semiconductors, pointing to downward pressure on South Korea's high-value-added semiconductor exports. These results provide some evidence of substantial negative impacts of US export controls on South Korea's semiconductor industry, and particularly with regard to its high-tech products.

Keywords: US Export Controls, South Korean Exports, Semiconductors, Export Control Classification Numbers (ECCNs), Gravity Equation
JEL Code: F13, F14, F51

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I. Introduction

The global trade paradigm is undergoing a significant transformation. The era of free trade, which has underpinned global economic growth for the better part of a half-century, is giving way to a new era of protectionism and economic nationalism, driven by the intense technological competition between the United States and China (Caliendo and Parro, 2023). This shift is particularly evident in the industries home to critical advanced technologies and related industries, such as artificial intelligence (AI), quantum computing, semiconductors, secondary batteries, and biotechnology, where governments are increasingly intervening to protect and nurture domestic players in these strategic sectors (Whang, 2021; European Parliamentary Research Service, 2021; The White House, 2023). This trend has profound impacts not only on the superpower belligerents but also on economies and actors connected to those two giants through global industrial ecosystems (Tung, Zander and Fang, 2023).

This paper empirically examines the impacts of recent US export controls on China, focusing on their effects on South Korea's semiconductor exports. By analyzing South Korean export data, we aim to shed light on the repercussions of US export restrictions on a third country not directly involved in the US-China trade dispute. Our analysis produces three key findings that taken together reveal that US export controls have had a substantial negative impact on South Korea's semiconductor industry, particularly on exports of its most advanced chip technologies.

Specifically, we found that South Korean semiconductor exports plunged by 14% following the imposition of US export controls in October of 2022. Drops in exports of three specific subsectors, memory semiconductors (32%), discrete devices (26%), and discrete device components (43%), accounted for this decline. We also observed a decrease in unit prices, especially for memory semiconductors, indicating that these controls also exerted some downward pressure on South Korea's high-value-added memory semiconductor exports. These results highlight the substantially negative impact of US export controls on South Korea's semiconductor industry, particularly on its high-tech products.

We focus on three instances of strengthened US export controls targeting China, occurring in May of 2020, October of 2022, and October of 2023. The measures promulgated on these three separate occasions hold significance for several reasons. First, in May of 2020, the US enhanced the Foreign Direct Product Rule (FDPR), which constrains the ability of major exporters of integrated circuits (ICs) such as South Korea and Taiwan to ship their products to China. In October of 2022, the US instituted broader export controls targeting the Chinese semiconductor industry by adding more Chinese companies to the Entity List, expanding the scope of export restrictions. Finally, October of 2023 saw the US reinforce these controls, extending them to related products and technologies.

South Korea serves as a compelling case study on the third-country effects of these export controls. According to the UN Comtrade database, in 2022 South Korea accounted for approximately 25% of global memory semiconductor (Harmonized Standard, HS 854232) exports. Notably, approximately 72% of South Korea's memory semiconductor exports went to China, including Hong Kong. Given this high level of dependence, analyzing changes in South Korean exports in response to US controls can provide valuable insight into the broader implications of the measures. Our analysis utilizes detailed South Korean export data categorized according to the Korean Harmonized Standard (KHS) 10-digit system. This quantitative approach allows us to present specific findings on the impact of US export controls, as given below.

First, using indicator variables to represent the targets of US export controls, we found a statistically significant negative correlation between South Korea's semiconductor exports to China and Hong Kong after October of 2022, which coincides with the implementation of stricter US export controls. No significant relationship was found for the periods after September of 2020 or October of 2023, however. Second, we analyzed specific subsectors within the semiconductor industry. The results of this analysis indicate a negative association between exports of products such as memory, discrete devices, and discrete device components for the period following the October 2022 restrictions. Finally, we also observed a negative association between unit prices and the aforementioned indicator variables, especially for memory semiconductors in the period following the October 2022 restrictions.

Together, these empirical findings provide compelling evidence that US export controls impacted South Korea's semiconductor exports to China, particularly exports of memory semiconductors. The data point to a substantial impact on exports of high-tech products, which typically carry higher unit prices. This highlights the significant influence of US trade policies on the global semiconductor market, with the export performance of South Korea in this crucial industry serving as a prime example of the consequences of the ongoing paradigm shift in the global trade order.

Our research builds upon recent empirical studies examining US trade sanctions against China. Hayakawa (2024) found a decline in exports of US ICs and equipment to China after the October 2022 controls were instituted and a decline in exports of IC products from South Korea and Taiwan to China after the August 2020 tightening of the FDPR. Hayakawa et al. (2023) also found that the August 2020 enhancement of the FDPR hurt Japanese exports of mobile phones and other wireless network devices to China. Ando et al. (2024) illustrated how the inclusion of Huawei on the US Entity List substantially reduced Japanese exports to China through Huawei's supply chain. Together, these studies collectively show how US export controls targeting China have ripple effects on third countries through interconnected global production networks.

Our study offers several contributions to this body of literature on the subject of US export controls and their impacts. First, we leverage more granular, product-level trade data from South Korea, categorized using the 10-digit KHS system. This detailed approach mitigates overestimation and underestimation issues that can arise with broader, 6-digit categories, given that the impact of export controls can vary across different products within the same category. Second, we delve deeper into the semiconductor industry by classifying products into eight distinct categories aligned with the corresponding 10-digit KHS codes. This fine-grained analysis illuminates how export controls affect specific product segments within the semiconductor industry, whereas prior studies relied on broader classifications such as ICs, processors, and equipment. Finally, we meticulously identify items subject to export controls through a comprehensive review of government documents that outlined the 2022 and 2023 measures. Using Export Control Classification Numbers (ECCNs), we compiled a list of controlled products and matched them to 10-digit KHS codes, utilizing the Korea Strategic Trade Management Institute's ECCN-KHS linkage system. This rigorous approach ensures our analysis focuses precisely on products targeted by the export controls and achieves a higher level of precision than the works in the extant literature, which have thus far focused on the broader semiconductor industry.

In addition to impacts on trade, export controls have broader economic ramifications. Cerdeiro et al. (2021) and Funke and Wende (2022) employed simulation models to analyze the economic effects of US export controls. The findings of these works point to a potential decline in GDP for both the US and China as well as global market disruptions due to trade diversions. Jones and Karreth (2010) investigated the influence of strategic trade controls on economic development, highlighting the reach of such controls in the trade in high-tech products. Their work observed the impacts on dual-use materials and found that producers incurred various new costs due to licensing complexities, among other issues.

While our work focuses on the impact of US export controls on Korea, a handful of studies in the literature have also used Korea as a case study. Two works in particular sought to investigate the impact of Korea's own export control system. Jang and Song (2021) examined how strategic product controls influenced Korean trade from 2015 to 2019, finding a positive effect on imports, particularly in capital-intensive industries. Similarly, Moon and Jang (2023) explored the influence of strategic product controls on Korean industrial productivity over the same period, observing a positive effect on productivity attributed to more robust international trade.

Despite growing interest in US export controls, empirical analyses of their economic and trade impacts remain rare apart from the handful of studies discussed earlier. Given the ongoing paradigm shift in the global industrial landscape, continuous investigation and methodological advancements are crucial for understanding government interventions. Our study contributes to this body of knowledge by providing a comprehensive analysis of the latest US export controls, shedding light on their intricate effects and implications for third countries such as South Korea.

The remainder of this paper is organized as follows. Chapter 2 discusses the background and methodology of the US export control regime, surveying the key features of the implemented policies and some underlying concepts. We also describe in detail the methodology used to construct the data set for our study, presenting three cases of US export controls. The chapter also summarizes how we classify the various segments of the semiconductor industry and the approach we used to compile the list of controlled ECCNs. Chapter 3 employs a gravity equation for an empirical assessment of the impact of US export controls on South Korea's semiconductor exports to China. Chapter 4 addresses the study's limitations and outlines potential directions for future research.

II. Background

Our analysis hinges on understanding the institutional framework and key features of the US export control framework and how it impacts South Korea's semiconductor exports. This chapter explores the key features of this system, and our findings here inform the empirical analysis of Chapter 3.

A. *US Export Controls*

1. Export Administration Regulations (EAR)

The US aims to safeguard its national security through robust export controls administered by the Bureau of Industry and Security (BIS). The Export Administration Regulations (EAR), given legal force through the Export Control Reform Act of 2018 (ECRA), serve as the primary legal framework for these controls (BIS, 2024a).

The EAR, bolstered by various statutes and executive orders, governs the exports of not only US goods, parts, and technologies, but also the export of goods by third countries containing US products, parts, or technologies. Violations can incur severe penalties, up to a trade ban with the United States (BIS, 2024b). Administered by the BIS under the Department of Commerce, the EAR also regulates dual-use items with both civilian and defense applications (BIS, 2024b).

The US export control system operates under a combination of executive authority, international multilateral agreements, and foreign economic sanctions. Different government agencies oversee controls for specific sectors, with the Department of Commerce responsible for managing trade in dual-use goods by private entities (BIS, 2024b).

2. Export Control Classification Numbers (ECCNs)

The BIS maintains the Commerce Control List (CCL), which identifies items requiring export control under the EAR (BIS, 2024c). Items on the CCL are assigned Export Control Classification Numbers (ECCNs) and must be licensed for export. An ECCN categorizes an item based on what type of product it is (i.e., software, commodity, technology), its key features, and its technical specifications. Conversely, EAR99 items, typically low-tech products, are exempt from licensing requirements unless destined for embargoed or sanctioned countries or prohibited end-uses. Determining export license requirements involves verifying if an item has a specific ECCN (BIS, 2024c). An ECCN is an alphanumeric code that identifies items regulated by the EAR and specifies licensing prerequisites. The first digit denotes an item's respective category on the CCL (electronics, computers, and sensors for example). The second letter indicates the specific product group (e.g., inspection and manufacturing, software, and technology).

Recent US export controls have increasingly focused on semiconductors and related equipment, which typically fall under Category 3 (electronic products) on the

CCL (OFR, 2022; 2023a; 2023b). As shown in the table below, ECCN categories are broad, but specific subcategories are delineated within (BIS, 2024d).

Commerce Control List Categories

0	Nuclear Materials, Facilities And Equipment (and Miscellaneous Items)
1	Materials, Chemicals, Microorganisms and Toxins
2	Materials Processing
3	Electronics
4	Computers
5	Part 1 -- Telecommunications and Part 2 -- Information Security
6	Sensors and Lasers
7	Navigation and Avionics
8	Marine
9	Aerospace and Propulsion

Five Product Groups

A	End Items, Equipment, Acce ssories, Attachments, Parts, Components, and Systems
B	Test, Inspection and Product ion Equipment
C	Materials
D	Software
E	Technology

FIGURE 1. STRUCTURE OF THE COMMERCE CONTROL LIST (CCL)

Source: BIS (2024c). "Export Control Classification Number (ECCN)," Retrieved on May 4, 2024. (https://www.bis.doc.gov/index.php/licensing/commerce-control-list-classification/export-control-classification-number-eccn).

TABLE 1— CATEGORY 3 ECCN CODES (SEMICONDUCTORS)

ECCN	Description
3A001	Electronic items as follows (see List of Items Controlled)
3A090	Integrated circuits as follows (see List of Items Controlled)
3A991	Electronic devices, and "components" not controlled by 3A001
3B001	Equipment for the manufacturing of semiconductor devices, materials, or related equipment, as follows (see List of Items Controlled) and "specially designed" "components" and "accessories" therefor.
3B002	Test or inspection equipment "specially designed" for testing or inspecting finished or unfinished semiconductor devices as follows (see List of Items Controlled) and "specially designed" "components" and "accessories" therefor
3D001	"Software" "specially designed" for the "development" or "production" of commodities controlled by 3A001.b to 3A002.h, or 3B (except 3B991 and 3B992)
3D002	"Software" "specially designed" for the "use" of equipment controlled by 3B001.a to .f and .k to .p, or 3B002
3E001	"Technology" according to the General Technology Note for the "development" or "production" of commodities controlled by 3A (except 3A980, 3A981, 3A991, 3A992, or 3A999), 3B (except 3B991 or 3B992) or 3C (except 3C992)

Source: BIS (2024d). "Supplement No. 1 to Part 774—The Commerce Control List," Retrieved on June 4, 2024. (https://www.bis.gov/ear/title-15/subtitle-b/chapter-vii/subchapter-c/part-774/supplement-no-1-part-774-commerce-control#3A090).

3. Foreign Direct Product Rule (FDPR)

The Foreign Direct Product Rule (FDPR) has been in place since 1959, originally designed by the US Department of Commerce to regulate foreign products containing US technology. The system was overhauled in 2020 by the US Department of Commerce (Cheong and Chae, 2023), which transformed it into a tool for imposing sanctions against Huawei (OFR, 2020). The FDPR has since served as a potent instrument for sanctioning general commercial entities, in a divergence from its traditional role. Indirect impacts of the FDPR on third countries are evident when the US applies it to Chinese semiconductor and communication equipment manufacturers, as sanctions affect global companies with semiconductor manufacturing plants in China and those engaged in chip trade with China (Hayakawa, 2024; Cheong and Chae, 2023).

The US seeks to regulate dual-use products containing American technologies beyond its borders. Through the FDPR, the US government can restrict the exports of foreign-made products containing US technology or software (BIS, 2024e). However, not all foreign-manufactured items subject to the EAR require a license (BIS, 2024e). The specific regulations are contingent upon the item's classification, destination, end use, and end user, with some exceptions possible (BIS, 2024e).

B. *Three Instances of Enhanced US Export Controls on China*

This study examines three recent instances where the US strengthened export controls on China, primarily motivated by national security concerns.[1]

August 2020

In response to perceived national security risks associated with Huawei and its foreign affiliates, the Bureau of Industry and Security (BIS) revised the Export Administration Regulations (EAR) on August 17, 2020 (OFR, 2020). These revisions introduced three key changes. First, the BIS added 38 foreign affiliates of Huawei to the Entity List due to potential activities that could threaten US national security and foreign policy interests (OFR, 2020). Second, the existing Temporary General License (TGL) for Huawei and its affiliates was revoked and replaced with more restrictive provisions. Finally, the BIS revised the EAR's General Prohibition 3 (EAR §736.2(b)(3)), commonly referred to as the Foreign Direct Product Rule (FDPR). These changes restricted the re-export, export from abroad, or in-country transfer of Huawei-related products manufactured overseas without a license issued by the BIS (OFR, 2020). In August of 2020, the Trump administration tightened restrictions on Huawei's access to computer chips. This move, implemented through an update to the Foreign Direct Product Rule (FDPR), aimed to broadly restrict Huawei's ability to acquire any chip that relied on US technology, regardless of the manufacturer. This escalation in sanctions significantly impacted Huawei's global sales, leading to a 28.5% decline between 2020 and 2021, despite the company's efforts to stockpile inventory (Allen, 2023).

[1]This study references Hayakawa (2024) in consider the instances of US sanctions against China.

TABLE 2 —TIMELINE OF RECENT US EXPORT CONTROLS

Time	Content
August 2020 Huawei FDPR	The Huawei FDPR extended US regulatory control over technology outside the US and mandated that businesses apply for and receive licenses for any transactions with Huawei and its affiliates and other firms in Huawei's supply chain.
October 2022 New FDPR rules for HPC, AI, and manufacturing equipment	Advanced computing chips, HPC components, and semiconductor manufacturing equipment were added to list of controlled items.
October 2023 Export restrictions tightened	Semiconductor export controls expanded to related manufacturing equipment and various loopholes closed

Source: OFR (2020; 2022; 2023a; 2023b).

October 2022

In October of 2022, the US announced significant export control measures designed to limit China's access to advanced commercial technologies with military applications and the potential for human rights abuses, such AI and high-performance computing (HPC) hardware and software (OFR, 2022). These high-level measures targeted the whole of China rather than specific companies and introduced several new restrictions. On October 7, 2022, the BIS announced specific enhanced controls on semiconductors and related production equipment destined for China. These strengthened measures included requiring a BIS license for the export of certain types of semiconductors, semiconductor manufacturing equipment, and related software and technology (OFR, 2022). In addition, exports to any Chinese companies on the Entity List became subject to stricter controls (OFR, 2022).

October 2023

One year after the October 2022 measures, the BIS further tightened controls on China (OFR, 2023a; 2023b). These revisions to the EAR expanded the scope of semiconductor chips and equipment subject to controls and closed off loopholes that China could exploit to circumvent the new controls (OFR, 2023a). These amendments were designed to thwart Chinese attempts to acquire the types of advanced semiconductor manufacturing equipment needed to produce cutting-edge integrated circuits crucial for next-generation weapon systems and military AI (OFR, 2023b).

C. *Semiconductor Industry Sectoral Classifications*

As discussed above, recent US export controls have sought to curtail Chinese access to and growth within the semiconductor industry. To better grasp the contours of the chip sector, here we parse trade data to paint an accurate portrait of the semiconductor industry.

This study adopts the semiconductor industry classification scheme proposed in Kim and Shim (2022). That work addressed the lack of standardization for semiconductor

TABLE 3—SEMICONDUCTOR INDUSTRY, CLASSIFICATION BY HS CODE

CATEGORY	SUBCATEGORY (MTI 6 DIGIT)	HS 10-DIGIT CODES (HSK)
MEMORY SEMICONDUCTORS	MEMORY SEMICONDUCTORS (831110)	8473304060 8542321010 8542321020 8542321030 8542321090 8542322000 8542323000
SYSTEM SEMICONDUCTOR (NON-MEMORY)	SYSTEM SEMICONDUCTORS (PROCESSORS/CONTROLLERS) (831120)1)	8542311000 8542312000 8542313000
	ANALOG SEMICONDUCTORS (831130)	8542331000 8542332000 8542333000
	OTHER INTEGRATED CIRCUIT SEMICONDUCTORS (831190)	8523521000 8542391000 8542392000 8542393000
INTEGRATED CIRCUIT PARTS	INTEGRATED CIRCUIT PARTS (831200)2)	8542900000 8543901000 8548001000
TRANSISTORS	TRANSISTORS (831310)	8541211000 8541219000
DIODES	DIODES (831320)2)	8541101000 8541109000 8541599000 8541511000 8541512000 8541513000 8541514000
OTHER DISCRETE COMPONENTS	OTHER DISCRETE SEMICONDUCTORS (831390)3)	8541301000 8541302000 8541303000 8541304000 8541491000 8541411000 8541419000 8541492000 8541409021 8541409022 8541409029 8541420000 8541430000 8541493000 8541499000 8541601000 8541609000
DISCRETE COMPONENT PARTS	DISCRETE SEMICONDUCTOR PARTS (831400)4)	8534002000 8541903000 8541909000
SILICON WAFERS	SILICON WAFERS (831500)5)	3818001000 3818002010 3818002090

Note: The semiconductor industry classification is based on the HS Codes as presented in Kim and Shim (2022). Some deleted codes have been reclassified according to 2024 HS standards (underlined HS codes).
1. Some codes were deleted in 2009 and integrated under 8542311000.
2. Some codes were deleted in 2022 and reclassified in 2024 HS based on their original names.
3. Some Photosensitive Semiconductor codes were deleted in 2022 and reclassified in 2024 HS based on their original names.
4. Some codes were deleted in 2013 and included under 8534002000 as lead frames.
5. Some codes were deleted in 2017 and reclassified in 2024 HS based on their original names.

Source: Korea Electronics and Telecommunications Industry Promotion Institute, re-cited from Kim and Shim (2022) in the HS & MTI Code Linkage of the Electronic Export-Import Statistics System.

products, with the goal of enhancing the reliability and accuracy of analyses of the semiconductor industry. The study examines classification standards from the Korea Semiconductor Industry Association, the Ministry of Trade, Industry and Energy (MOTIE), and information from the Korea Electronics Industry Promotion Agency's electronic import and export statistics system. These classifications are then linked with MOTIE and HS codes to classify semiconductor products. Building upon the aforementioned study, we establish a standard semiconductor product classification system by categorizing semiconductor items into those with MTI 6-digit, HS 6-digit, and KHS 10-digit codes (see Table 3). However, some codes required revisions and others had been deleted; we updated these codes based on their original names, which are underlined in the table.

Next, again following Kim and Shim (2022), we categorize semiconductors into eight sub-categories:

1. Memory semiconductors
2. System semiconductors (non-memory)
3. Parts for integrated circuits
4. Transistors
5. Diodes
6. Other discrete components
7. Parts for discrete components
8. Silicon wafers

This comprehensive, granular categorization of the semiconductor industry facilitates a more nuanced characterization of the industry and distinguishes this study from previous works in the literature, which often employed broad categorizations of integrated circuits (ICs) into four large groups — processors, memory, amplifiers, and other ICs — along with IC manufacturing equipment (IME), all grouped under HS 848620. In contrast, our approach offers a more descriptive delineation of semiconductor components.

D. *Matching ECCN to KHS*

This section outlines the four-step process we employed to identify products targeted by recent enhancements to US export controls targeting China (refer to Table 4). Our approach involved cross-referencing US Export Control Classification Numbers (ECCNs) with Korean Harmonized System (KHS) codes using information from a data portal managed by MOTIE.

The first step involved reviewing US documents detailing revisions to export control regulations. We focused on amendments strengthening the Foreign Direct Product Rule (FDPR) to assess their impact on third countries, a central theme of this study. Our examination encompassed the 2022 amendments targeting high-performance computing (HPC), semiconductor manufacturing items, and semiconductor end-use.

TABLE 4—PROCESS FOR IDENTIFYING PRODUCTS TARGETED BY US EXPORT CONTROLS

STEP 1		STEP 2		STEP 3		STEP 4
REVIEW US EXPORT ADMINISTRATION REGULATIONS & AMENDMENTS	→	IDENTIFY AND SORT STRENGTHENED ECCN CODES IN THE EXPORT ADMINISTRATION REGULATIONS (EAR)	→	MATCH ECCN CODES WITH 10-DIGIT KHS CODES	→	IDENTIFY PRODUCT TARGETED BY US EXPORT CONTROLS

Source: The authors.

Because these regulations were subsequently revised in 2023, we also reviewed the relevant export control documents pertaining to semiconductor manufacturing equipment.

The second step involved identifying and listing the ECCNs with enhanced export controls within US documents. Key revisions for 2020 included adding advanced computing chips, computer commodities containing them, and associated software and technology to the Commerce Control List (CCL) (OFR, 2022). Major revisions for 2022 were made to several ECCN categories, including 3A090 (high-performance integrated circuits), 4A090 (computers, electronic assemblies, and components not elsewhere specified containing ECCN 3A090 ICs) (OFR, 2022). A new code (3B090) was established to strengthen control over advanced semiconductor manufacturing equipment. In addition, controls over related software and technologies were strengthened, with revisions to several codes (3D001, 3E001, 4D090, and 4E001) (OFR, 2022).

In 2023, yet more revisions were made to the Export Administration Regulations (EAR) across multiple categories. Category 3 saw amendments to ECCNs 3A001, 3A090, 3A991, 3D001, and 3E001 (OFR, 2023a). For Category 4 (Computers), revisions were made to ECCNs 4A003, 4A004, 4A005, 4A090, 4A994, 4D001, and 4E001 (OFR, 2023a). Additionally, Category 5 (Telecommunications and Information Security) was modified, with changes to ECCNs 5E001, 5A002, 5A992, 5A004, 5B002, 5D002, 5D992, 5E002, 5E992, 9A004, and 9A515, along with revisions to associated references and technical notes (OFR, 2023a). With regard to semiconductor manufacturing items, the 2023 revisions saw the removal of ECCN 3B090, with amendments to 3B001, 3B002, 3D001, 3D002, 3D003, and 3E001 (OFR, 2023b). ECCNs subject to the above revisions and enhancement measures were noted in the 2022 and 2023 documents.

The third step involved matching the identified ECCNs with 10-digit KHS codes. We utilized MOTIE's Yestrade[2] portal, through which the ECCNs corresponding to KHS codes can be found. The platform facilitated the identification of ECCNs from the 2020-2023 export control regulations and their corresponding 10-digit KHS codes (Yestrade, 2024). We must acknowledge here that while most ECCN codes are accessible through the Yestrade portal, some codes are not. We were not able to find the KHS 10-digit codes corresponding to ECCNs 3A090 (specified high-performance ICs) or 4A090 (advanced computing or supercomputing related items), for example. For these two codes and others, we relied on the Related Controls information associated with those specific ECCNs (BIS, 2024d).

Finally, for the fourth and last step of the process, we classified products subject to strengthened US export controls into those with KHS 10-digits codes[3] for use in the empirical analysis described in the next chapter. Prior studies in this line of inquiry have noted that the precise identification of export control targets through trade data poses many challenges. However, because in this instance controls are applied to specific products and technologies using ECCNs, our approach here facilitates a more precise analysis.

[2]Selecting "Strategic Materials (Dual Use)" on the page (https://www.yestrade.go.kr/user/userBoard.do?method=board&BD_NO=1) will cause a search window to appear.

[3]Note: The final table of matched ECCN-HS codes was not included in this paper due to the extensive nature of the data. For further inquiries, please contact the author.

III. Methodology and Data

A. *Regression Equation and Variable Construction*

In this section, we describe the empirical analysis used to estimate changes in South Korea's exports to China resulting from the imposition of US export controls on China. The analysis follows Hayakawa (2024). Consider the following gravity equation:

$$y_{jpt} = \beta_0 + \beta_1 \cdot I^{China}_{Semi.,\ Sep2020} + \beta_2 \cdot I^{China}_{Semi.,\ Oct2022} + \beta_3 \cdot I^{China}_{Semi.,\ Oct2023} + \eta_{jp} + \eta_{jt} + \eta_{pt} + \varepsilon_{jpt}$$

Here, y represents the trade variable of product p to country j at time t. For this study, we primarily consider export value as the trade variable. Taking into account that US export controls are focused on high-tech products, we consider and analyze unit prices and quantities separately.

Next, the variables $I^{China}_{Semi.,\ Sep2020}$, $I^{China}_{Semi.,\ Oct2022}$, and $I^{China}_{Semi.,\ Oct2023}$ are dummy variables, artificial variables that take on only two values, typically 0 or 1. In this case, these dummy variables represent US export controls implemented at different points in time. Specifically, $I^{China}_{Semi.,\ Sep2020}$ is set to 1 for semiconductor products with ECCNs exported to either China or Hong Kong after September of 2020, or 0 otherwise. Similarly, $I^{China}_{Semi.,\ Oct2022}$ and $I^{China}_{Semi.,\ Oct2023}$ follow the same logic, incorporating the same product and country parameters, but for later timeframes. By including these dummy variables in the regression equation, the coefficients β_1, β_2, and β_3 will capture changes in the exports of these products to China subject to US export controls across the three specific periods.

η_{jp}, η_{jt}, and η_{pt} are dummy variables that control for the interaction fixed effects of country j, for product p, at time t, respectively. Finally, β_0 is a constant, and ε_{jpt} represents the error term.

To estimate the gravity equation, we leverage detailed monthly trade data at the 10-digit Korean Harmonized System (KHS) code level. The KHS code is an internationally standardized product classification system used by South Korea's Trade Statistics Service (TRASS) to categorize goods for recordkeeping and analytical purposes. These 10-digit codes provide a very granular level of detail, allowing us to track exports according to the specific product type. Our analysis utilizes data ranging from January of 2018 to March of 2024, encompassing the most recent information available at the time of this writing.[4] We conducted the analysis using the ordinary least squares (OLS) estimation method.

[4]The starting point for the empirical analysis follows Hayakawa (2024). The data extend to the most recent available period (March 2024) as of this writing. See Appendix Figure A1 for recent trends in Korean semiconductor exports to both China and Hong Kong, and Figure A2 for trends for each of them individually.

B. *Estimation Results: Exports and Unit Prices*

Here we examine the results of our empirical analysis and explore the impacts of US export controls on South Korean exports to China. Table 5 summarizes the results of the analysis. We observe in Column 1 that the coefficient of the dummy variable for South Korean semiconductor exports to China after October of 2022 is negative, at -0.147. This result, controlling for fixed effects such as the exporting country, product, and time period, indicates that US export control measures targeting semiconductor exports to China instituted in October of 2022 led to a 13.7% decrease in South Korean semiconductor exports to China.[5] The analysis revealed no statistically significant impacts on Korean exports in the other two timeframes under consideration.

We found that the impact of US export control measures on the South Korean semiconductor industry varied across different product categories. The coefficient of the dummy variable representing memory chip exports to China after October of 2022 is -0.385 and statistically significant. This result indicates a 31.9% decrease in exports of South Korean memory semiconductors to China following the imposition of these controls. Similarly, exports of discrete components and parts showed statistically significant negative associations with the October 2022 controls, with estimated decreases of 26% and 43%, respectively. We did not find any statistically significant evidence suggesting that US export controls had negative impacts on exports of other South Korean semiconductor products to China.

Next, we investigate the impact of US export controls on the unit prices of South Korean semiconductor exports to China. We conducted separate OLS estimations using unit price and quantity as the dependent variables. The empirical results indicate that US export controls, particularly those implemented in October of 2022, helped contribute to a shift in South Korean semiconductor exports to China from high-value-added to low-value-added products.

[5]We calculate this as EXP(β)-1.

TABLE 5—IMPACTS OF US EXPORT CONTROLS ON KOREAN SEMICONDUCTOR EXPORTS

VARIABLES	Log (Export)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Semi. All	Memory	System	IC Parts	Transistors	Diodes	Other Discrete Components	Discrete Component Parts	Silicon Wafers
After Sep. 2020	0.030 [0.041]	0.286*** [0.083]	0.039 [0.081]	-1.460 [0.959]	[0.086] -0.142	0.149 [0.224]	0.014 [0.103]	-0.199** [0.102]	0.046 [0.239]
After Oct. 2022	-0.147*** [0.049]	-0.385*** [0.099]	0.159 [0.107]	0.517 [0.619]	[0.116] -0.010	-0.207 [0.236]	-0.258*** [0.091]	-0.427*** [0.120]	-0.226 [0.235]
After Oct. 2023	-0.010 [0.106]	-0.011 [0.225]	-0.155 [0.256]	-0.785 [0.574]	[0.238] -0.120	0.442 [0.372]	0.327** [0.159]	-0.458 [0.303]	0.068 [0.351]
Constant	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]
Country-Product Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Product-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376
R-squared	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimation results of the relationship between South Korea's exports to China and Hong Kong and the dummy variables for export-controlled items following U.S. export control measures. "After Sep. 2020," "After Oct. 2022," and "After Oct. 2023" represent dummy variables for the periods following each respective export control implementation. The columns show the estimated results for the specific products targeted by these export controls.

The analysis using unit price as the dependent variable shows a 34.6% decrease in the unit price of memory chips for the period following the October 2022 (see Table 6) controls. The dummy variable for memory chip exports after October of 2022 is statistically significant and negatively associated with unit prices (-0.425). However, changes in export quantities were less evident. Table 7 presents the estimation results for export volumes. The dummy variable for memory chip exports after October of 2022 is statistically insignificant.

These findings suggest that the October 2022 export controls targeted high-tech, high-value-added semiconductor products. In response, South Korean memory exports shifted toward lower-value-added products to circumvent the controls, reflecting a change in the composition of export products but not a significant change in export quantities. The September 2020 US export controls, on the other hand, led to a notable increase in export quantities accompanied by a modest shift toward lower-value-added products, ultimately resulting in an overall increase in export value, as previously estimated. These observations constitute evidence that US export

TABLE 6 — IMPACTS OF US EXPORT CONTROLS ON KOREAN SEMICONDUCTOR EXPORT UNIT PRICES

	Log (Unit Price)					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Semi. All	Memory	System	Transistor	Diodes	Other Discrete Components
After Sep. 2020	0.047 [0.046]	-0.109* [0.060]	0.062 [0.078]	0.232*** [0.088]	0.169 [0.334]	0.032 [0.134]
After Oct. 2022	0.009 [0.056]	-0.425*** [0.071]	0.046 [0.090]	-0.003 [0.155]	1.233** [0.489]	0.107 [0.116]
After Oct. 2023	0.080 [0.100]	0.081 [0.134]	-0.105 [0.164]	0.336 [0.287]	0.632 [0.581]	0.100 [0.186]
Constant	4.188*** [0.001]	4.188*** [0.001]	4.188*** [0.001]	4.188*** [0.001]	4.188*** [0.001]	4.188*** [0.001]
Country-Product Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Country-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Product-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,386,336	2,386,336	2,386,336	2,386,336	2,386,336	2,386,336
R-squared	0.867	0.867	0.867	0.867	0.867	0.867
Robust standard errors in brackets						
*** p<0.01, ** p<0.05, * p<0.1						

Note: This table presents the estimation results of the relationship between South Korea's export unit prices to China and Hong Kong and the dummy variables for export-controlled items following U.S. export control measures. "After Sep. 2020," "After Oct. 2022," and "After Oct. 2023" represent dummy variables for the periods following each respective export control implementation. The columns show the estimated results for the specific products targeted by these export controls.

TABLE 7—IMPACTS OF US EXPORT CONTROLS ON KOREAN SEMICONDUCTOR EXPORT QUANTITIES

VARIABLES	Log (Quantity) (1) Semi. All	(2) Memory	(3) System	(4) Transistors	(5) Diodes	(6) Other Discrete Components
After Sep. 2020	-0.017 [0.059]	0.366*** [0.089]	-0.059 [0.104]	-0.400*** [0.104]	-0.052 [0.363]	-0.053 [0.168]
After Oct. 2022	-0.165** [0.072]	0.009 [0.104]	0.066 [0.122]	-0.214 [0.187]	-1.551*** [0.482]	-0.403*** [0.149]
After Oct. 2023	-0.014 [0.138]	-0.061 [0.225]	-0.051 [0.273]	-0.280 [0.305]	-0.172 [0.654]	0.234 [0.231]
Constant	5.014*** [0.001]	5.014*** [0.001]	5.014*** [0.001]	5.014*** [0.001]	5.014*** [0.001]	5.014*** [0.001]
Country-Product Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Country-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Product-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,390,491	2,390,491	2,390,491	2,390,491	2,390,491	2,390,491
R-squared	0.846	0.846	0.846	0.846	0.846	0.846

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimation results of the relationship between South Korea's export quantities to China and Hong Kong and the dummy variables for export-controlled items following U.S. export control measures. "After Sep. 2020," "After Oct. 2022," and "After Oct. 2023" represent dummy variables for the periods following each respective export control implementation. The columns show the estimated results for the specific products targeted by these export controls.

controls targeting high-value-added semiconductors can influence third-country trade dynamics by driving changes in the composition of export baskets.[7]

The impact of US export controls on unit prices varied depending on the semiconductor product category. As shown in Tables 6 and 7, the relationship between unit prices and each export control measure was not statistically significant for the semiconductor industry as a whole. However, the October 2022 controls exhibited a statistically significant negative relationship with export quantities, pointing to lower overall chip export volumes. This finding provides empirical evidence that these controls decreased overall semiconductor exports from South Korea to China.

[7]Our findings concerning memory align with those of Hayakawa (2024). However, we also observed some discrepancies in the estimated changes in unit prices and quantities across specific sub-product categories in semiconductor exports. These differences underscore the need to gain a deeper understanding of specific product categories (e.g., wafers, diodes) within the semiconductor industry and call for future research on this topic.

C. *Comparison With and Without ECCNs*

This subsection explores how the results of our analysis are affected by our consideration of Export Control Classification Numbers (ECCNs). Our study refines the controlled items using the list of ECCNs designated by the US export controls. Relying solely on HS codes runs the risk of underestimating the impact of export controls, as HS categories can include semiconductor products not targeted by export controls. We utilize ECCNs to focus exclusively on the targeted items and thus mitigate this bias.

Table 8 presents the key findings based on the statistical significance of the dummy variable representing US export controls on semiconductor products, without considering ECCNs. These results show that the decline in memory semiconductor exports following the October 2022 export controls is less pronounced when ECCNs are not considered. This tells us that an analysis using HS codes alone may indeed underestimate the effect, and that using ECCNs can help mitigate this.

However, the results are not entirely consistent. For instance, the overall results for semiconductor products following the October 2022 export controls show a larger coefficient in analyses that do not use ECCNs. In some cases, changes in export values are more significant when the analysis is not limited to products with an ECCN designation. This suggests that, in some instances, considering ECCNs may not be sufficient to capture the full impact of export controls.

There are several possible explanations for this. First, most semiconductor products are already pre-designated under ECCNs, limiting the methodological improvement from including them in the analysis.[8] Second, the level of technology indicated by 10-digit KHS codes may be more relevant than ECCNs in capturing the impact of export controls. This aligns with our earlier finding of changes in the product composition within the same KHS code, as evidenced by unit price variations.

The interconnectedness of the semiconductor industry could also be a factor. Export controls on specific products may have cascading effects on related industries. For instance, if product A is subject to export controls, exports of related product B may also decrease. The extent to which such cascading effects occur can influence the overall results, potentially making ECCNs a less effective indicator in some cases.

Taken together, our findings suggest that while ECCNs could help refine the analysis and mitigate underestimation bias, using them may not always be the most effective approach. Further research is needed to explore alternative methods for capturing the nuanced effects of export controls in interconnected industries.

[8]Approximately 92% of South Korean semiconductor exports to China and Hong Kong in the periods under analysis are linked to ECCNs.

TABLE 8—IMPACTS OF US EXPORT CONTROLS ON KOREAN SEMICONDUCTOR EXPORTS (W/O CONSIDERING ECCNS)

	Log (Export)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	Semiconductor All	Memory	System	IC Parts	Transistors	Diodes	Other Discrete Components	Discrete Component Parts	Silicon Wafers
After Sep. 2020	0.051 [0.035]	0.168** [0.073]	0.039 [0.081]	-0.366** [0.157]	-0.120 [0.086]	-0.053 [0.098]	0.263*** [0.077]	-0.199** [0.102]	0.074 [0.223]
After Oct. 2022	-0.167*** [0.046]	-0.287*** [0.087]	0.159 [0.107]	-0.105 [0.181]	-0.142 [0.116]	0.067 [0.139]	-0.379*** [0.097]	-0.427*** [0.120]	-0.601** [0.259]
After Oct. 2023	-0.093 [0.099]	0.059 [0.192]	-0.155 [0.256]	-0.549*** [0.201]	-0.010 [0.238]	-0.319 [0.303]	0.066 [0.185]	-0.458 [0.303]	0.350 [0.363]
Constant	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]	9.312*** [0.001]
Country-Product Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Product-Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376	6,391,376
R-squared	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Note: This table presents the estimation results of the relationship between South Korea's exports to China and Hong Kong and the dummy variables for export-controlled items following U.S. export control measures. "After Sep. 2020," "After Oct. 2022," and "After Oct. 2023" represent dummy variables for the periods following each respective export control implementation. The columns show the estimated results for the specific products targeted by these export controls without considering ECCNs.

IV. Conclusion

This study empirically examined how recent US export control measures targeting China impacted South Korea's semiconductor exports to China. Utilizing detailed 10-digit HS data from Korea, the analysis reveals a decline in semiconductor exports, particularly for memory chips, discrete components, and discrete component parts, in the period following the imposition of enhanced US export controls in October of 2022. Notably, the unit price of memory chip exports from Korea to China decreased, suggesting a significant impact on high-tech memory products targeted by the export control measures.

Using granular, product-level data, this research contributes to the literature on the effects of such export controls by providing some empirical evidence of changes to a third country's exports following the imposition of US export controls targeting China. The findings demonstrate the effects of these controls in influencing the composition and value of South Korean semiconductor exports.

The analysis employed a list of Export Control Classification Numbers (ECCNs) to refine the targeted items and enhance the precision of the results. However, we discovered limitations to this approach. First, the export controls primarily focus on high-tech products, and many individual semiconductor products remain undifferentiated in the ECCNs-KHS linkage system. This occurs because numerous products in the semiconductor industry are already pre-designated under ECCNs. Future research should explore alternative methods that more precisely link targeted items with trade data to improve the analysis of export control effects on specific products considering the level of technology embedded within those products.

Furthermore, to gain a more complete understanding of the trade dynamics at play, further research is needed that combines empirical analysis with theoretical exploration. This study focused on recent export control measures, investigating relatively recent phenomena over a short timeframe. The observed variations in export and price changes across different semiconductor products highlight the complexity of the industry, the interconnectedness of various components, and the potential impact of company relocations due to these controls. Investigating the mechanism(s) behind these results, particularly when exports increased or decreased under heightened uncertainty, would be valuable. Future in-depth research that considers these factors would provide a more comprehensive understanding of the dynamics at play.

APPENDIX

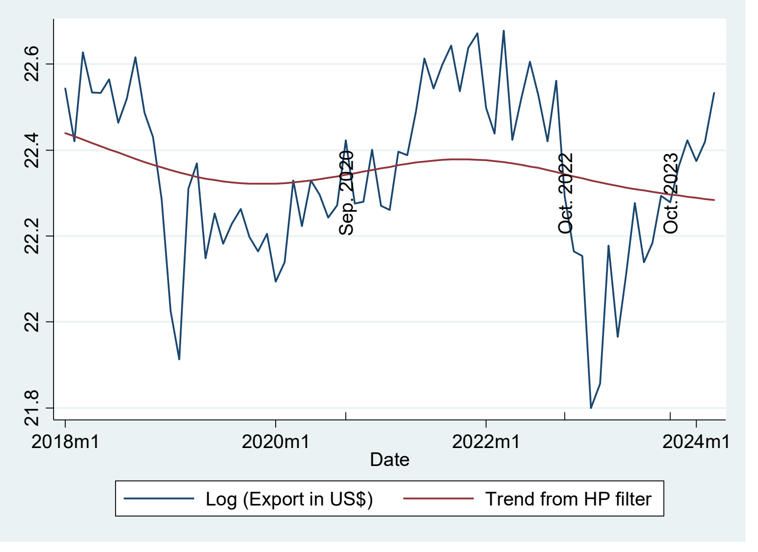

FIGURE A1. SOUTH KOREAN EXPORTS TO CHINA (INCL. HONG KONG), 2018-2024

Note: We estimated the trend using Korean monthly export statistics for the period from January of 2018 to March of 2024, following the methodology outlined in Hodrick and Prescott (1997).

Source: The authors' calculations.

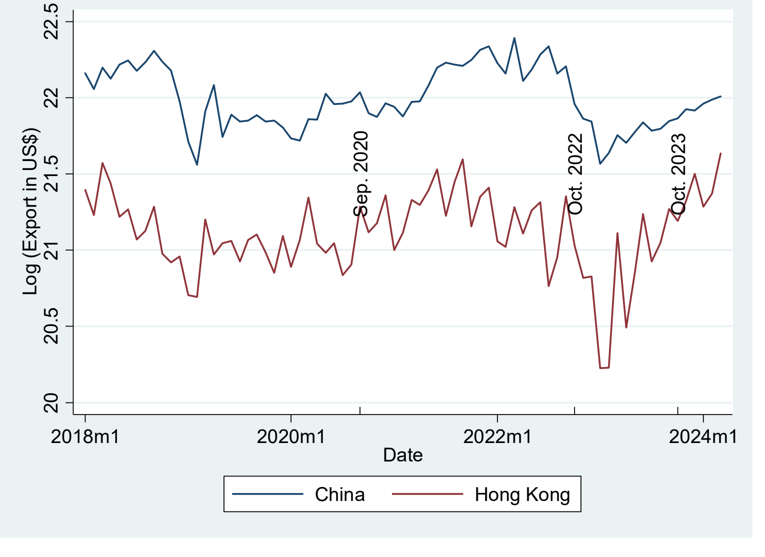

FIGURE A2. SOUTH KOREAN EXPORTS TO CHINA AND HONG KONG, 2018-2024

Note: We estimated the trend using Korean monthly export statistics for the period from January of 2018 to March of 2024, following the methodology outlined in Hodrick and Prescott (1997).

Source: The authors' calculations.

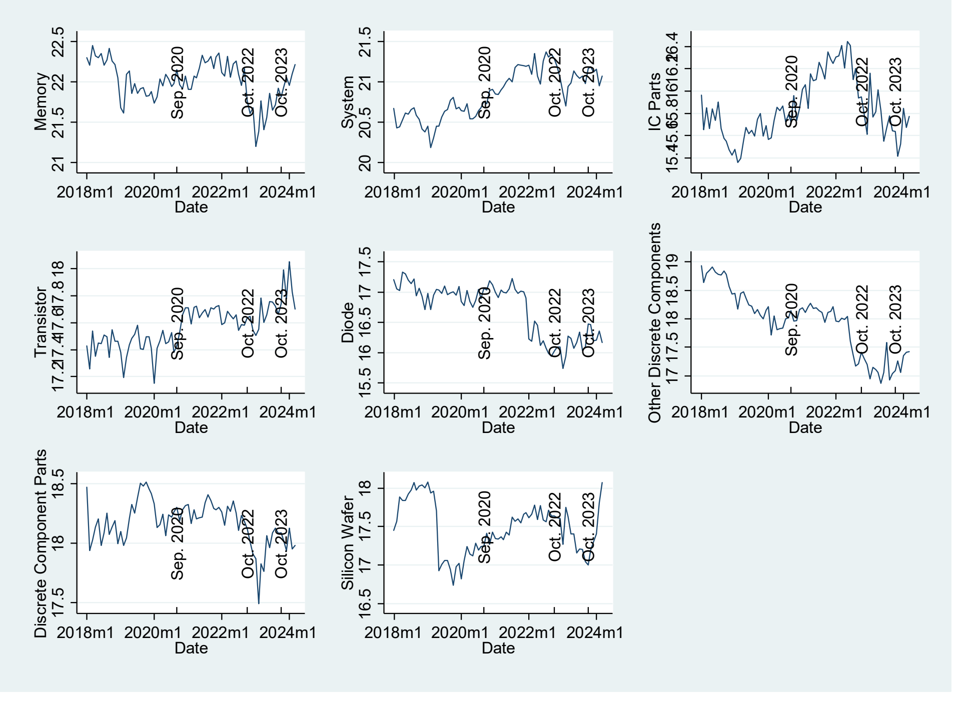

FIGURE A3. SOUTH KOREAN EXPORTS TO CHINA AND HONG KONG BY PRODUCT, 2018-2024

Note: We estimated the trend using Korean monthly export statistics for the period from January of 2018 to March of 2024, following the methodology outlined in Hodrick and Prescott (1997). Unit: USD, log of exports.

Source: The authors' calculations.

TABLE A1—SHARE OF ECCNS (OF TOTAL EXPORTS)

	Share of ECCNs
Total	92.0%
Memory	91.2%
System	100.0%
IC Parts	0.1%
Transistors	100.0%
Diodes	22.8%
Other Discrete Components	14.4%
Discrete Component Parts	100.0%
Silicon Wafers	98.1%

Note: We calculate the share of ECCNs of total Korean semiconductor exports to China and Hong Kong for the period from January of 2018 to March of 2024.

Source: The authors.

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