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Keywords: US, Export control, China, integrated circuits, semiconductors
JEL classification: F15, F53

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The Trade Effects of the US Export Control Regulations

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Abstract**:** This study empirically investigates the trade effects of US export regulations. In particular, we focus on regulations on the export of integrated circuits (ICs) and IC manufacturing equipment (IME). We employ monthly worldwide trade data from January 2018 to September 2023. Our findings from gravity estimations can be summarized as follows: First, changes in US export regulations significantly decreased US exports to China. In particular, the exports of the main IC products (i.e., processors) decreased by reducing export quantities after the US tightened its export regulations in October 2022. This tightening also significantly decreased US exports of IME to China. Second, tightening the foreign direct product rule did not change the exports of the main IC product from Taiwan (i.e., other ICs) to China but significantly decreased exports from Korea (i.e., memories). Third, these regulations significantly decreased the IME exports from the Netherlands to China, whereas Japanese IME exports to China did not change significantly. In short, the effects in third economies are not uniform.

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1. Introduction

The US government has strengthened export control regulations from a national security perspective and regulated key technologies and components exports to China. Many Chinese firms have been added to the Entity List (EL), the list of parties of concern. Examples include Huawei Technologies Co., Ltd. (hereafter, Huawei), a Chinese company that designs, develops, manufactures, and sells telecommunications equipment, consumer electronics, and smart devices such as smartphones. Another is Semiconductor Manufacturing International Corporation (SMIC), a semiconductor foundry company and

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the largest chipmaker in China. When exporting, re-exporting, or transferring items subject to the US Export Administration Regulations (EAR), applications are reviewed with the presumption of denial by the US government. The Foreign Direct Product Rule (FDPR) of the EAR was also strengthened to require prior authorization by the US government to even exporters outside of the US if products are produced using US-origin technology or software (called "direct products"). Thus, US export regulations could affect exports from the US and third countries to China.

This study empirically investigates the trade effects of the US export regulations. We focus on regulations on the export of integrated circuits (ICs) and equipment for the manufacture of semiconductor devices or ICs (IC-manufacturing equipment, IME). These products and equipment have been the main targets of the US export regulations against China. We first examine the effect of several changes in export regulations on US exports to China and then explore their effect on exports from third countries (e.g., Japan or South Korea) to China. To this end, we employ monthly worldwide trade data at the harmonized system (HS) six-digit level from January 2018 to September 2023. This period included changes in US export regulations, including adding specific companies to the EL, strengthening FDPR, and introducing strict end-use-based regulations.

Compared with studies on the effect of the US-China *tariff* war, there are few studies on the effect of US export control regulations. One reason may be that, although a wide range of products are potentially subject to export control regulations, export permission is required only for specific types of products (Hayakawa et al., 2023). Our empirical analysis regresses standard gravity equations and examines dummy variables for products subject to export regulations. Specifically, we regard products in specific HS codes (i.e., HS848620 and HS8542) as "treated" products. However, not all items in these codes are subject to export restrictions. For example, license applications are denied for products capable of supporting the development or production of telecom systems, equipment, and devices at the 5G level but are approved for those at the 4G level. Thus, it is inevitable that the dummy variables contain some errors that bias the estimates toward zero. Nevertheless, it is worth showing the estimates because this issue results in an underestimation, rather than an overestimation, of the adverse effects of export controls on trade.

At least three studies on the trade effect of US export controls use a similar approach. First, Ando et al. (2023a) examine the effect of US regulations on US exports of IME (HS848620) to China. They found an insignificant effect of adding SMIC to EL in December 2020 but a significantly negative effect of tightening export regulations on those products in October 2022. Second, Hayakawa et al. (2023) show that tightening the FDPR in August 2020 significantly decreased Japan's exports of HS8517 products (including telephones for cellular networks and other wireless networks) to China. The third study, Ando et al. (2023b), also investigated the effect of FDPR on Japan's exports but extended the study products. They found a significant decrease in Japan's exports of advanced technology products used in the production of smartphones (HS8517) to China. They also investigated the effect of adding the chip maker to the EL in December 2020 on Japan's exports of inputs for semiconductors and ICs to China but found a significantly positive effect, which is the sign opposite to prior expectations.

Compared with existing studies, this study is more comprehensive. First, although Ando et al. (2023a) examine the effect of US export regulations on US exports of IME, we also investigate that on US exports of ICs (HS8542). Second, this study investigates the effects of US regulations on exports from not only the US and Japan but also Korea, the Netherlands, and Taiwan. This extension is important because export products from some countries may not be "direct products" and thus do not need to obtain permission from the US. As a result, these countries may increase, rather than decrease, their exports to China–trade diversion. Third, and more importantly, we investigate the effects on not only trade values but also the trade quantity and unit trade price. Changes in unit prices may reflect the product quality in trade. For example, the analysis of unit prices plays a key role in detecting the substitution effects between cutting-edge ICs (i.e., advanced ICs) and legacy ICs (i.e., less advanced ICs).

Our findings can be summarized as follows: First, changes in US export regulations significantly decreased US exports to China. Although adding Huawei to the EL did not change those of the main IC products (i.e., processors), their exports to China significantly decreased by reducing export quantities after tightening export regulations in October 2022. This tightening also significantly decreased the US exports of IME. Second, while we found a significant decrease in exports of the main IC product from Korea (memories) to China after tightening FDPR, exports of the main IC product from Taiwan (other ICs) did not change significantly. Third, adding SMIC to EL and tightening export regulations in October 2022 significantly decreased exports of IME from the Netherlands to China. In particular, the former decreased export quantities, whereas the latter decreased export prices. However, these regulations did not significantly affect Japanese IME exports to China.

In addition to the above-mentioned literature on the trade effects of US export regulations, several related studies have been conducted. For example, Cerdeiro et al. (2021) and Funke and Wende (2022) conducted simulation analyses of the economic impact of US export control regulations. These studies demonstrate the GDP loss in both China and the US and the trade diversion effect in the rest of the world. More broadly, there is literature on the trade effects of economic sanctions. Studies in this literature mainly examine the trade effects of sanctions against Iran around 2010 (e.g., Haidar, 2017; Crozet et al., 2021) and Russia around 2014 (e.g., Crozet et al., 2020; 2021). The sanctions examined in these studies included export and import restrictions, asset freezes, and travel bans. Fuhrmann (2008) and Afesorgbor (2019) examined the effects of export restrictions on exports. The former found that democratic states received more dual-use exports from the US, whereas the latter examined global trade from 1962 to 2014 and showed no significant effects of export restrictions on trade. Our study of recent US export regulations adds new evidence on the trade effects of export restrictions.

The remainder of this study is organized as follows. The next section provides an overview of recent US export control regulations changes. After explaining our empirical framework in Section 3, we present the estimation results in Section 4. Finally, section 5 concludes the study.

2. Background

This section briefly overviews US export control measures in chronological order. A more detailed discussion is available in several previous studies (e.g., Ando et al., 2023). The Export Control Reform Act (ECRA), signed into law on August 13, 2018, requires the US Commerce Department's Bureau of Industry and Security (BIS) to impose export controls on emerging and foundational technologies "essential to the national security of the US."[1] Roughly, products subject to the EAR include (i) all US-origin items wherever located, (ii) re-exports of a foreign-made commodity incorporating controlled US-origin commodities or 'bundled' with US-origin software valued at more than 25% of the total value (hereafter, called "re-exported products of US goods"), (iii) certain foreign-produced "direct products" of specified "technology" and "software" (see Part 734.3 of the EAR). Exports outside the US may also be restricted if they fall into either category.

Recently, there have been many changes to the US export regulations. In May 2019, the US added Huawei and its affiliates to EL. This addition may decrease US exports of ICs to these companies and the exports of re-exported ICs from third countries. Furthermore, in May 2020, the FDPR of the EAR was strengthened to require prior authorization if "direct products" were to be used in the production or development of chipsets and other products designed by Huawei and its affiliates. In August 2020, the regulations were further tightened to require prior authorization to produce or develop chipsets purchased or ordered by Huawei or its affiliates. Due to these FDPR reforms, exports of advanced ICs from third countries will likely be "direct products" and thus subject to the EAR. Consequently, third countries may have decreased their IC exports to China. In December 2020, the US added SMIC to EL. This addition may decrease US exports of IME, in addition to exports of re-exported IME from third countries.

However, exporting all products to Huawei and SMIC is not necessarily prohibited. In the case of Huawei, as mentioned in the previous section, license applications were denied for items required for telecom systems, equipment, and devices at the 5G level[2]. Regarding the SMIC, the presumption of denial is applied to items uniquely required for producing semiconductors at advanced technology nodes (10 nm and below, including

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[1] The ECRA repealed the Export Administration Act (EAA) of 1979, which served as the basis for dual-use export controls.

[2] Also see https://gop-foreignaffairs.house.gov/wp-content/uploads/2021/10/Huawei-Licensing-Information.pdf.

extreme ultraviolet technology)[3]. Because such items can be produced in a limited number of countries/firms, not all countries are affected by these regulations. For example, only Korea and Taiwan could produce chips with less than ten nanometer-node as of 2019[4]. Extreme ultraviolet lithography machines can only be produced in the Netherlands.

In October 2022, the US government introduced stringent regulations. According to Part 744.23 in the EAR, firms are prohibited from exporting the items destined for the development and production of a "supercomputer" located in or destined for China or Macau or for the development or production of ICs at a semiconductor fabrication facility located in China or Macau that fabricates "advanced integrated circuits[5]." This measure restricts firms' exports of cutting-edge ICs and the IME for ICs based on their end use rather than on their importers. Firms in third countries may not be allowed to export re-exported products to all firms in China, including their overseas affiliates[6], if the items are destined for end use. At the same time, the FDPR was tightened against exporting advanced computing and supercomputers. Thus, exports of these products from third countries are more likely to be subject to EAR.

In addition, by the end of 2022, more companies have been added to EL. For example, Beijing Sensetime Technology Development (an artificial intelligence (AI) software company), Changsha Jingjia Microelectronics (a company of military-use products), and National Supercomputing Centers were added in October. The companies added in December include Yangtze Memory Technologies Corporation (YMTC, a semiconductor integrated device manufacturer specializing in flash memory chips), Cambricon Technologies Co., Ltd (an AI chip startup), and Shanghai Micro Electronics Equipment (a manufacturer of semiconductor equipment). Furthermore, FDPR has tightened exports to some of these companies. Adding these companies to the EL and tightening the FDPR will decrease the exports of cutting-edge ICs and the IME for ICs from the US and third countries to China.

The remaining measure to slow down the development of semiconductor industries in China is to prevent China's imports of advanced semiconductors and their devices that do not fall into "products subject to the EAR." To this end, the US government requested that the Dutch and Japanese governments join forces with the US and introduce similar

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[3] Also see https://gop-foreignaffairs.house.gov/wp-content/uploads/2021/10/SMIC-Licensing-Information.pdf.

[4] https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/

[5] These integrated circuits include (A) logic integrated circuits using a nonplanar transistor architecture or with a production technology node of 16/14 nanometers or less; (B) NOT AND (NAND) memory integrated circuits with 128 layers or more; or (C) Dynamic random-access memory (DRAM) ICs using a production technology node of 18 nanometer half-pitch or less.

[6] According to Part 742.6(b)(10) in the EAR, license applications for semiconductor manufacturing items destined to end users in China that are headquartered in the U.S. or some developed countries (countries in Country Group A:5 or A:6 in Supplement No. 1 to Part 740 in the EAR) will be considered on a case-by-case basis, taking into account factors including technology level, customers, and compliance plans.

export restrictions. Accordingly, the Dutch and Japanese governments started restricting IME exports from September 1 to July 23. The former restricts the export of not only advanced equipment (i.e., extreme ultraviolet lithography equipment) but also less advanced equipment (e.g., deep ultraviolet lithography equipment). The latter restricts the export of 23 items (e.g., items for lithography, film deposition, or wafer cleaning). Unlike the above regulations, this restriction has a "direct effect" on Dutch and Japanese firms' exports of related products to China.

Let us provide an overview of the monthly changes in exports to China. Figure 1 shows ICs (HS 8542) and IME (HS 848620) exports to China. "China" includes not only mainland China but also Hong Kong, as we explain this reason in the next section. The ICs include processors (HS 854231), memory (HS 854232), amplifiers (HS 854233), and other ICs (HS 854239). We use exporter-side data obtained from the Global Trade Atlas. We show the exports of ICs from the US, Korea, and Taiwan and those of IME from the US, Japan, and the Netherlands. Korea and Taiwan are the main exporters of cutting-edge ICs. Japan is the top exporter of IME to China, whereas the Netherlands exports the most advanced IME. The figure shows that the main export IC products differ across the three economies: processors in the US, memories in Korea, and other ICs in Taiwan.

=== Figure 1 ===

In the US, processor exports seem to increase until the middle of 2021 but afterward decline gradually. In particular, exports have decreased considerably since the fourth quarter of 2022. In Korea, the export of memories declined in the latter half of 2018 and seemed stable until 2021. However, this number has been gradually declining since 2022. The exports of other ICs from Taiwan gradually increased throughout the study period. The IME exports to China fluctuated significantly among the three countries. Exports from the US have gradually increased but have decreased since the latter half of 2021. Japan's exports seem to have gradually increased. Those from the Netherlands did not show a clear trend before 2023 but skyrocketed from May 2023. Overall, during this study period, the increase in work-from-home to avoid COVID-19 infections dramatically increased the demand for ICs in the latter half of 2020 and 2021. In response, their demand dropped sharply in 2022, resulting in a dramatic drop in the prices of memory ICs. Rather than US export regulations, these global trends may account for the above changes in exports to China. Therefore, in the following sections, we conduct an econometric analysis to control for these global trends.

3. Empirical Framework

This section explains our empirical framework for investigating the trade effects of US export regulations. To this end, we examine monthly trade data obtained from the Global

Trade Atlas from January 2018 to September 2023. For reasons explained later, we employ the export data of 36 countries[7]. Their partner countries (i.e., importing countries) include 190. The study products are defined at the HS six-digit level and are restricted to intermediate and capital goods in HS 84 (general machinery) and HS 85 (electric machinery)[8]. In total, 672 products are studied. Our dependent variable is $\mathbf{X}_{ijpt}$, which is a vector of the export outcomes of HS six-digit code p from countries i to j at time t. This includes the logs of export values, quantities, and unit export prices. The unit price is computed by dividing export values by export quantities. We focus on observations with positive trade values, take their logs, and estimate our models by using the ordinary least squares (OLS) method.[9]

First, we examine the effects of two types of US policies on US ICs and IME exports to China. One is to add Huawei and SMIC to EL, and the other is to tighten US export regulations in October 2022. The estimation equation is as follows:

$$\mathbf{X}_{ijpt} = \mathbf{Z}_1'\boldsymbol{\beta} + \mathbf{Z}_2'\boldsymbol{\gamma} + \mathrm{u}_{ijp} + \mathrm{u}_{ipt} + \mathrm{u}_{jpt} + \mathrm{u}_{ijt} + \epsilon_{ijpt}, \tag{1}$$

where

$$\mathbf{Z}_1'\boldsymbol{\beta} = US_iCN_jJun19_t\mathbf{IC'}_p\boldsymbol{\beta}_1 + US_iCN_jOct22_t\mathbf{IC'}_p\boldsymbol{\beta}_2,$$
$$\mathbf{Z}_2'\boldsymbol{\gamma} = \gamma_1 US_iCN_jIME_pJan21_t + \gamma_2 US_iCN_jIME_pOct22_t.$$

US_i takes a value of one if exporter i is US, while CN_j does so if importer j is China. $Jun19_t$ takes a value of one since June 2019, while $Jan21_t$ does so since January 2021. $Oct22_t$ takes a value of one since October 2022. $\mathbf{IC}_p$ is a vector of dummy variables for ICs, including processors (HS 854231), memory (HS 854232), amplifiers (HS 854233), and other ICs (HS 854239). IME_p does so if product p is an IME–that is, HS 848620. By examining $US_iCN_jJun19_t\mathbf{IC'}_p$ and $US_iCN_jIME_pJan21_t$, we investigate the effects of adding Huawei and SMIC to EL. Because of the introduction of these two variables, the coefficients for $US_iCN_jOct22_t\mathbf{IC'}_p$ and $US_iCN_jIME_pOct22_t$ indicate the *additional* effects of the US tightening export regulations in October 2022 on US ICs and IME exports, respectively.

Four types of fixed effects (FEs) were included: country-pair product (u_{ijp}), exporter-product-time (u_{ipt}), importer-product-time (u_{jpt}), and country-pair-time (u_{ijt}) FEs. Country pair-product FEs control for time-invariant country-pair characteristics at the product level, including product preference, geographical distance, and language commonality. Exporter-

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[7] AR, AT, AU, BE, BR, CA, CH, CN, DE, DK, ES, FI, FR, GB, GR, ID, IE, IN, IT, JP, KR, LU, MX, MY, NL, NZ, PH, PT, RU, SE, SG, TH, TW, US, VN, ZA.

[8] We use the Broad Economic Categories for this restriction.

[9] Roughly, our dataset includes 36 countries' exports of 672 products to 190 partner countries for 69 months. The multiplication of these four numbers exceeds 300 million. The estimation for such an extremely large number of observations is beyond our computation capacity. In addition, unit export prices can be observed only when positive values of exports are realized. Therefore, we estimate our models by the OLS rather than the Poisson pseudo maximum likelihood method, which is often used in the gravity estimation.

product-time FEs include supply side characteristics, especially technology and factor prices, such as wages. Importer-product-time FEs include demand-side characteristics, especially the demand for products using ICs as inputs. The product-time component in these types of FEs also controls for the global IC demand trend. The country pair-time FEs capture the trade effects of trade agreements and exchange rates. Furthermore, this type of FEs contributes to controlling for changes in China's tariffs against the US based on the US-China tariff war because most products in HS 84 and 85 fall into the product list of China's retaliation tariffs. In addition, country pair-time FEs will control for the trade effects of economic sanctions on Russia's invasion of Ukraine in February 2022.

An empirical identification issue is worth discussing. As mentioned in previous sections, the product codes in trade statistics are too broad to identify regulated products. Thus, our dummy variables inevitably contain errors that bias our estimates toward zero. Furthermore, decreasing trade in cutting-edge ICs may increase demand and trade in less advanced ICs. Mixing these changes also decreases the absolute magnitude of the estimates. In short, these two issues resulted in an underestimation of our estimates. On the other hand, a decrease in US exports to China may increase exports from other countries. This increase results in overestimating our estimates of the variables for US exports. As in the second and third equations, this overestimation is reduced when adding dummy variables to potential exporting countries to China.

Another related issue is the interpretation of the estimates. In the standard partial equilibrium model of import demand and export supply, with a perfectly competitive market structure[10], a negative supply shock decreases export quantities and increases export prices. However, in the context of US export control regulations, this force in the demand-supply nexus may be weak because the US bans exports of cutting-edge ICs rather than imposing an export tax. Furthermore, owing to the strengthening of FDPR, no alternative country may supply cutting-edge ICs to China. Moreover, export prices could decrease if the restriction on cutting-edge ICs increases the exports of legacy ICs because prices for legacy ICs are lower than those for cutting-edge ICs. Our estimates indicate the net effect of these mechanisms on export indicators within the HS six-digit codes. A more detailed discussion is presented in the following section.

Next, we examine the effects of tightening FDPR in 2020 and 2022 in third economies. Specifically, we explore the exports of Korea and Taiwan, the major producers of advanced ICs, to China. These two economies cannot export cutting-edge ICs (without approval by the BIS) if those ICs are "direct products" (or "re-exported products of US goods"). The following equation is estimated:

$$\mathbf{X}_{ijpt} = \mathbf{Z}_1'\boldsymbol{\beta} + \mathbf{Z}_2'\boldsymbol{\gamma} + \mathbf{Z}_3'\boldsymbol{\varphi} + \mathrm{u}_{ijp} + \mathrm{u}_{ipt} + \mathrm{u}_{jpt} + \mathrm{u}_{ijt} + \epsilon_{ijpt}, \qquad (2)$$

where

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[10] Namely, the foreign export supply curve rises with prices, while the home import demand falls with prices.

$$\mathbf{Z}_3'\boldsymbol{\varphi} = KR_iCN_jSep20_t\mathbf{IC'}_p\boldsymbol{\varphi}_1 + KR_iCN_jOct22_t\mathbf{IC'}_p\boldsymbol{\varphi}_2 + TW_iCN_jSep20_t\mathbf{IC'}_p\boldsymbol{\varphi}_3 + TW_iCN_jOct22_t\mathbf{IC'}_p\boldsymbol{\varphi}_4.$$

KR_i and TW_i take the value of one if exporter i is Korea and Taiwan, respectively. $Sep20_t$ has assumed a value of one since September 2020. The coefficients for $KR_iCN_jSep20_t\mathbf{IC'}_p$ and $TW_iCN_jSep20_t\mathbf{IC'}_p$ indicate the effects of tightening the FDPR in September 2020 on IC exports from Korea and Taiwan to China, respectively. Similarly, the effects of tightening the FDPR in October 2022 are captured by $KR_iCN_jOct22_t\mathbf{IC'}_p$ and $TW_iCN_jOct22_t\mathbf{IC'}_p$.

Finally, we investigate the effects of US export regulations on IME exports from Japan and the Netherlands to China. We examine two types of IME export regulations. One lists SMIC as EL, while the other is the US tightening export regulations in October 2022. The former restricts exports of the IME for cutting-edge ICs from Japan and the Netherlands to the SMIC if their machines are re-exported products of US goods. Furthermore, the latter event restricts them if their equipment is used for the production/development of supercomputers or cutting-edge ICs (and are reexported products). To examine these effects, we modify equation (1) as follows:

$$\mathbf{X}_{ijpt} = \mathbf{Z}_1'\boldsymbol{\beta} + \mathbf{Z}_2'\boldsymbol{\gamma} + \mathbf{Z}_4'\boldsymbol{\delta} + \mathrm{u}_{ijp} + \mathrm{u}_{ipt} + \mathrm{u}_{jpt} + \mathrm{u}_{ijt} + \epsilon_{ijpt}, \qquad (3)$$

where

$$\mathbf{Z}_4'\boldsymbol{\rho} = \rho_1 JP_iCN_jIME_pJan21_t + \rho_2 JP_iCN_jIME_pOct22_t + \rho_3 NL_iCN_jIME_pJan21_t + \rho_4 NL_iCN_jIME_pOct22_t.$$

The coefficients for $JP_iCN_jIME_pJap21_t$ and $NL_iCN_jIME_pJan21_t$ capture the effect of adding SMIC to EL, whereas those for $JP_iCN_jIME_pOct22_t$ and $NL_iCN_jIME_pOct22_t$ indicate the effects of the US tightening export regulations in October 2022.

One data issue is worth discussing. As mentioned above, we use export data. Owing to the significance of Hong Kong's re-exports from and to China, we must carefully design the dataset to examine trade with China. To reduce the complexity, we integrate Hong Kong into China. Since December 2020, exports to Hong Kong have been treated as transactions destined for China under the US Export Control System[11]. Suppose that the US exports to China and Hong Kong. As Day (2015) and Ferrantino and Wang (2008) explore, the following relationship holds:

$$\begin{aligned}&Exports\ from\ US\ to\ CN\ (US) + Exports\ from\ US\ to\ HK\ (US)\\ &\quad - Reexports\ of\ HK\ from\ US\ to\ Non\ CN(HK)\\ &\quad \cong Imports\ of\ CN\ from\ US\ (CN) + Imports\ of\ HK\ from\ US\ (HK)\\ &\quad - Reexports\ of\ HK\ to\ US\ to\ CN(HK)\end{aligned}$$

The names in parentheses indicates the reporters. The right- and left-hand sides are not exactly the same because of f.o.b./c.i.f. differences and Hong Kong's re-export markups.

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[11] https://www.bis.doc.gov/index.php/all-articles/220-eco-country-pages/1060-hong-kong-export-control-information

We avoid using data on Hong Kong's re-exports in the econometric analyses because these data will only be available in the Global Trade Atlas until 2022. According to the Global Trade Atlas, over 90% of Hong Kong re-exports from the US have gone to China in recent years. The second largest destination is Taiwan, which accounts for 2-3%. In other words, the magnitude of "$Reexports\ of\ HK\ from\ US\ to\ Non\ CN(HK)$" is trivial compared with that of "$Reexports\ of\ HK\ to\ US\ to\ CN(HK)$." Thus, to minimize the bias from ignoring Hong Kong's re-exports, we use "$Exports\ from\ US\ to\ CN\ (US) + Exports\ from\ US\ to\ HK\ (US)$" as a proxy for US exports to China and Hong Kong, i.e., exporter-side data. Another reason is that our primary interest lies in China's imports, and we believe that the trade data reported by developed countries are more accurate. In the following, exports to China include those to Hong Kong.

4. Empirical Results

This section presents the results of the estimation. We cluster the standard errors at the country-pair-product level in all the estimations. We first report our estimation results for equations (1)–(3) and then estimate additional models. Finally, we present the results of the event study analyses.

4.1. Baseline Estimation

We estimate equation (1) for export values, quantities, and prices. The results are summarized in Table 1. Although we introduce four types of IC variables, we focus on the results for the major product, the processors, shown in Figure 1. The exports of processors to China decreased significantly, especially after tightening export regulations in October 2022, but not after adding Huawei to the EL. The former decrease is realized mainly through a significant decrease in export quantities rather than in export prices. Specifically, export quantities of processors decrease by 56% (=exp(−0.83)−1). The insignificant changes in export prices indicate no quality changes in the exported IC products and simply decreased export quantities of existing IC products.

=== Table 1 ===

On the other hand, the insignificant results of adding Huawei to EL may be because the presumption of denial is applied only when exporting specific and cutting-edge products to Huawei. Thus, the changes in US exports of these cutting-edge products may not be significant enough to create significant changes in the average export prices and quantities. Another possible interpretation of the insignificant result may be an increase in the exports of less advanced ICs to Huawei or those of advanced ICs to other smartphone makers such as Xiaomi and Apple. However, an insignificant but positive price result may reject the increase in exports of non-cutting-edge ICs to Huawei.[12] Thus, the decrease in IC exports to Huawei may be counteracted by increased IC exports to other smartphone makers[13].

In the IME, export values do not change significantly after adding SMIC to EL. However, we observe a significant decline in export prices and a significant increase in export quantities. These results may indicate an increase in the exports of low-priced IME for legacy ICs, that is, non-cutting-edge ICs, instead of high-priced IME for cutting-edge ICs.[14] This increase may have been driven by the rising demand for IME to prepare for further restrictions. Specifically, export prices decline by 44% (=exp(−0.58)−1), while export quantities increase by 88% (=exp(0.63)−1). After tightening export regulations in October 2022, export prices and quantities decreased significantly. These results indicate a dramatic decrease in IME exports for cutting-edge ICs. Specifically, the export values of IME decrease by 63% (=exp(−1.0)−1)[15]. Overall, the export regulations introduced in October 2022 significantly adversely affected US exports of ICs and IME to China.

Next, we estimate equation (2) to investigate the effects of FDPR tightening in 2020 and 2022. Table 3 presents the estimated results. We do not show the results for US exports of non-major IC products and IME to save space. We introduce only interaction terms with dummy variables for the main IC products: memory ICs for Korean exports and other ICs for Taiwanese exports. The results of the previous variables on the US exports of ICs do not change qualitatively compared to those in Table 1. We can observe a significant decrease in the export of memories from Korea to China after the FDPR was tightened in 2020. Indeed, the major Korean exporters, Samsung and SK Hynix, stopped shipping to China in August 2020[16]. Specifically, export values decrease by 39% (=exp(−0.49)−1). Tightening the FDPR in 2022 also decreases those exports from Korea by 31% (=exp(−0.37)−1) through the reduction of export prices, which may indicate the decrease of the share of advanced memories in exports.

=== Table 2 ===

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[12] We assume that unit prices are lower in less advanced ICs than in advanced ICs.

[13] According to the investigation by AUN CONSULTING, inc., the global shares of Apple and Xiaomi have risen while that of Huawei has declined. See https://www.auncon.co.jp/press/release/2023-02-08/.

[14] The old studies demonstrated that the introduction of minimum quality standards and voluntary export restraints lead to quality upgrading of export products (e.g., Donnenfeld and Mayer, 1987; Das and Donnenfeld, 1989). Our result on the US export control regulations suggests the opposite effect. Those regulations may be taken as a kind of maximum quality standard.

[15] The result of the significant decrease in exports of IME is consistent with the finding in Ando et al. (2023a).

[16] https://www.nikkei.com/article/DGXMZO64178390U0A920C2000000/

However, the results for other ICs in Taiwan show insignificant changes in exports after FDPR was tightened in 2020 and 2022. As in the case of Korean exporters, the major Taiwanese exporter, the Taiwan Semiconductor Manufacturing Company (TSMC), stopped its shipments to China in August 2020. However, as found in export prices, an (insignificant) decrease in export quantities may raise export prices significantly through the demand-supply mechanism, resulting in an insignificant change in export values. One crucial difference in the effect of the FDPR reform in 2022 on exports from Korea and Taiwan is that export prices decline significantly in Korea but not in Taiwan, creating a difference in the results for export values. This difference may be due to the differences between memory ICs and other ICs. The memory market is generally tougher because of the relatively large number of producers. Thus, price differentials over quality may be large. The decrease in the exports of cutting-edge memory ICs may dramatically lower average export prices. On the other hand, other ICs produced by Taiwanese firms may maintain relatively high prices, even for less advanced products.

Table 3 shows the estimation results of equation (3), which investigates the effects of US export regulations on IME exports from Japan and the Netherlands to China. To save space, we show only the results for IME. The results for US IME exports do not change compared with those in Table 1. In Japan, adding SMIC to EL and tightening export regulations in October 2022 did not significantly affect IME exports to China. However, the latter reform significantly increased export prices and decreased export quantities. As this result contradicts the expectation that exports of IME for cutting-edge ICs will decrease, it may reflect the demand-supply mechanism. However, adding SMIC to EL significantly decreases Dutch IME exports to China through a significant decrease in export quantities. The tightening of export regulations in October 2022 did not significantly affect IME exports. These results are discussed later in the study.

=== Table 3 ===

4.2. Other Estimation

In this subsection, we conduct three additional estimations. First, we control for the trade effect of US economic sanctions on Russia. Russia and Ukraine went to war in 2014 over the status of Crimea and Donbas. The conflict expanded dramatically after Ukraine's full-scale Russian invasion in February 2022. During this invasion, the US introduced a full list of economic sanctions, including export control regulations. Specifically, it added many Russian companies to EL and tightened FDPR and end-use restrictions. As a result, the exports of most study products to Russia are subject to the EAR. Although our fixed effects already capture the average effect of these restrictions, we also control for the effects specific to ICs. Specifically, we add $US_i RU_j IC_p Mar22_t$, $KR_i RU_j IC_p Mar22_t$, $TW_i RU_j IC_p Mar22_t$, and $US_i RU_j IME_p Mar22_t$ to equation (2): RU_j takes the value of one if importer j is Russia. We only examined the exports of the main IC product in each country and those of IME from the US.

The estimation results are presented in Table 4. Adding the new variables did not change the results of the previous variables. Namely, the US decreases the exports of processors and IME to China, Korea decreases those of memories, and Taiwan does not change the exports of other ICs. The results for exports to Russia are as follows: The US dramatically decreased processor exports to Russia after the invasion. In particular, the decrease in export quantities was remarkable, increasing export prices. Consequently, the export value of the processors decreased by 78%. The exports of other ICs from Taiwan also declined significantly through a reduction in export prices rather than a decrease in export quantities. Thus, Taiwanese firms may only export low-end ICs to Russia. In contrast, the export of memories from Korea does not change significantly. The US has not significantly changed its exports of IME to Russia.

=== Table 4 ===

Second, we examine the trade effects of another type of product. In August 2022, the US restricted the export of AI computer chips to China, especially graphics processing units (GPUs). The market for these products is dominated by two US companies: Nvidia and Advanced Micro Devices. In particular, Nvidia GPUs are indispensable for driving large language models such as ChatGPT. Nvidia outsourced the production of its flagship models, the A100 and H100 GPUs, to TSMC. Thus, US regulations potentially affect exports of GPUs from Taiwan to China. To observe this effect, we add $TW_iCN_jGPU_pSep22_t$ to equation (2). GPU_p takes the value of one if product p is GPUs, namely, HS 847330. We chose September 2022 as the starting month of the restriction because Nvidia received notification of licensing requirements on the exports of these chips from the US Department of Commerce in August 2022[17]. We then examine how this restriction on GPUs changes GPU exports from Taiwan to China.

The estimation results are presented in Table 5. The results for the ICs did not change compared to those in Table 2. The interaction term with the GPU dummy has a significantly positive coefficient for exports due to the significant increase in export quantities. For export prices, the coefficient is negative but insignificant. Thus, we observe a significant increase in the exports of GPUs from Taiwan to China after US restrictions. This result is unexpected but understandable because Nvidia developed chips called A800 and H800, which reduced some of the capabilities of A100 and H100 and are legally exported to China[18]. Thus, Taiwan has increased exports of these downgraded products to China to meet the growing demand

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[17] For example, see https://asia.nikkei.com/Business/Tech/Semiconductors/U.S.-tightens-chip-export-rules-to-China-hitting-Nvidia-and-AMD.

[18] For example, see the following. https://www.reuters.com/technology/nvidia-tweaks-flagship-h100-chip-export-china-h800-2023-03-21/

for chips to develop generative AI technologies. Furthermore, our results suggest that the growing demand does not significantly change GPU export prices of GPUs to China.

=== Table 5 ===

Finally, Figure 1 shows a dramatic rise in IME exports from Japan and the Netherlands in the second quarter of 2023. We speculate that this increase was driven by the last-minute demand for IME in China before these two governments began restricting IME exports in the third quarter of 2023. On March 31, the Japanese government publicized a draft amendment to this restriction and started collecting public comments[19]. Thus, this announcement may have increased China's IME imports from these countries until the restriction began. To observe this announcement effect, we add two interaction terms, $JP_iCN_jIME_pApr23_t$ and $NL_iCN_jIME_pApr23_t$ to equation (3). $Apr23_t$ takes a value of one since April 2023. Notably, in $JP_iCN_jIME_pApr23_t$, $Apr23_t$ takes a value of zero since August 2023 because of the introduction of an export restriction in Japan, as explained below: Furthermore, our observations include exports from Japan until September 2023 and from the Netherlands until August 2023. The Japanese and Dutch governments began restricting IME exports on July 23 and September 1, respectively. To examine the direct effect of export restrictions in Japan, we also introduce an interaction term, $JP_iCN_jIME_pAug23_t$, where $Aug23_t$ takes a value of one since August 2023.

The estimation results are reported in Table 6. In Japan, the results in the interaction terms with *Jan21* and *Oct22* for IME exports are unchanged compared to those in Table 3, although those with *Oct22* become insignificant in both export prices and quantities. In the Netherlands, the results in the interaction term with *Jan21* are unchanged, while those with *Oct22* are significantly negative for exports. Thus, controlling for the effect of last-minute demand, we find that tightening export regulations in October 2022 significantly decrease IME exports from the Netherlands to China. Since a significant decline in export prices drives this decrease, the Netherlands seems to decrease its exports of IME for cutting-edge ICs. Thus, the adverse effects of US export regulations on IME are found more in Dutch exports than in Japanese exports. This result may indicate that Dutch IME is produced using more US-origin technology and, thus, is more likely to fall into re-exported products of US goods than Japanese IME.

=== Table 6 ===

The interaction term on *Apr23* has a significantly positive coefficient for exports from Japan and the Netherlands. We also find that this increase in exports is due to a significant rise in export prices, although these coefficients are not significant for export quantities.

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[19] See the following announcement: https://www.meti.go.jp/english/speeches/press_conferences/2023/0331001.html.

Thus, the significant increase in IME exports to China in the second quarter of 2023 is driven not by the increase in export quantities but by the increase in export prices, which may be based on the expectation of a future shortage of IME in China. Finally, in Japan, the coefficient of the interaction term with *Aug23* is negative but insignificant for export quantities. It is insignificant and positive in export prices and, thereby, in export values. Thus, the direct impact of Japanese export restrictions remains insignificant within two months of their initiation.

4.3. Event Study

Thus far, we have examined dummy variables at specific times. Multiple events–that is, multiple regulatory reforms–can affect trade. Furthermore, each event may also have its announcement effect. In addition, several Chinese companies were subsequently added to EL. Therefore, it is natural to adopt an event study approach to investigate export changes over the entire period.

First, we examine changes in the exports of processors and IMEs from the US to China. To this end, we estimate the following equation:

$$\mathbf{X}_{ijpt} = \sum\nolimits_{k\neq Sep22}\left(\beta_k US_i CN_j Processor_p Time_k\right) + \sum\nolimits_{k\neq Sep22}\left(\gamma_k US_i CN_j IME_p Time_k\right) + \mathbf{W}_1'\boldsymbol{\tau} + \mathrm{u}_{ijp} + \mathrm{u}_{ipt} + \mathrm{u}_{jpt} + \mathrm{u}_{ijt} + \epsilon_{ijpt}, \quad (4)$$

where

$$\mathbf{W}_1'\boldsymbol{\tau} = \tau_1 US_i CN_j Jun19_t Memory_p + \tau_2 US_i CN_j Oct22_t Memory_p + \tau_3 US_i CN_j Jun19_t Other\ IC_p + \tau_4 US_i CN_j Oct22_t Other\ IC_p,$$

The base time is set to September 2022, one month before the US government introduced strict export regulations. $Processor_p$, $Memory_p$, and $Other\ IC_p$ take a value of one if product p is a processor ICs, memory ICs, or other ICs, respectively. $Time_k$ takes the value one if time t is k.

Panel (i) of Figure 2 depicts the time-series changes in the point estimates of the processors. Consistent with the results in Table 1, export values decreased since October 2022, mainly through a reduction in export prices. Before this time, export values were higher, mainly because of the larger export quantities. In particular, export quantities were much larger in 2019 and 2020 than after the base period. Panel (ii) shows the results for the IME. The vertical axis indicates relatively large fluctuations in the three export indicators. Drastic fluctuations occurred in export prices and quantities a few months before the strengthening of export controls in October 2022. A dramatic increase in export quantities may lower export prices. Except for this period with drastic changes, export quantities did not seem to differ before and after the base time. However, relatively low export prices may significantly decrease IME export values after the base period, as shown in Table 1.

=== Figure 2 ===

Next, to observe changes in ICs from Korea or Taiwan to China, we estimate the following equation:

$$\mathbf{X}_{ijpt} = \sum\nolimits_{k \neq Aug20} \left(\varphi_k KR_i CN_j Memory_p Time_k\right) + \sum\nolimits_{k \neq Aug20} \left(\varphi_k TW_i CN_j Other\ IC_p Time_k\right) + \mathbf{Z}_1'\boldsymbol{\beta} + \mathbf{Z}_2'\boldsymbol{\gamma} + \mathrm{u}_{ijp} + \mathrm{u}_{ipt} + \mathrm{u}_{jpt} + \mathrm{u}_{ijt} + \epsilon_{ijpt}, \quad (5)$$

The base time is set to August 2020, the month of strengthening FDPR. Panel (iii) presents the results for South Korea. As shown in Table 2, export values seem to be smaller after the base period than before, although we also see a large drop in export quantities in June and July 2020, just after the first FDPR reform in May 2020. Although we did not find significant changes in Table 2, export quantities declined in the middle of 2022. Panel (iv) presents the results for Taiwan. Although we did not find significant changes in Table 2, export quantities seem to decline from August 2020 (the base time) to October 2022 (another time of strengthening FDPR), whereas export prices appear to rise. These contrasting changes yielded insignificant changes in export values.

Finally, to observe changes in IMEs from Japan or the Netherlands to China, we estimate the following equation:

$$\mathbf{X}_{ijpt} = \sum\nolimits_{k \neq Sep22} \left(\rho_k JP_i CN_j IME_p Time_k\right) + \sum\nolimits_{k \neq Sep22} \left(\rho_k NL_i CN_j IME_p Time_k\right) + \mathbf{Z}_1'\boldsymbol{\beta} + \mathbf{Z}_2'\boldsymbol{\gamma} + \mathrm{u}_{ijp} + \mathrm{u}_{ipt} + \mathrm{u}_{jpt} + \mathrm{u}_{ijt} + \epsilon_{ijpt}, \quad (6)$$

The base time is set to September 2022. Panel (v) reports the point estimates for Japan. As shown in Table 6, on average, export values did not seem to change dramatically before and after the base time. A significant export increase during the last minute of the demand period may only be realized in April 2023. In September 2023, after introducing export restrictions in Japan in July 2023, we observed a significant increase in export prices and a significant decline in export quantities. Panel (vi) reports the results for the Netherlands. As shown in Table 6, the export values were lower after the base time, especially in the fourth quarter of 2022. In addition, during the last minute, export values rose.

5. Concluding Remarks

This study empirically investigated the trade effects of US export regulations by applying monthly trade data from January 2018 to August 2023 to gravity equations. We found that these changes in US export regulations decreased US exports of ICs and IME to China. This result is expected in terms of its effect on the own trade. Strengthening export control regulations in October 2022 had more adverse effects than adding Chinese companies to EL. This result may indicate that restricting exports to specific companies does not have large effects compared with restrictions based on end-use, at least partly because the former encourages other companies to increase their imports.

Conversely, the effects in third economies are not uniform. IC exports to China decreased in Korea but not in Taiwan. This contrast may be due to differences in the main export product, i.e., memory ICs in Korea versus other ICs in Taiwan. Although the memory market is tougher, other ICs produced in Taiwan may be highly competitive. Similarly, the IME declined in the Netherlands but not in Japan. Since the largest IME producer in the Netherlands, ASML, introduced US technology, Dutch IME may be more likely to be subject to EAR in the US than Japanese IME. Nevertheless, Japan and the Netherlands enjoyed last-minute demand for IME in China before their restrictions on IME exports. In summary, the effect of export control regulations on exports from third economies depend on the product type and technology used in the export products.

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Table 1. Estimation Results on US Exports

	Value	Price	Quantity
Processor * Jun19 * US * CN	0.16	0.1944	-0.0345
	[0.1402]	[0.1289]	[0.1512]
Processor * Oct22 * US * CN	-1.0264***	-0.1933	-0.8331***
	[0.1590]	[0.1478]	[0.1682]
Memory * Jun19 * US * CN	-0.2255	1.0124***	-1.2379***
	[0.1716]	[0.1585]	[0.2498]
Memory * Oct22 * US * CN	-0.4351***	0.4336***	-0.8688***
	[0.1317]	[0.1624]	[0.2021]
Amplifier * Jun19 * US * CN	-0.3552*	0.2553	-0.6105***
	[0.1855]	[0.1848]	[0.1849]
Amplifier * Oct22 * US * CN	-0.4078**	-0.4569***	0.0491
	[0.1748]	[0.1311]	[0.1825]
Other IC * Jun19 * US * CN	0.0449	0.0638	-0.0188
	[0.1220]	[0.1235]	[0.1561]
Other IC * Oct22 * US * CN	-0.3612***	-0.1265	-0.2346
	[0.1077]	[0.1231]	[0.1517]
IME * Jan21 * US * CN	0.0568	-0.5760***	0.6327***
	[0.1641]	[0.1606]	[0.2239]
IME * Oct22 * US * CN	-1.0005***	-0.5033***	-0.4972***
	[0.2045]	[0.1812]	[0.1900]
Number of observations	26,992,723	26,992,723	26,992,723
Adjusted R-squared	0.766	0.906	0.881

Notes: This table reports the estimation results obtained using the OLS method. The dependent variables are export value, unit export price, and export quantity reported by the exporting countries. ***, **, and * indicate 1%, 5%, and 10% levels of statistical significance, respectively. The standard errors reported in parentheses are clustered at the country-pair-product level. In all the specifications, we control for country-pair-product, exporter-product-time, importer-product-time, and country-pair-time FEs.

Table 2. Estimation Results on Third Economies' Exports of ICs

	Value	Price	Quantity
Processor * Jun19 * US * CN	0.1599	0.1944	-0.0345
	[0.1402]	[0.1289]	[0.1512]
Processor * Oct22 * US * CN	-1.0265***	-0.1933	-0.8331***
	[0.1590]	[0.1478]	[0.1682]
Memory * Sep20 * KR * CN	-0.4877**	-0.1393	-0.3484
	[0.1932]	[0.2043]	[0.2736]
Memory * Oct22 * KR * CN	-0.3702**	-0.3246**	-0.0455
	[0.1876]	[0.1562]	[0.2106]
Other IC * Sep20 * TW * CN	0.0361	0.2492**	-0.2131
	[0.1484]	[0.1179]	[0.1720]
Other IC * Oct22 * TW * CN	-0.0943	-0.0844	-0.0099
	[0.1078]	[0.1302]	[0.1580]
Number of observations	26,992,723	26,992,723	26,992,723
Adjusted R-squared	0.766	0.906	0.881

Notes: This table reports the estimation results obtained using the OLS method. The dependent variables are export value, unit export price, and export quantity reported by the exporting countries. ***, **, and * indicate 1%, 5%, and 10% levels of statistical significance, respectively. The standard errors reported in parentheses are clustered at the country-pair-product level. In all the specifications, we control for country-pair-product, exporter-product-time, importer-product-time, and country-pair-time FEs. We do not show the results for US exports of non-major ICs and IME to save space.

Table 3. Estimation Results on Third Economies' Exports of IME

	Value	Price	Quantity
IME * Jan21 * US * CN	0.0343	-0.5684***	0.6027***
	[0.1708]	[0.1700]	[0.2273]
IME * Oct22 * US * CN	-1.0191***	-0.5124***	-0.5067**
	[0.2195]	[0.1896]	[0.2038]
IME * Jan21 * JP * CN	0.1455	-0.2312	0.3766**
	[0.1655]	[0.1880]	[0.1914]
IME * Oct22 * JP * CN	0.0443	0.4919**	-0.4476*
	[0.2272]	[0.2456]	[0.2538]
IME * Jan21 * NL * CN	-0.4479**	0.3359**	-0.7838***
	[0.2276]	[0.1646]	[0.2725]
IME * Oct22 * NL * CN	-0.3374	-0.6309***	0.2935
	[0.2695]	[0.1934]	[0.2514]
Number of observations	26,992,723	26,992,723	26,992,723
Adjusted R-squared	0.766	0.906	0.881

Notes: This table reports the estimation results obtained using the OLS method. The dependent variables are export value, unit export price, and export quantity reported by the exporting countries. ***, **, and * indicate 1%, 5%, and 10% levels of statistical significance, respectively. The standard errors reported in parentheses are clustered at the country-pair-product level. In all the specifications, we control for country-pair-product, exporter-product-time, importer-product-time, and country-pair-time FEs. To save space, we do not show the results for the US exports of ICs.

Table 4. Estimation Results: Controlling for Exports to Russia

	Value	Price	Quantity
Processor * Jun19 * US * CN	0.1583	0.1973	-0.039
	[0.1401]	[0.1290]	[0.1512]
Processor * Oct22 * US * CN	-1.0337***	-0.1803	-0.8534***
	[0.1590]	[0.1472]	[0.1673]
Memory * Sep20 * KR * CN	-0.4877**	-0.1392	-0.3485
	[0.1932]	[0.2043]	[0.2736]
Memory * Oct22 * KR * CN	-0.3701**	-0.3247**	-0.0455
	[0.1876]	[0.1562]	[0.2106]
Other IC * Sep20 * TW * CN	0.0366	0.2495**	-0.2129
	[0.1485]	[0.1179]	[0.1720]
Other IC * Oct22 * TW * CN	-0.094	-0.0843	-0.0098
	[0.1078]	[0.1302]	[0.1580]
IME * Jan21 * US * CN	0.0558	-0.5773***	0.6331***
	[0.1640]	[0.1606]	[0.2241]
IME * Oct22 * US * CN	-0.9999***	-0.5024***	-0.4975***
	[0.2044]	[0.1811]	[0.1900]
Processor * Mar22 * US * RU	-1.5096*	2.7255***	-4.2352***
	[0.7857]	[0.6056]	[0.5712]
Memory * Mar22 * KR * RU	0.092	-0.5791	0.6714
	[0.7569]	[0.7496]	[1.0549]
Other IC * Mar22 * TW * RU	-1.0233*	-0.5446**	-0.4787
	[0.5869]	[0.2405]	[0.5578]
IME * Mar22 * US * RU	-0.6836	-0.8631	0.1795
	[0.5358]	[2.1374]	[2.4352]
Number of observations	26,992,723	26,992,723	26,992,723
Adjusted R-squared	0.766	0.906	0.881

Notes: This table reports the estimation results obtained using the OLS method. The dependent variables are export value, unit export price, and export quantity reported by the exporting countries. ***, **, and * indicate 1%, 5%, and 10% levels of statistical significance, respectively. The standard errors reported in parentheses are clustered at the country-pair-product level. In all the specifications, we control for country-pair-product, exporter-product-time, importer-product-time, and country-pair-time FEs. We do not show the results for US exports of non-major ICs and IME to save space.

Table 5. Estimation Results on Taiwan's Exports of GPUs to China

	Value	Price	Quantity
Processor * Jun19 * US * CN	0.1599	0.1944	-0.0345
	[0.1402]	[0.1289]	[0.1512]
Processor * Oct22 * US * CN	-1.0265***	-0.1933	-0.8331***
	[0.1590]	[0.1478]	[0.1682]
Memory * Sep20 * KR * CN	-0.4877**	-0.1393	-0.3484
	[0.1932]	[0.2043]	[0.2736]
Memory * Oct22 * KR * CN	-0.3702**	-0.3246**	-0.0455
	[0.1876]	[0.1562]	[0.2106]
Other IC * Sep20 * TW * CN	0.0361	0.2492**	-0.2131
	[0.1484]	[0.1179]	[0.1720]
Other IC * Oct22 * TW * CN	-0.0936	-0.0847	-0.0088
	[0.1078]	[0.1302]	[0.1580]
GPU * Sep22 * TW * CN	0.2322*	-0.1042	0.3364**
	[0.1403]	[0.1297]	[0.1464]
Number of observations	26,992,723	26,992,723	26,992,723
Adjusted R-squared	0.766	0.906	0.881

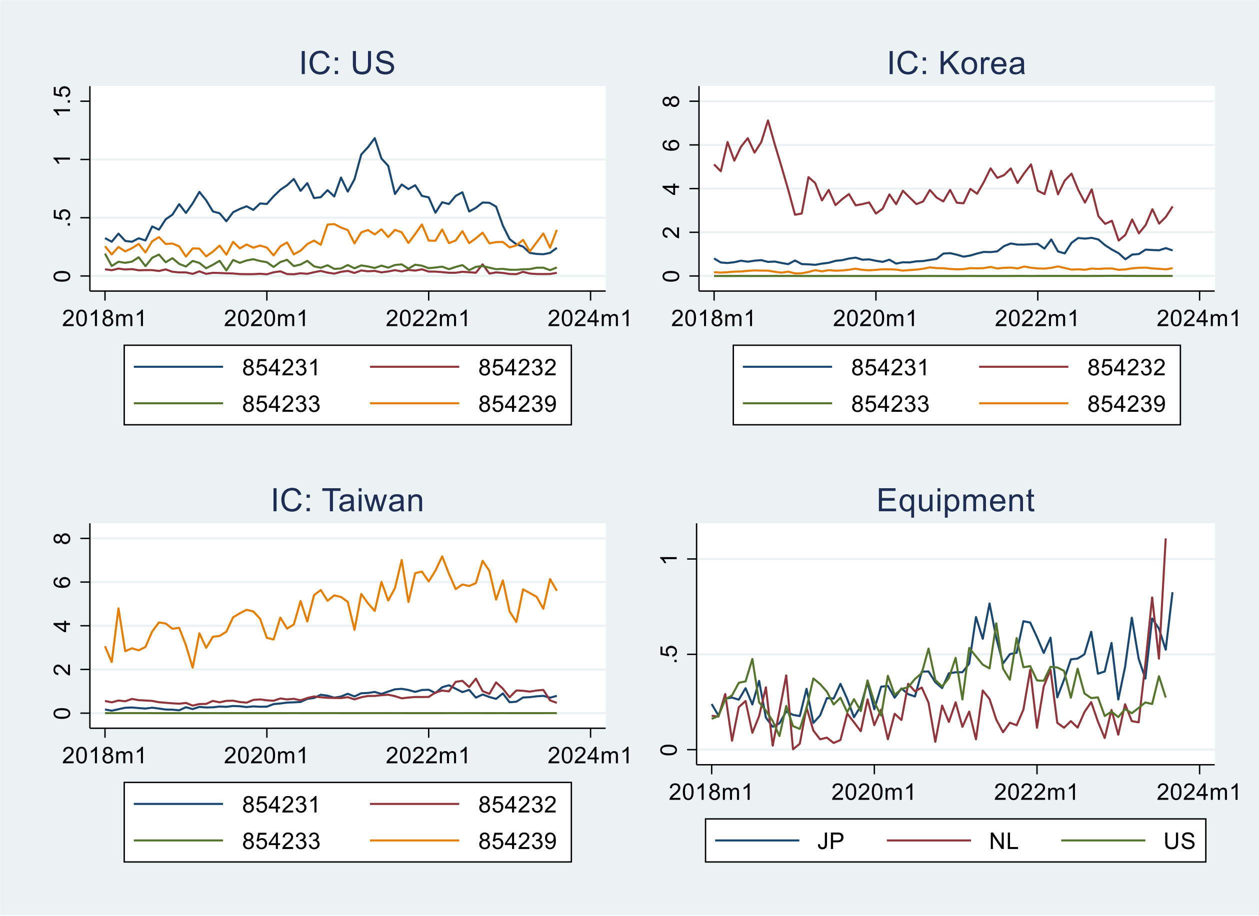
Notes: This table reports the estimation results obtained using the OLS method. The dependent variables are export value, unit export price, and export quantity reported by the exporting countries. ***, **, and * indicate 1%, 5%, and 10% levels of statistical significance, respectively. The standard errors reported in parentheses are clustered at the country-pair-product level. In all the specifications, we control for country-pair-product, exporter-product-time, importer-product-time, and country-pair-time FEs. We do not show the results for US exports of non-major ICs and IME to save space.

Table 6. Estimation Results on Third Economies' Exports of IME: Announcement Effects

	Value	Price	Quantity
IME * Jan21 * US * CN	0.0342	-0.5685***	0.6026***
	[0.1708]	[0.1700]	[0.2273]
IME * Oct22 * US * CN	-1.0180***	-0.5149***	-0.5031**
	[0.2194]	[0.1894]	[0.2032]
IME * Jan21 * JP * CN	0.1453	-0.2311	0.3764**
	[0.1655]	[0.1880]	[0.1914]
IME * Oct22 * JP * CN	-0.1978	0.0092	-0.207
	[0.2499]	[0.2137]	[0.2357]
IME * Apr23 * JP * CN	0.5854**	0.7638**	-0.1784
	[0.2890]	[0.3015]	[0.3548]
IME * Aug23 * JP * CN	0.2956	1.4536	-1.1581
	[0.3789]	[1.0047]	[0.9995]
IME * Jan21 * NL * CN	-0.4482**	0.3358**	-0.7840***
	[0.2276]	[0.1646]	[0.2724]
IME * Oct22 * NL * CN	-0.9472***	-0.9822***	0.0349
	[0.3045]	[0.2263]	[0.2805]
IME * Apr23 * NL * CN	1.3487***	0.7690***	0.5797
	[0.3525]	[0.2420]	[0.4057]
Number of observations	26,992,723	26,992,723	26,992,723
Adjusted R-squared	0.766	0.906	0.881

Notes: This table reports the estimation results obtained using the OLS method. The dependent variables are export value, unit export price, and export quantity reported by the exporting countries. ***, **, and * indicate 1%, 5%, and 10% levels of statistical significance, respectively. The standard errors reported in parentheses are clustered at the country-pair-product level. In all the specifications, we control for country-pair-product, exporter-product-time, importer-product-time, and country-pair-time FEs. To save space, we do not show the results for the US exports of ICs.

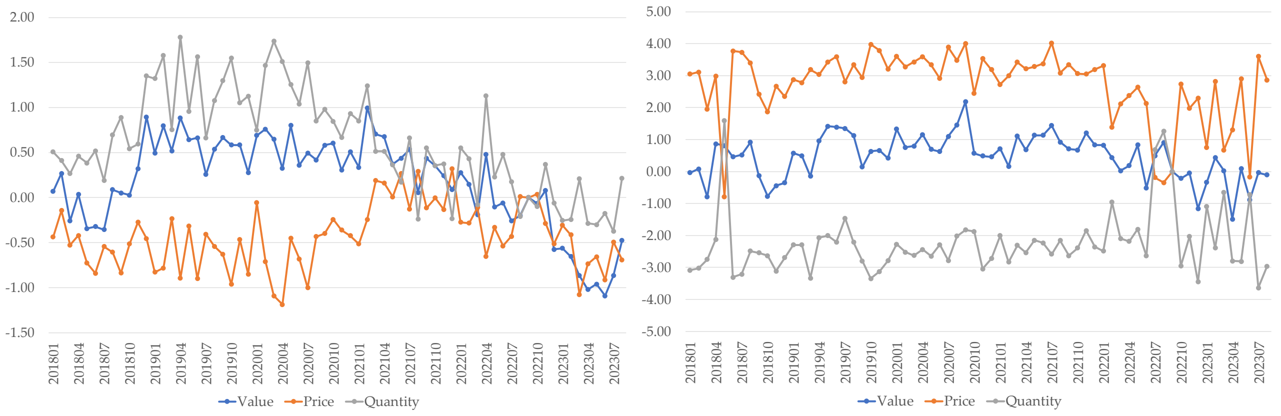
Figure 1. Exports of ICs and IME to China (Billion USD)



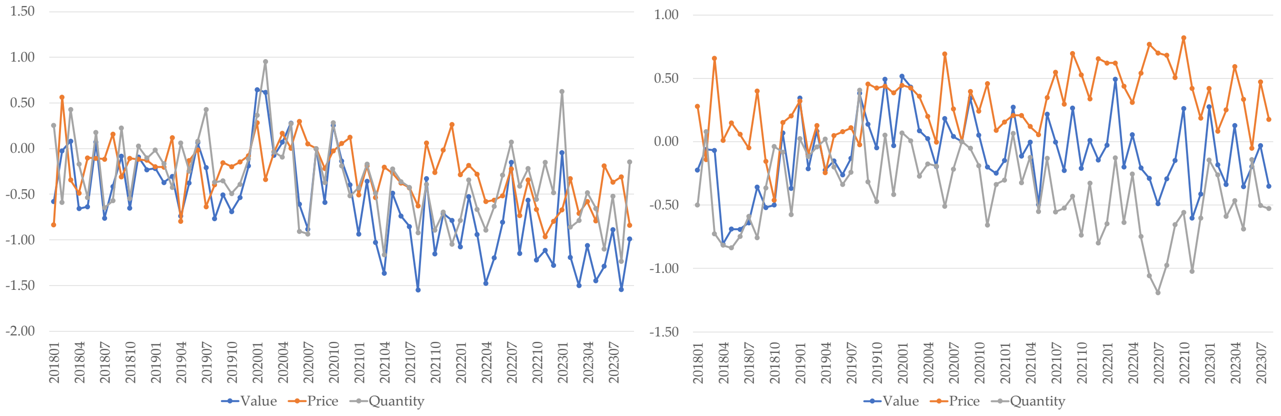
Source: Global Trade Atlas

Note: ICs include processors (HS 854231), memory ICs (HS 854232), amplifiers (HS 854233), and other ICs (HS 854239).

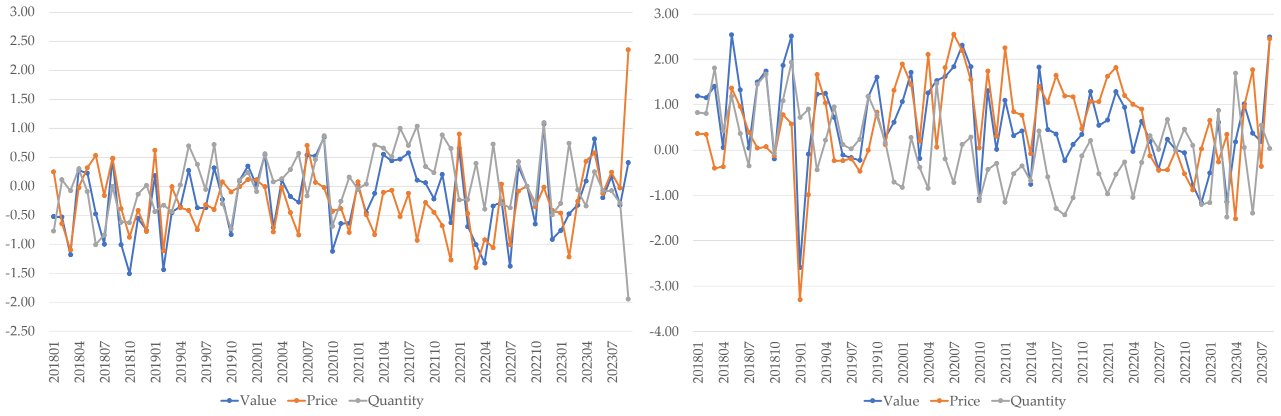
Figure 2. Time-series Changes of Point Estimates


(i) Processor ICs in the US

(ii) IME in the US


(iii) Memory ICs in Korea

(iv) Other ICs in Taiwan


(v) IME in Japan

(vi) IME in the Netherlands

Source: Author's estimation

Notes: In Panels (i), (ii), (v), and (vi), the base time is set to September 2022. In Panels (iii) and (iv), it is set to August 2020.