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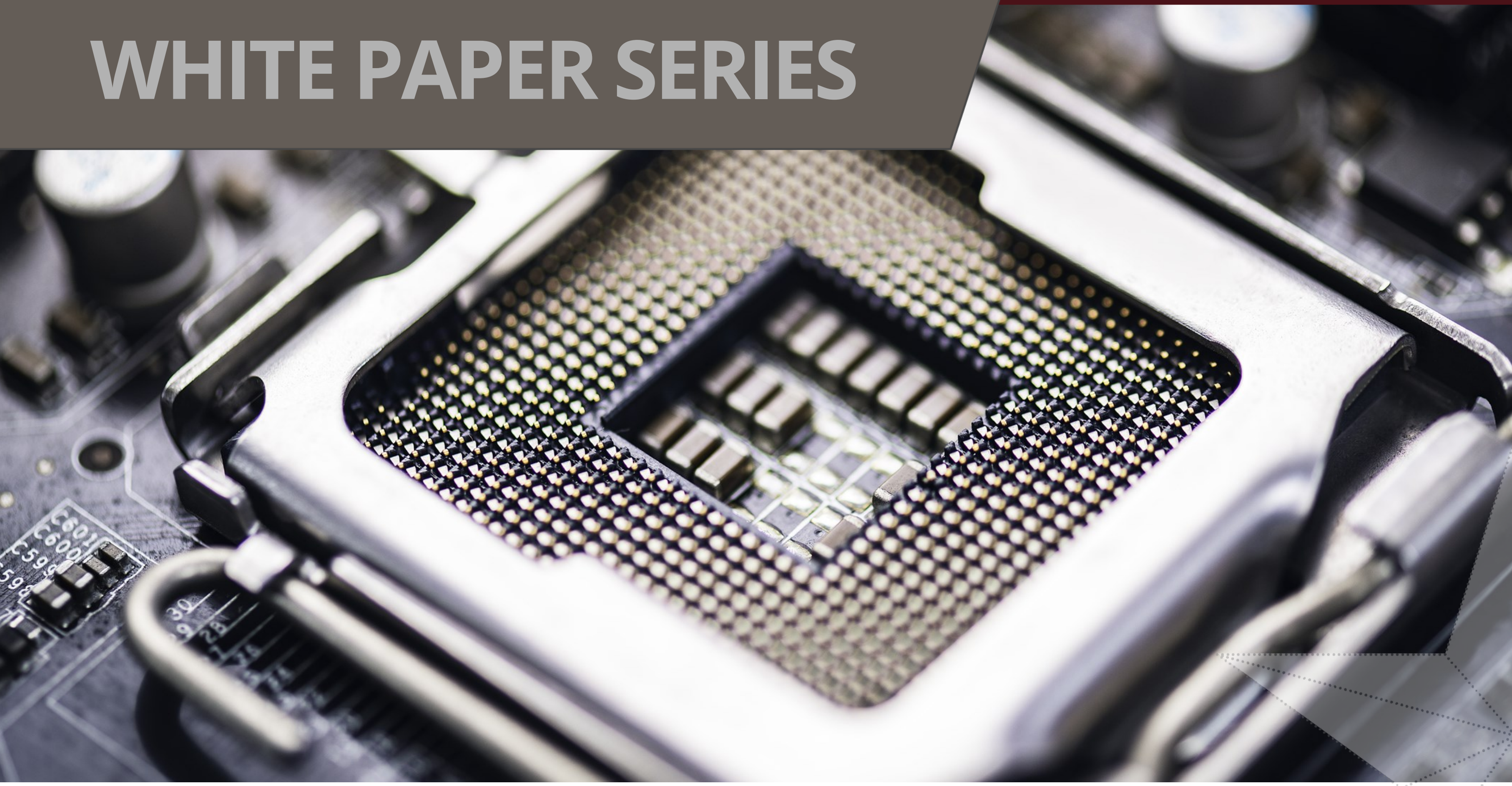

BEYOND THE BATTLE FOR SUPREMACY

RESHAPING THE GLOBAL SEMICONDUCTOR SUPPLY CHAIN

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VOLUME 3 | ISSUE 1 | REVISED VERSION
JANUARY 2024
https://bush.tamu.edu/mosbacher/white-papers/

Mosbacher Institute *for*
Trade, Economics, and Public Policy
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INTRODUCTION

As hegemonic competition between the United States and Mainland China (hereafter referred to as "China") intensifies, competition is increasingly acute in Artificial Intelligence (AI), 5G, and autonomous vehicles. These technologies depend on the semiconductor industry, which is the foundation for the development of big data, robots, aerospace, super quantum computing, and other advanced products. The multipurpose use of these semiconductor-based industrial technologies has far-reaching implications for both economic competition and national security because drones, robots, mobile communication, and aerospace technology have ubiquitous military applications..

China's semiconductor industry has grown rapidly since 2000. Chinese semiconductor exports grew at an astonishing average annual rate of 26% since 2000, far exceeding the U.S. semiconductor industry's average export growth rate of 6%. The average annual import growth rate of China's semiconductor industry also rose to 23%[1] because China is the world's leading producer of electronic devices, accounting for 75% of smartphones, 80% of tablets, 90% of laptops, 50% of digital TVs, 90% of display panels, and 60% of set-top boxes for telecommunications (Jeong, 2022c, p. 93).[2] China established a comprehensive ecosystem encompassing vertical series and design-process-manufacturing applications such as design (fabless), foundry (consignment production), Outsource Semiconductor Assembly and Test (OSAT), and application production helping China become the largest consumer market for memory semiconductors (DRAM and NAND Flash) and system semiconductors (logic and analog integrated circuits (IC) and micro components).

The United States recognizes that the rapid development of Chinese semiconductors can pose a significant risk to national security. As a response, the Biden administration has been imposing various restrictions including export regulations, investment sanctions, and financial sanctions targeting China's semiconductor industry.[3] The U.S. measures require companies from Japan, the Netherlands, South Korea, and Taiwan, China to substantially ban transactions with China's Huawei and Hi-Silicon companies and ban the sale of AI training chips to China. Furthermore, the U.S. sanctions prohibit the supply of advanced fab equipment and the employment of Americans in Chinese advanced fabs, thus making it difficult for Chinese companies to obtain any equipment and services from their previous U.S. suppliers (or U.S.-allied suppliers). Consequently, this acts as a major impediment to the development of China's semiconductor industry.[4] The U.S. policies raise three key questions:

First, can China overcome U.S. sanctions and continue to develop the semiconductor industry?

In other words, is China's semiconductor industry competitive enough to overcome U.S. sanctions, upgrade its industry, and maintain its position in the global semiconductor supply chain? To address this question, our analysis calculates competitiveness measures for the seven largest semiconductor producing regions (the USA; China; Japan; Korea; Taiwan, China; Germany; and the Netherlands) that cover the 2000-2021 period. Calculating Revealed Symmetric Comparative Advantage (RSCA) measures allow us to compare different semi-conductor-producing and consuming regions along the value chain.

Second, how will U.S. sanctions against China's semiconductor industry affect the global semiconductor industry and the current global semiconductor supply chain?

To answer this question, this study presents a network analysis of the global semiconductor supply chain, focusing on 20 regions that account for approximately 97% of the global semiconductor trade. This analysis not only schematizes the global semiconductor supply chain network but also calculates three key centrality measures (betweenness, degree, and eigenvector centrality) for major regions to further analyze the role and status of each region in the supply chain. Betweenness centrality helps provide an understanding of the degree of the region's role and its status as an intermediate goods supplier in the global semiconductor supply chain. Degree centrality is an indicator of how many regions a particular region has direct transaction relationships with, providing a means to identify its position in the global supply chain. Eigenvector centrality reflects the importance of supply chain relationships and helps to determine which regions are playing a pivotal role in the global supply chain.

Third, what will be the outcome of the U.S.-China semiconductor hegemonic competition, and what policy implications will arise from it?

By combining insights from the competitive and network analysis, this study further explores the potential of reshaping the global semiconductor supply chain beyond the conflict between the United States and China and examines the policy implications of the battle for semiconductor supremacy.

THE COMPETITIVE POSITION OF MAJOR SEMICONDUCTOR PRODUCERS

Data and Summary Statistics

The first step towards evaluating industry competitiveness is understanding differences in semiconductor exports and imports across regions over time. To understand these differences, we constructed a global semiconductor trade dataset by using UN Comtrade data based on the MTI classification criteria (described in detail in Appendix A) released by the Korea International Trade Association (KITA). Using MTI codes, we divide the semiconductor industry into twelve fields, including semiconductors and semiconductor equipment.

Table 1 shows the status of the top 20 global semiconductor exporting regions in 2000 and 2021. In 2000, the United States was the leading exporter of semiconductors, accounting for 20.7% ($60.79 billion) of global semiconductor exports. By 2021, however, the United States had fallen to seventh place in global semiconductor exports with a share of 5.4% ($61.93 billion) of the total. Japan, which accounted for 13.8% of global semiconductor exports in 2000, also dropped significantly by 2021, ranking eighth with 4.2% ($48.96 billion). By 2021, leadership had shifted to Hong Kong and China.

In 2000, Hong Kong held eighth place with 4.4% ($13.05 billion) in semiconductor exports, but by 2021 had increased to 19.9% ($229.75 billion) of the global total. In 2000, China's semiconductor exports accounted for only a paltry 1.6% ($4.58 billion) of the global total. By 2021, China's share had grown to 18.1% ($209.42 billion), making it the second-highest exporter in the world.

Table 1: Top 20 Global Semiconductor Exporting Regions in 2000 and 2021

Region	Exports 2000 (USD)	Share (%)	Region	Exports 2021 (USD)	Share (%)
USA	60,788,561,684	20.7	Hong Kong, China	229,752,567,334	19.9
Japan	40,676,176,695	13.8	China	209,418,831,830	18.1
Singapore	33,439,915,649	11.4	Taiwan, China	163,839,747,711	14.2
Rep. of Korea	21,275,145,625	7.2	Singapore	125,100,899,432	10.8
Taiwan, China	20,445,097,108	7.0	Rep. of Korea	115,450,652,006	10.0
Malaysia	17,831,483,162	6.1	Malaysia	68,346,599,837	5.9
Philippines	16,661,486,171	5.7	USA	61,931,345,016	5.4
Hon Kong, China	13,049,272,979	4.4	Japan	48,962,266,215	4.2
Germany	12,590,838,000	4.3	Philippines	25,761,949,143	2.2
United Kingdom	8,750,870,159	3.0	Germany	25,210,357,724	2.2
France	7,845,432,945	2.7	Netherlands	17,307,536,734	1.5
Netherlands	7,355,556,416	2.5	Ireland	11,378,359,569	1.0
Thailand	5,465,461,909	1.9	Thailand	11,144,023,319	1.0
China	4,576,812,473	1.6	France	9,904,525,127	0.9
Ireland	4,163,624,629	1.4	Mexico	4,226,550,321	0.4
Canada	3,444,721,289	1.2	Israel	4,012,243,000	0.3
Italy	2,874,896,939	1.0	Italy	2,732,688,198	0.2
Mexico	2,574,717,898	0.9	United Kingdom	2,649,821,875	0.2
Belgium	1,782,894,094	0.6	Belgium	2,090,045,112	0.2
Malta	1,516,745,903	0.5	Austria	2,006,590,479	0.2
Total	**287,109,711,727**	**97.6**	**Total**	**1,141,227,599,982**	**98.6**

Source: Authors' elaboration aggregating UN Comtrade data into MTI classification.

When taking into account Hong Kong's semiconductor exports, which are mainly manufactured and shipped through China, the total of China's semiconductor exports in 2021 reached 38.0%. The figure of 34.5% that the United States and Japan accounted for in total global semiconductor exports in 2000 is dwarfed by the current figure. It is important to note, however, that not all semiconductors exported from China are manufactured by Chinese companies; multinational companies operating in China account for a significant share of these exports. In 2021, Taiwan, China; Singapore; and South Korea ranked third, fourth, and fifth respectively in global semiconductor exports, with the top five regions accounting for a staggering 73.0% of the total worldwide.

Over the past two decades, there have been significant changes in semiconductor imports (Table 2). In 2000, the United States was the leading importer, accounting for 15.7% (US$49.37 billion) of global semi-conductor imports. By 2021,however,its share had dropped to 4.4% (US$57.22 billion), placing it sixth in the global rankings. Singapore ranked second in 2000 with 9.7% (USD 30.27 billion) of global semiconductor imports, and third in 2021 with 7.8% (USD 102.17 billion). In 2000, China ranked eighth in global semiconductor imports with 5.7%, worth $17.76 billion, but in 2021, it rose to first place with 35.8% of the global market, worth $470.22 billion. Hong Kong followed close behind as the second-largest importer, accounting for 18.4% of the global market at $241.41 billion.

Their combined figures equate to 54.2% of the global market. Singapore; Taiwan, China; and South Korea ranked third, fourth, and fifth, respectively, with all five regions making up 73.2% of global semiconductor imports. Overall, China and Hong Kong's total semiconductor imports in 2021 amounted to $711.6 billion, while their total exports equaled $439.2 billion, resulting in a semiconductor trade deficit of $272.4 billion.

The semiconductor manufacturing equipment (SME) industry has traditionally been dominated by advanced regions (Table 3), Japan accounted for 39.4% of global semiconductor manufacturing equipment exports in 2000, the United States 36.6%, the Netherlands 13.6%, Germany 3.0%, and the United Kingdom 2.7%. By 2021, Japan (23.6%), the United States (21.3%), and the Netherlands (15.1%) had retained the top three positions, though their market shares had decreased significantly. Notably, Singapore, South Korea, and Taiwan, China have all seen a considerable rise in their share of the global semiconductor manufacturing equipment export market since 2000, with Singapore in particular having grown from 0.5% to 15% in 2021.

In general, semiconductor-producing regions account for a large proportion of imports from the semiconductor manufacturing equipment indus-

Table 2: Top 20 Global Semiconductor Importing Regions in 2000 and 2021

Region	Imports 2000 (USD)	Share (%)	Region	Imports 2021 (USD)	Share (%)
USA	49,374,717,384	15.7	China	470,224,814,790	35.8
Singapore	30,268,970,034	9.7	Hong Kong, China	241,414,821,935	18.4
Taiwan, China	24,109,157,120	7.7	Singapore	102,173,263,363	7.8
Malaysia	23,365,196,499	7.5	Taiwan, China	88,363,057,044	6.7
Japan	20,492,542,911	6.5	Rep. of Korea	58,977,311,068	4.5
Rep. of Korea	19,695,600,981	6.3	USA	57,216,166,191	4.4
Hong Kong, China	19,283,329,310	6.1	Malaysia	48,394,174,988	3.7
China	17,757,934,798	5.7	Japan	31,610,401,482	2.4
Germany	14,157,747,000	4.5	Germany	25,919,239,891	2.0
United Kingdom	12,247,802,880	3.9	Mexico	25,243,644,448	1.9
Mexico	10,771,044,876	3.4	Netherlands	20,069,378,438	1.5
Philippines	10,634,799,193	3.4	Thailand	18,380,495,361	1.4
France	8,698,827,606	2.8	India	17,792,167,993	1.4
Canada	8,331,312,755	2.7	Philippines	17,626,729,188	1.3
Thailand	7,172,893,564	2.3	Brazil	8,348,310,335	0.6
Netherlands	6,742,967,297	2.2	France	7,357,370,509	0.6
Italy	3,840,734,909	1.2	Ireland	6,155,677,692	0.5
Ireland	3,104,227,086	1.0	Poland	5,613,130,611	0.4
Belgium	2,623,511,095	0.8	Hungary	4,757,109,351	0.4
Brazil	2,093,338,158	0.7	Czechia	4,202,185,201	0.3
Total	**294,766,655,456**	**94.0**	**Total**	**1,259,839,449,879**	**95.9**

Source: Authors' elaboration aggregating UN Comtrade data into MTI classification.

try (Table 4). In 2000, Taiwan, China accounted for 26.9% of global imports, followed by the United States, which held a 17.7% share. Given that the United States was the leading exporter of semiconductors in 2000, it is clear that the import share of semiconductor manufacturing equipment in the United States is substantial. Korea followed with 13.6%, Japan with 7.9%, and Singapore with 7.4%. On the other hand, China has seen a dramatic increase in its share of imports, rising to 28.5% in 2021 from a meager 2.4% in 2000, thus becoming the largest importer of semiconductor manufacturing equipment. Taiwan, China ranked second with 21.9%, and South Korea third with 18.3%.

Measuring Competitiveness

Our next step is to assess national competitiveness and network position of individual regions. To measure competitiveness, we use the Revealed Symmetric Comparative Advantage (RSCA) index and the Trade Specialization Index (TSI). The RSCA index, with a value ranging from -1 to 1, has a relative comparative advantage if its value is greater than 0, and a comparatively inferior state if it is less than 0. On the other hand, the TSI

Table 3: Semiconductor Manufacturing Equipment Exports by Region in 2000 and 2021

Region	Exports 2000 (USD)	Share (%)	Region	Exports 2021 (USD)	Share (%)
Japan	5,532,445,067	39.4	Japan	31,464,687,626	23.6
USA	5,137,257,159	36.6	USA	28,396,052,236	21.3
Netherlands	1,904,710,208	13.6	Netherlands	20,118,976,540	15.1
Germany	415,497,000	3.0	Singapore	20,016,135,717	15.0
United Kingdom	375,461,264	2.7	Rep. of Korea	7,976,413,377	6.0
France	106,105,026	0.8	Taiwan, China	4,839,071,703	3.6
Italy	84,852,567	0.6	China	3,768,495,967	2.8
Rep. of Korea	80,807,275	0.6	Malaysia	3,594,454,337	2.7
Belgium	73,301,653	0.5	Germany	3,530,606,391	2.6
Singapore	65,834,659	0.5	Hong Kong, China	3,401,044,230	2.5
Hong Kong, China	44,134,261	0.3	Israel	1,453,371,000	1.1
Canada	37,743,411	0.3	Austria	1,360,198,058	1.0
Sweden	36,899,700	0.3	United Kingdom	793,898,414	0.6
Mexico	23,393,321	0.2	Italy	587,354,528	0.4
Switzerland	18,936,816	0.1	Switzerland	460,496,290	0.3
Austria	15,227,072	0.1	Philippines	216,796,782	0.2
Taiwan, China	12,314,419	0.1	France	214,350,734	0.2
Australia	11,033,552	0.1	Thailand	212,245,692	0.2
Ireland	8,943,557	0.1	Czechia	164,145,538	0.1
Denmark	7,358,172	0.1	Sweden	145,292,315	0.1
Total	**13,992,256,159**	**99.7**	**Total**	**132,714,087,475**	**99.5**

Source: Authors' elaboration aggregating U N Comtrade data into MTI classification.

is an indicator used to compare the competitiveness of regions in a specific market. The TSI is calculated by dividing the difference between imports and exports of a product by the sum of its exports and imports, which measures the relative comparative advantage in exports of a region under the assumption that items with more exports than imports are competitive. A TSI of one indicates a region is completely export-specialized, meaning all production is exported and there are no imports. The closer the TSI index is to one, the higher the degree of export specialization and competitiveness in the global market. A TSI greater than 0.5 signifies a highly competitive industry. Conversely, an index close to "-1" means the region is highly import-specialized, leading to low competitiveness in the global market.

Examining the global import and export share and ranking of individual regions in the semiconductor and semiconductor manufacturing equipment (SME) industries, Figure 1 illustrates the comparative advantages of each region in the two industries from 2000 to 2021. In the semiconductor industry, Japan; Taiwan, China; and the United States had comparative advantages in 2000. Taiwan, China and Korea greatly increased their

Table 4: Semiconductor Manufacturing Equipment Imports by Region in 2000 and 2021

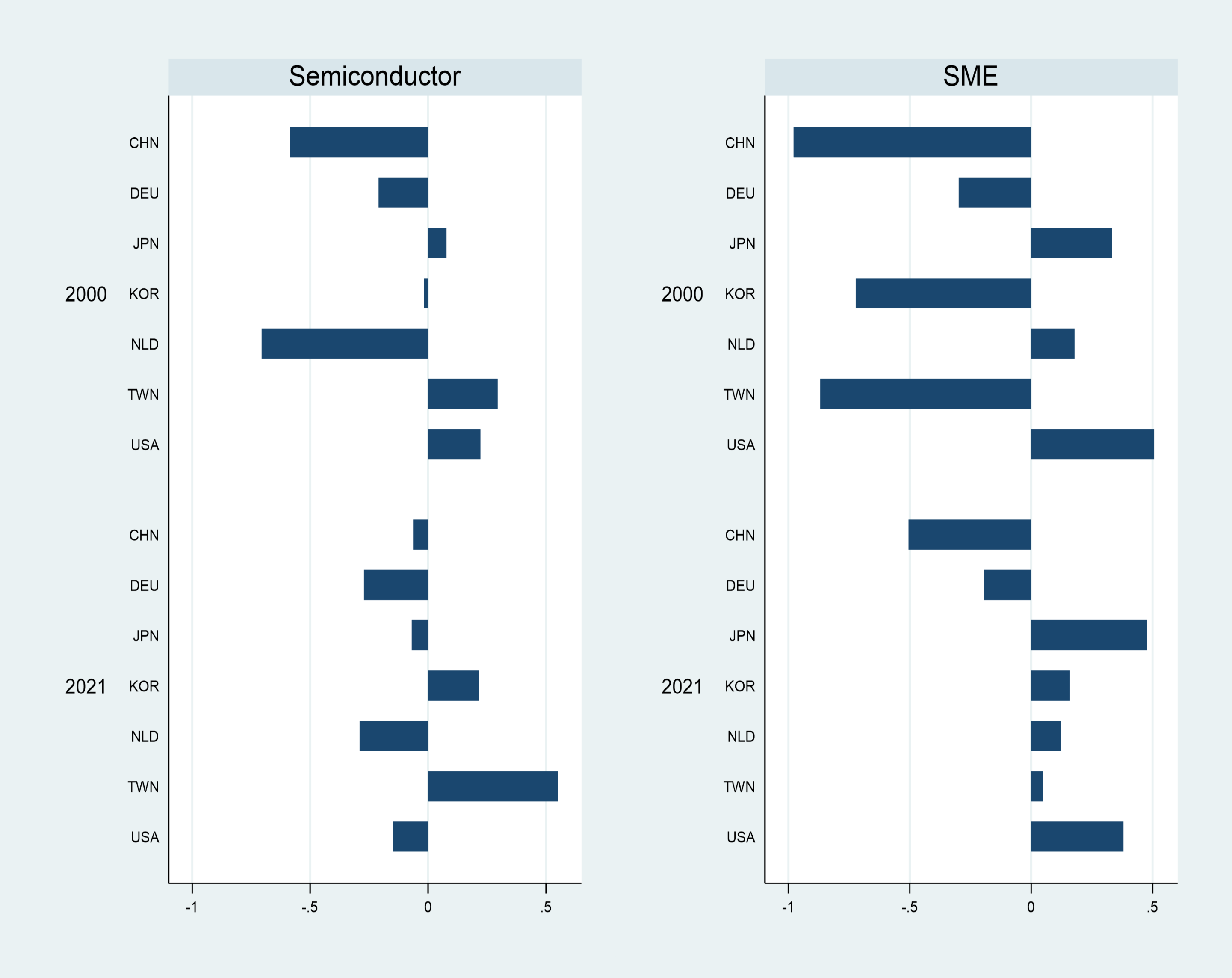
Region	Imports 2000 (USD)	Share (%)	Region	Imports 2021 (USD)	Share (%)
Taiwan, China	3,954,705,420	26.9	China	38,952,052,212	28.5
USA	2,601,358,729	17.7	Taiwan, China	29,910,320,272	21.9
Rep. of Korea	1,998,607,225	13.6	Rep. of Korea	25,013,877,425	18.3
Japan	1,161,162,338	7.9	USA	9,970,468,576	7.3
Singapore	1,096,028,776	7.4	Singapore	8,710,225,957	6.4
Germany	727,973,000	4.9	Netherlands	5,569,027,963	4.1
France	586,050,023	4.0	Japan	5,344,926,666	3.9
Malaysia	387,014,676	2.6	Germany	2,255,352,574	1.7
China	354,278,192	2.4	Malaysia	2,069,487,873	1.5
Italy	327,465,846	2.2	Hong Kong, China	1,953,077,964	1.4
Ireland	269,795,441	1.8	Israel	1,180,264,000	0.9
Israel	255,126,000	1.7	Austria	929,326,309	0.7
United Kingdom	200,481,099	1.4	Philippines	791,557,619	0.6
Netherlands	97,432,674	0.7	France	788,433,168	0.6
Hong Kong, China	92,677,353	0.6	Ireland	540,703,711	0.4
Philippines	88,572,645	0.6	Thailand	413,338,498	0.3
Austria	87,218,787	0.6	Italy	357,364,842	0.3
Belgium	79,358,860	0.5	United Kingdom	305,705,474	0.2
Canada	77,707,738	0.5	Mexico	257,967,816	0.2
Portugal	36,688,310	0.2	Switzerland	163,440,488	0.1
Total	**14,479,703,132**	**98.3**	**Total**	**135,476,919,407**	**99.1**

Source: Authors' elaboration aggregating UN Comtrade data into MTI classification.

competitive edge by 2021, while the United States and Japan experienced a sharp decline in comparative advantage. In the semiconductor manufacturing equipment industry, Japan, the Netherlands, and the United States had a high comparative advantage in 2000. By 2021, however, Korea and Taiwan, China showed considerable improvement in their comparative advantage.

The semiconductor supply chain is complicated because it involves numerous steps and multiple parties, including chip designers, foundries, component manufacturers, distributors, and end users. Each step of the supply chain is highly interconnected, and each party in the chain has different needs and objectives. Additionally, the semiconductor industry is highly dynamic and complex, with many different types of aforementioned components and technologies. The changes in competitiveness in the semiconductor manufacturing industry across different countries and regions over the past two decades reflect these characteristics of the semiconductor industry. At

Figure 1: Revealed Symmetric Comparative Advantage (RSCA) Change Comparison



Source: Authors' elaboration aggregating UN Comtrade data into MTI classification. SME stands for Semiconductor Manufacturing Equipment. For information on the industrial classification of semiconductors and semiconductor manufacturing equipment, refer to Appendix A.. Regions are represented with ISO 3 Codes. CHN represents Mainland, China. TWN represents Taiwan, China.

the beginning of the 2000s, semiconductor manufacturing shifted to areas where the process was simple and repeatable and production costs were low. East Asia became more competitive than the United States, Japan, and Europe in terms of production. South Korea and Taiwan, China specialized in memory and system semiconductors respectively, while China focused on Outsource Semiconductor Assembly and Test (OSAT) in the semiconductor production process.

In response to this, advanced regions such as the United States, Japan, and the Netherlands began to specialize in developing semiconductor manufacturing equipment (SME), SME parts, design, and software with a higher added value. As a result of the division of labor in the semiconductor production process, monopolization of the same field by one or very few regions emerged. For instance, the United States, Japan, and the Netherlands have a high competitiveness in SMEs, SME parts, and technology-intensive products like wafers. These regions have monopolized the SMEs and SME parts. Additionally, due to the nature of the semiconductor production process, the elasticity of substitution across regions is very small because different regions are specializing in very different components, meaning that any exclusion from the global value chain could lead to serious disruptions in semiconductor production.

We use the Trade Specialized Index (TSI) to compare and analyze the competitiveness of 12 semiconductor industries in 2021 versus 2000. Recall that a TSI greater than 0.5 signifies a highly competitive industry. The panels in Figure 2 compare the changes in the TSI for each semiconductor sector between 2000 and 2021. In some industries, due to the difficulty in obtaining statistics from 2000, the data represent 2007.

Notably, the TSI index for semiconductor memory indicates that Korea is the most competitive in the field. In addition, all regions depicted in the diagram have seen an improvement in their competitiveness relative to 2007. Japan's competitive-

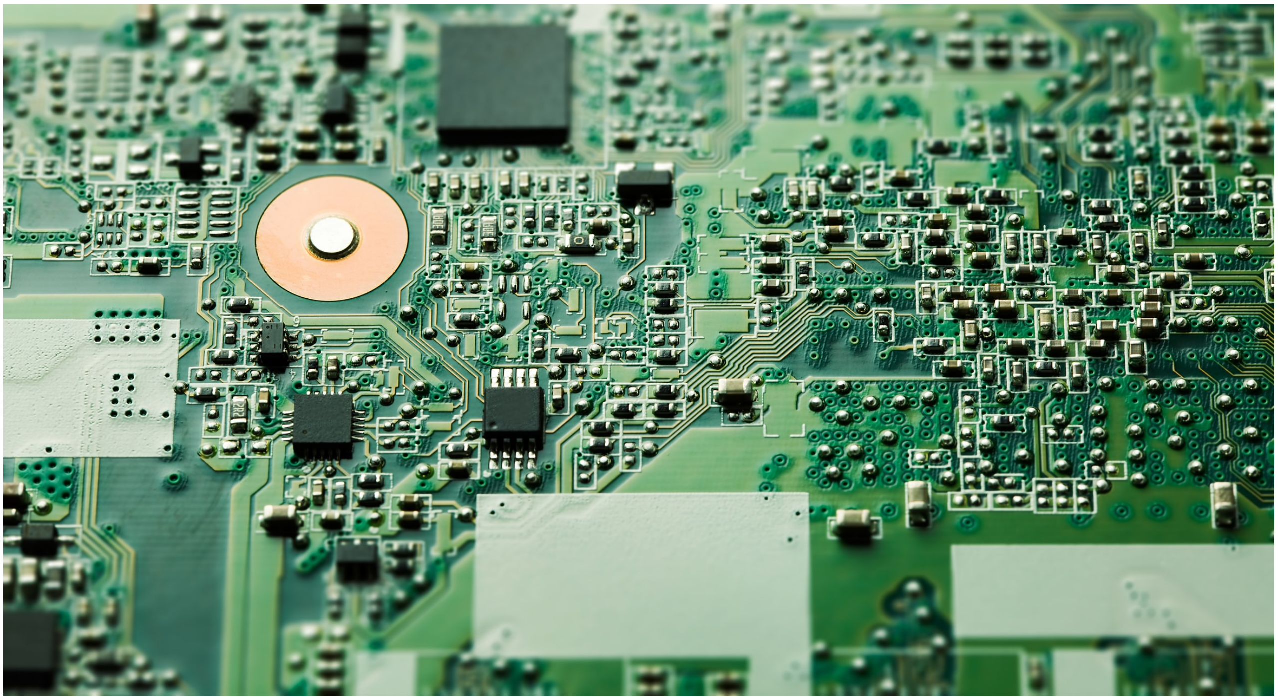
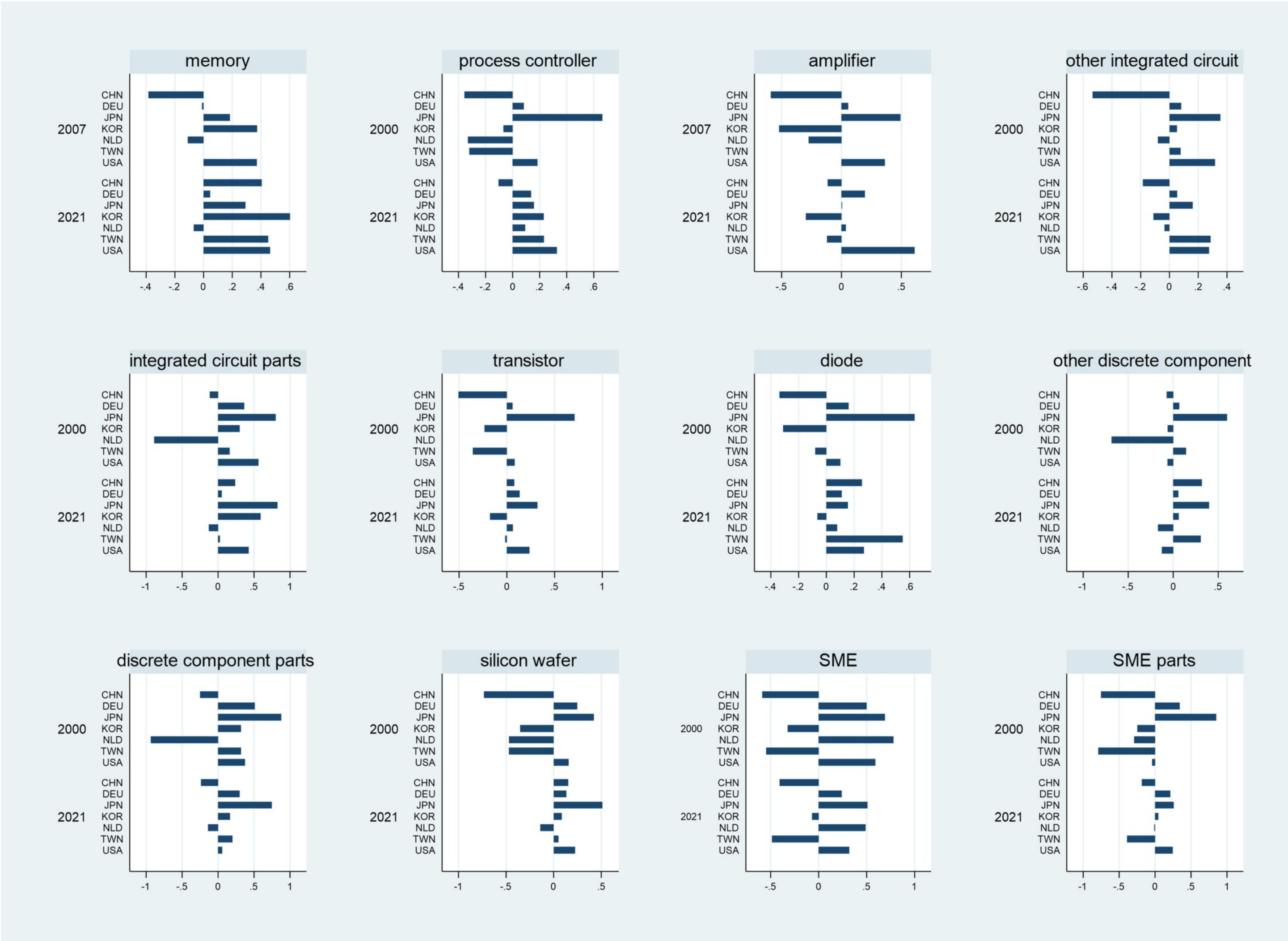


Figure 2: TSI Comparison between 2000 and 2021 by Product and Region



Source: Authors' elaboration using UN Comtrade data. TSI stands for Trade Specialization Index as defined in the text. SME stands for Semiconductor Manufacturing Equipment. Regions are represented with ISO 3 Codes. CHN represents Mainland, China. TWN represents Taiwan, China.

ness in 2021, while still high, was notably lower than in 2000. The competitiveness of most other regions, however, had increased. Only China was less competitive in this field.

With regard to amplifiers, the United States has seen a marked improvement in competitiveness since 2007 and is now the most competitive among the comparable regions. The U.S. TSI index above 0.5 is a clear indication of its robust global market presence. Others, such as Japan, lost competitiveness in amplifiers.

Currently, Germany; Japan; China; Taiwan, China; and the United States remain highly competitive in other integrated circuits, with Taiwan, China being the most competitive. In 2021, Japan and Korea's IC parts were highly competitive, and other regions, with the exception of the Netherlands, were also competitive.

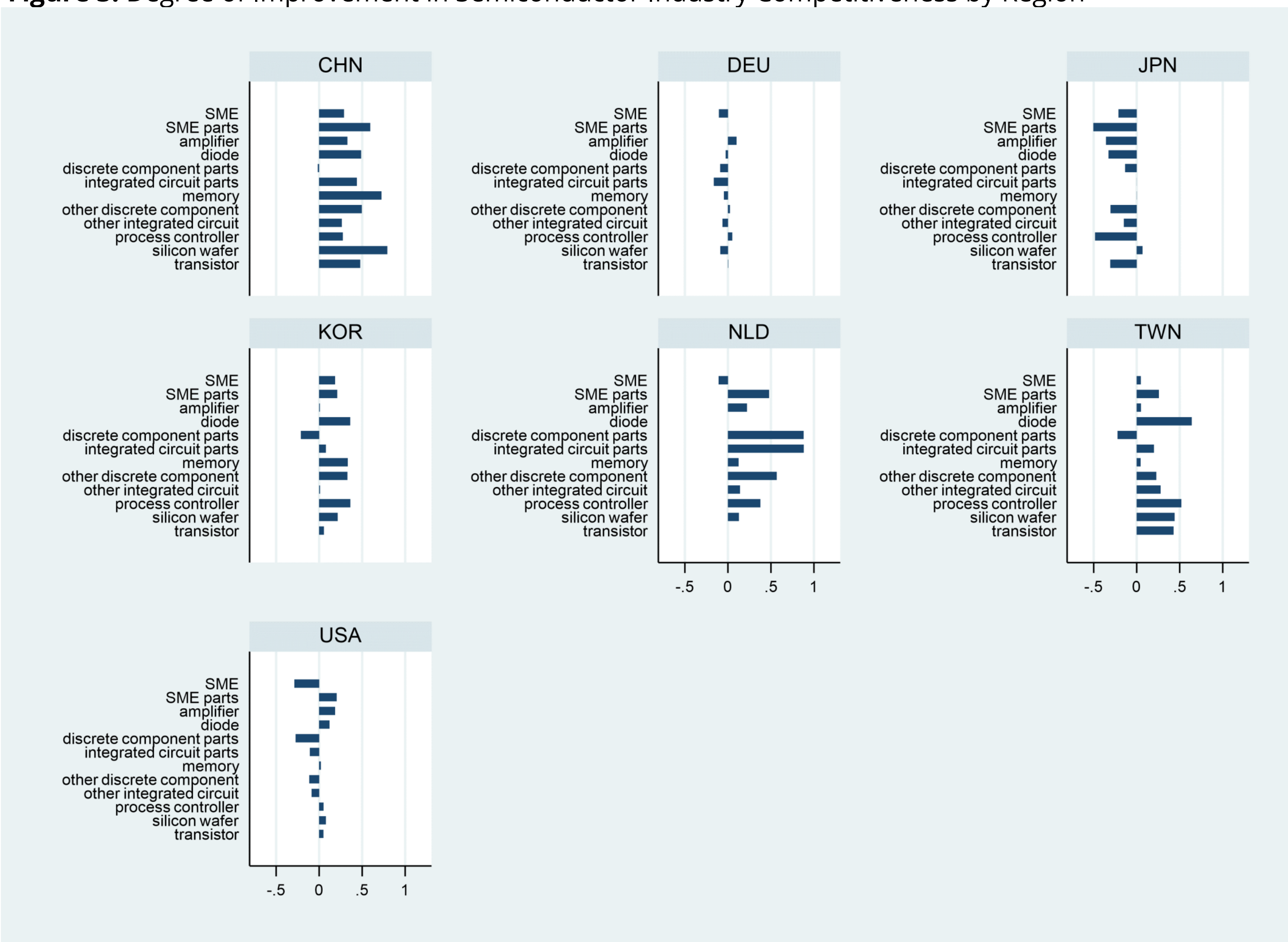
In the case of transistors, all regions, apart from Korea, are competitive. In the case of diodes, only Korea is less competitive; the rest of the regions are more competitive. Japan was highly competitive in this field in 2000, but its competitiveness has declined significantly over the past two decades. Conversely, Taiwan, China's competitiveness has increased drastically since 2000.

In the discrete component parts sector, Japan has demonstrated unrivaled competitiveness both in 2000 and 2021. In the case of silicon wafers, Japan had the highest competitiveness in 2000 and continues to lead the way in 2021. China, Germany, and the United States are also competitive in this field, but Japan is still the strongest.

In the case of semiconductor manufacturing equipment, Japan, the Netherlands, Germany, and the United States were all very competitive in 2000. While Japan and the Netherlands remained very competitive in 2021, the TSI for both the United States and Germany dropped well below 0.5. The U.S. TSI for the semiconductor manufacturing equipment industry went from a highly competitive 0.55 in 2000 to 0.26 in 2021. China; Korea; and Taiwan, China SME TSI values were low in both 2000 and 2021, but Korea made notable improvements. With regard to semiconductor manufacturing parts, other regions besides China and Taiwan, China remain competitive and show no significant difference in TSI.

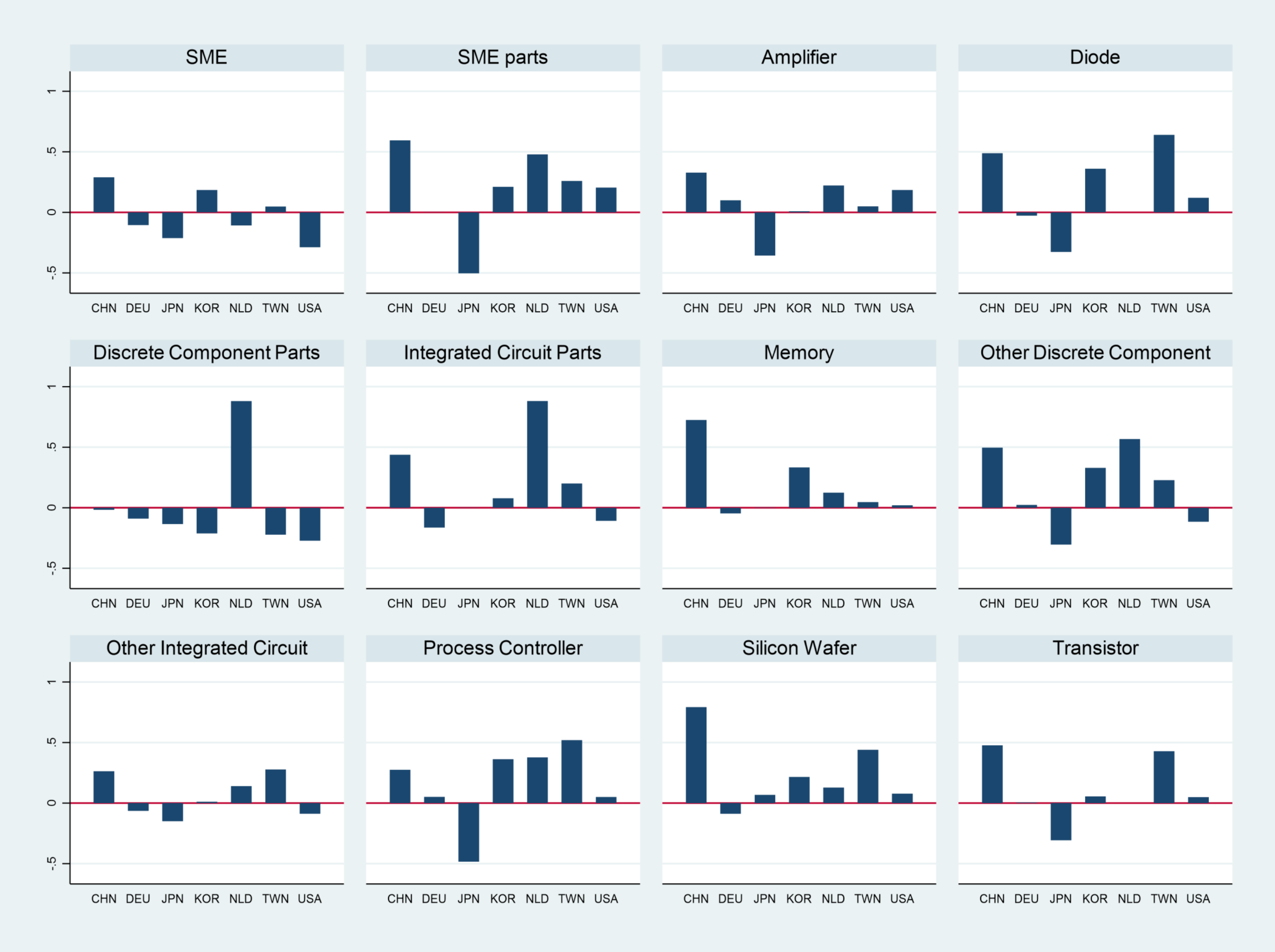
The panels in Figure 3 illustrate the degree to which the competitiveness of the 12 semiconduc-

Figure 3: Degree of Improvement in Semiconductor Industry Competitiveness by Region



Source: Authors' elaboration using UN Comtrade data. SME stands for Semiconductor Manufacturing Equipment. Regions are represented with ISO 3 Codes. CHN represents Mainland, China. TWN represents Taiwan, China.

Figure 4: Changes in the TSI by Sector between 2000 and 2021



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tor industries has improved by region. To assess the difference between 2000, 2001, and 2002 and 2019, 2020, and 2021, the TSI average was first calculated and then compared. Mainland China achieved impressive growth in all 12 semiconductor industries, particularly the silicon wafer sector. Moreover, the Netherlands and Taiwan, China have made considerable advances in most sectors, particularly in discrete parts and integrated circuit parts for the Netherlands and diodes for Taiwan, China. On the other hand, the United States has lost competitiveness in fields beyond SME parts, amplifiers, and diodes in the semiconductor industry. Germany and Japan are no longer as competitive as they were in the early 2000s in this sector. Japan's competitiveness in the semiconductor equipment industry has significantly decreased in most areas, with the exception of silicon wafers, over the last two decades. Meanwhile, Korea's competitiveness has improved across the semiconductor industry, except for discrete component parts.

Figure 4 illustrates the varying degrees of improvement in the competitiveness of individual regions in 12 semiconductor industry sectors. Notably, China has witnessed a significant increase in its competitiveness in SME, SME parts, amplifiers, diodes, memory, other discrete components, silicon wafers, and transistors. The Netherlands has particularly excelled in discrete component parts, integrated circuit parts, and other discrete components.

A NETWORK ANALYSIS OF THE SEMICONDUCTOR INDUSTRY

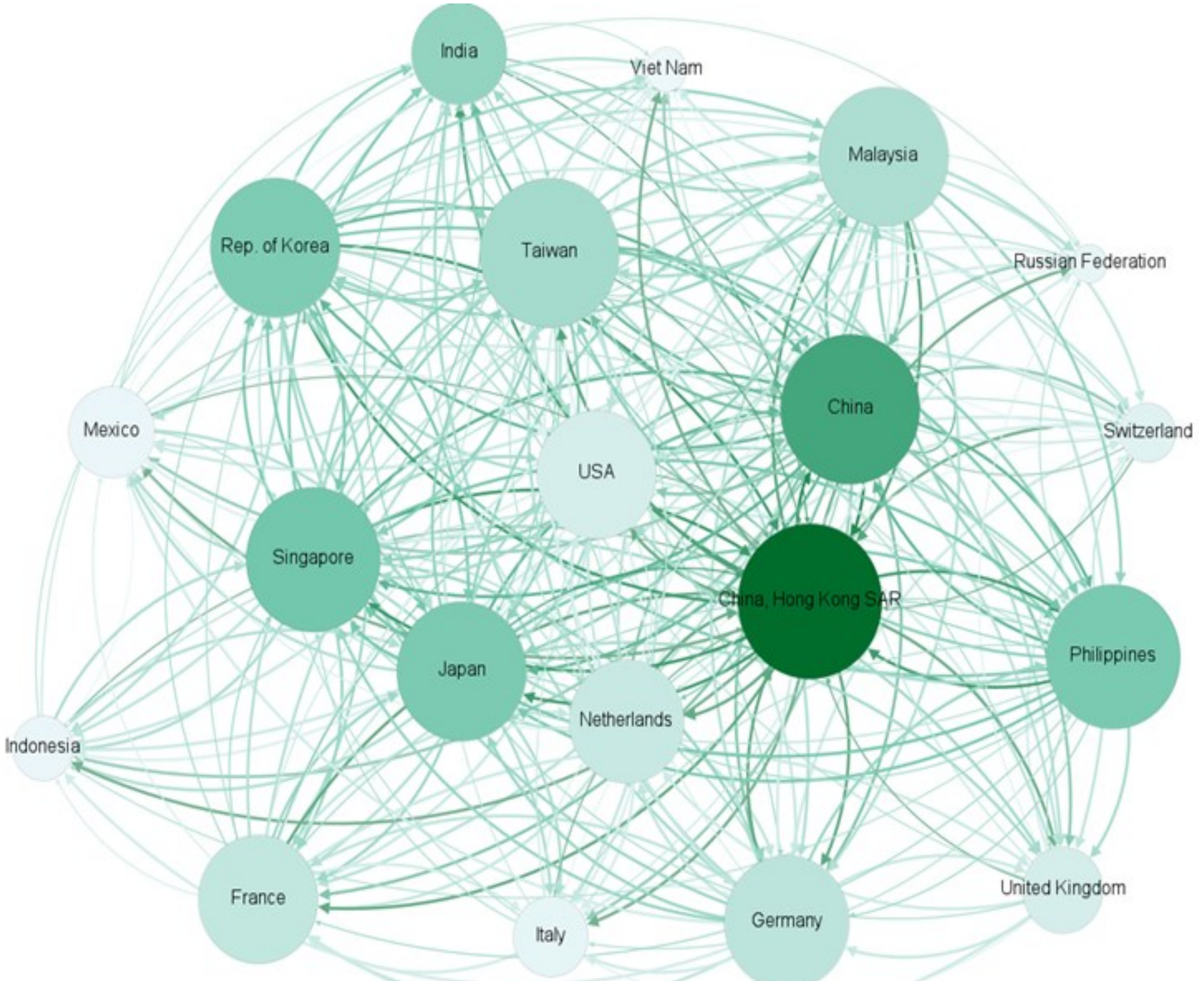
Network analysis complements competitiveness analysis in two important ways. First, network analysis highlights the production connections between regions that make up the links in the global supply chain. Second, we can assess the importance of different links in ways that reveal the potential alternative development following policies designed to limit or break certain links. As mentioned before, our strategy is to schematize the global semiconductor industry supply chain and calculate betweenness centrality, degree centrality, and eigenvector centrality.

Table 5: Centralities with 20 Regions

Region	In-Degree	Out-Degree	Degree	Betweenness Centrality	Eigenvector Centrality
Hong Kong, China	17	19	36	13.35	1.00
China	15	20	35	8.84	0.91
Taiwan, China	15	20	35	3.51	0.90
Philippines	15	19	34	5.67	0.88
Singapore	15	19	34	6.03	0.90
Malaysia	14	19	33	3.16	0.83
Rep. of Korea	15	18	33	5.40	0.90
Japan	15	18	33	5.62	0.90
Germany	13	19	32	2.38	0.78
USA	12	19	31	1.17	0.73
France	13	18	31	2.09	0.78
Netherlands	13	17	30	1.82	0.78
India	16	10	26	4.41	0.95
Mexico	12	12	24	0.14	0.73
United Kingdom	12	11	23	1.17	0.74
Italy	12	10	22	0.33	0.72
Indonesia	13	6	19	0.13	0.80
Switzerland	14	4	18	0.60	0.84
Viet Nam	15	0	15	0.00	0.91
Russian Federation	13	1	14	0.18	0.79

Source: Authors' elaboration using UN Comtrade data.

Figure 5: Global Semiconductor Supply Chain (20 Leading Regions)



Source: Authors' elaboration using UN Comtrade data. Each node denotes a region and its size reflects its connectivity or degree of centrality as described in the text. The darker color indicates a larger value of betweenness centrality and a more influential "hub" role in the semiconductor supply chain between regions. Arrows illustrate the import and export value of each region. Outward-pointing arrows represent exports and inward-pointing arrows represent imports. "Taiwan" represents Taiwan, China. "China" represents Mainland, China.

The regions subject to network analysis were limited to 20 regions that play a major role in the global semiconductor supply chain and those regions that have trade relations with them. These 20 regions also account for 97% of global semiconductor trade. Figure 5 is a schematic result of the global supply chain of the semiconductor industry in 2021. In the figure, the supply chain is connected by an edge between nodes marked as regions. Looking at the state of connection in the supply chain, it is possible to confirm which region is important in the supply chain, and the criterion for this judgment is centrality. In other words, centrality is analyzed to know which regions play an important role in the supply chain. First, the importance of degree centrality is determined by how many edges are connected to the node. The total count of incoming edges to a particular vertex is known as the in-degree of that vertex, and the total number of outgoing edges from a particular vertex is known as the out-degree of that vertex. The more edges connected, the higher the importance. As shown in Table 5, the regions with the highest number of degrees are Hong Kong with 36, China and Taiwan, China with 35, followed by the Philippines and Singapore with 34. Korea, Japan, and Malaysia also showed 33 degrees, indicating that they are major regions in the global semiconductor supply chain.

Figure 5 illustrates the global semiconductor supply chain based on the 2021 semiconductor industry import and export of individual regions. Here, each node denotes a region and its size reflects its connectivity or degree centrality. According to the figure, many regions share similar node sizes. Hong Kong leads the pack in terms of degree centrality, followed by China and Taiwan, China. The presence of nodes of varying sizes further attests to the fact that the semiconductor supply chain is not concentrated in one location, which perfectly encapsulates the nature of the semiconductor industry: one that is not produced in just one region, but rather, one that requires collaboration between multiple regions to bring it to fruition. Moreover, the color of the node in the figure is correlated with the betweenness centrality, with darker green indicating a higher value. This implies that the darker the green color, the more the region serves as a hub in the semiconductor supply chain between regions. Evidently, Hong Kong is playing a major role in the global semiconductor supply chain, with its betweenness centrality value of 13.25 being significantly

Table 6: Centralities without China and Hong Kong, China

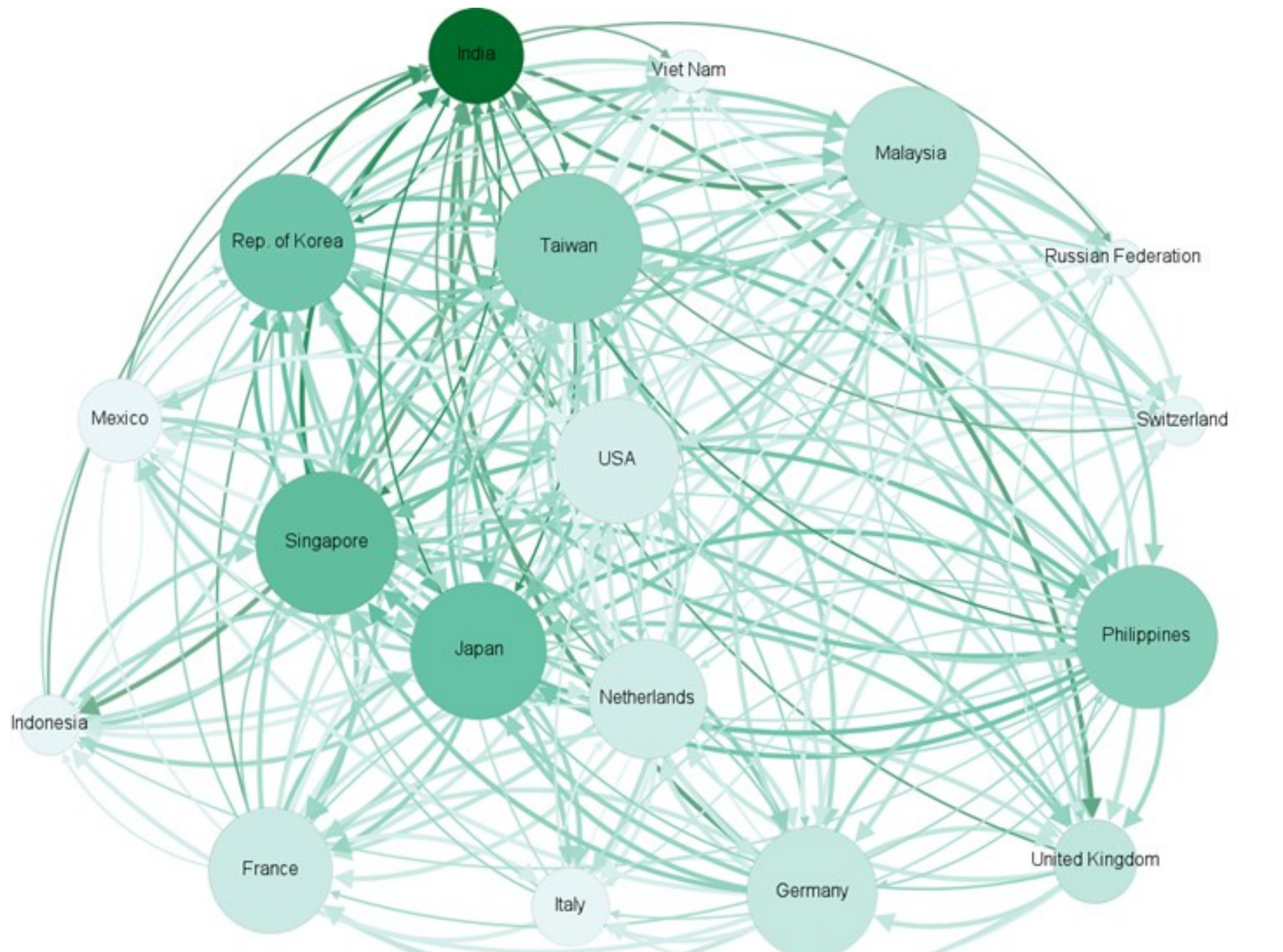
Region	In-Degree	Out-Degree	Degree	Betweenness Centrality	Eigenvector Centrality
Taiwan, China	15	20	35	6.12	0.94
Singapore	15	19	34	9.05	0.93
Philippines	15	19	34	6.42	0.91
Japan	15	18	33	8.55	0.93
Rep. of Korea	15	18	33	7.95	0.93
Malaysia	14	19	33	3.49	0.85
Germany	13	19	32	2.48	0.79
France	13	18	31	2.15	0.79
USA	12	19	31	1.46	0.73
Netherlands	13	17	30	1.84	0.79
India	16	10	26	17.14	1.00
Mexico	12	12	24	0.17	0.73
United Kingdom	12	11	23	2.82	0.75
Italy	12	10	22	0.38	0.72
Indonesia	13	6	19	0.33	0.81
Switzerland	14	4	18	0.44	0.86
Viet Nam	15	0	15	0.00	0.95
Russian Federation	13	1	14	0.20	0.80

Source: Authors' elaboration using UN Comtrade data.

greater than that of China, the second highest at 8.84. Singapore, occupying the third position, has a betweenness value of 6.03, which is notably lower than that of Hong Kong. Historically, Hong Kong has served as a broker port, but with regard to semiconductor supply chains, most of them are delivered to, or processed in China before being exported to other regions via Hong Kong. Similarly, Singapore, as an entrepôt city, also plays a significant role in the global semiconductor supply chain.

This study classifies the semiconductor industry into 12 sectors to analyze the global competitiveness of individual regions and identify the structure of the global supply chain. The competitiveness of the semiconductor industry in individual regions has changed significantly over the past 20 years. Accordingly, the global supply chain structure has also undergone significant changes. The major changes in the semiconductor industry over the past 20 years have significantly lowered the role of the United States and Japan as semi-

Figure 6: Global Semiconductor Supply Chain without China and Hong Kong, China.



Source: Authors' elaboration using UN Comtrade data. Each node denotes a region and its size reflects its connectivity or degree centrality as described in the text. The darker color indicates a larger value of betweenness centrality and a more influential "hub" role in the semiconductor supply chain between regions. Arrows illustrate the import and export value of each region. Outward-pointing arrows represent exports and inward-pointing arrows represent imports. "Taiwan" represents Taiwan, China. "China" represents Mainland, China.

conductor suppliers, while China and Taiwan, China have replaced them. China, especially, has made significant progress in the global competitiveness of the semiconductor industry over the past 20 years.

Moreover, Hong Kong (1.0), along with China (0.91) and India (0.95), have high eigenvector values, indicating that they are highly connected to major sources that are essential in the global semiconductor supply chain.

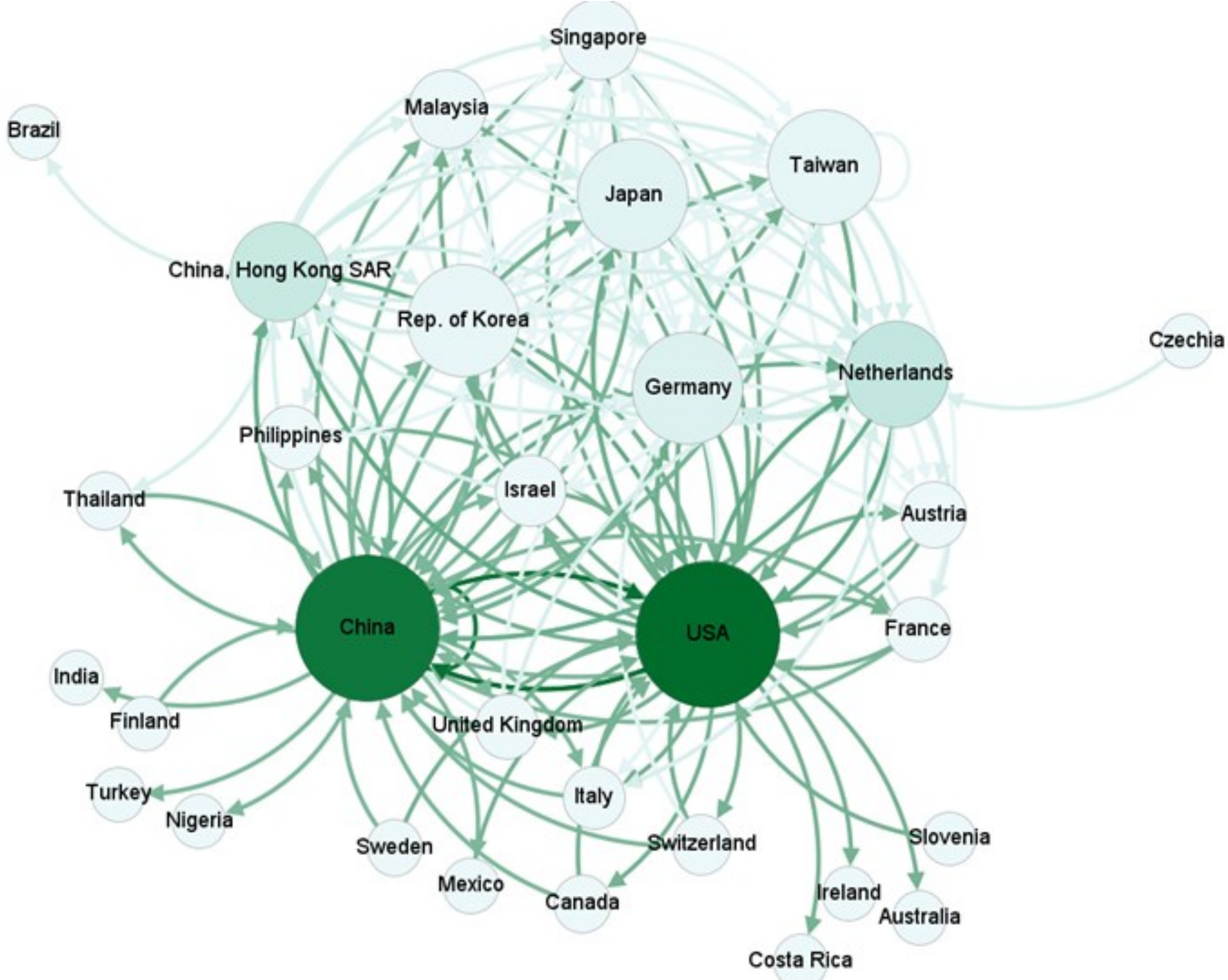
The arrows in Figure 5 illustrate the import and export value of each region; outward-pointing arrows represent exports and inward-pointing arrows represent imports, with the darkness of the color indicating the magnitude of the value. Notably, arrows from key semiconductor supply chain regions such as Hong Kong and China are particularly thick, demonstrating their significance in the global semiconductor industry. In contrast, the nodes of regions such as the United States, the United Kingdom, and the Netherlands, which have an advantage mainly in software and equipment, are comparatively smaller than East Asian regions as they are less competitive in semiconductor production. This emphasizes the pivotal role of China and Hong Kong in the global semiconductor supply chain.

Table 7: Centralities Semiconductor Manufacturing Equipment

Regions	In-Degree	Out-Degree	Degree	Betweenness Centrality	Eigenvector Centrality
China	28	25	53	205.36	1.00
USA	26	27	53	220.86	0.90
Taiwan, China	18	17	35	5.61	0.88
Rep. of Korea	17	17	34	3.78	0.85
Japan	17	17	34	9.60	0.83
Germany	17	17	34	12.72	0.77
Netherlands	14	16	30	34.13	0.63
Hong Kong, China	13	13	26	30.58	0.64
Singapore	8	8	16	0.28	0.45
Malaysia	7	8	15	0.07	0.40
Israel	4	7	11	0.00	0.24
Austria	4	4	8	0.00	0.22
Philippines	5	2	7	0.00	0.29
United Kingdom	2	5	7	0.00	0.13
France	4	3	7	0.00	0.24
Italy	4	2	6	0.00	0.23
Switzerland	1	3	4	0.00	0.06
Thailand	2	1	3	0.00	0.11
Canada	1	2	3	0.00	0.06
Mexico	1	1	2	0.00	0.07
Sweden	0	2	2	0.00	0.00
India	1	0	1	0.00	0.07

Source: Authors' elaboration using UN Comtrade data.

Figure 7: Global Semiconductor Manufacturing Equipment Supply Chain



Source: Authors' elaboration using UN Comtrade data. Each node denotes a region and its size reflects its connectivity or degree centrality as described in the text. The darker color indicates a larger value of betweenness centrality and a more influential "hub" role in the semiconductor supply chain between regions. Arrows illustrate the import and export value of each region. Outward-pointing arrows represent exports and inward-pointing arrows represent imports. "Taiwan" represents Taiwan, China. "China" represents Mainland, China.

U.S. SANCTIONS ON MAINLAND CHINA

Let us now turn our attention to the U.S. sanctions on China. If we make the extreme assumption that China and Hong Kong are entirely excluded from the global semiconductor supply chain due to U.S. sanctions, what would be the outcome? To gain further insight into this, we removed China and Hong Kong from the supply chain we previously constructed, recalculated the centralities, and redrew the global semiconductor supply chain (see Table 6 and Figure 6).

Taiwan, China has the highest degree centrality value, due to its prominent role as a semiconductor supplier in the global supply chain, which excludes China and Hong Kong, effectively supplanting their roles as hubs. Singapore, with its second -degree centrality value, is also gaining increased prominence as a hub in the global semiconductor supply chain. Meanwhile, Japan and Korea remain relatively unchanged in their roles within the chain that excludes China and Hong Kong.

As shown in Figure 6, the sizes of the nodes representing each region are largely unchanged. However, the value of betweenness centrality, which measures its role as an intermediate supplier between regions, significantly shifts. Table 6 reveals that India has a value of 17.14 and Singapore 9.05, thus indicating a considerable difference. To put it another way, India and Singapore will likely replace China and Hong Kong as the main intermediate supplier in the global semiconductor supply chain. Additionally, eigenvector centrality values in India and Singapore are also high, making these two regions likely to assume a major role in the global semiconductor supply chain, in place of China and Hong Kong.

On the other hand, excluding China and Hong Kong from the global semiconductor supply chain will not cause a major change in the role and status of the United States, Germany, and the Netherlands. If the United States were to impose more stringent sanctions on China's semiconductor industry, it would become increasingly difficult for China and Hong Kong to serve as hubs for semiconductor supplies as they have done in the past. In such a scenario, India is likely to emerge as a formidable semiconductor production and consumption destination, if not a hub. Whilst Vietnam may be able to partially fill the void left by China, it would be difficult for it to completely replace China under the current supply chain structure.

Turning our attention to semiconductor manufacturing equipment, as previously mentioned, the Biden administration has prohibited the export of semiconductor manufacturing equipment with advanced technology to China. As can be seen in Table 7 and Figure 7, the United States and China occupy a dominating position in the global supply chain of semiconductor manufacturing equipment. The United States and China have equal values (53), but the United States has a greater influence as a supplier with its higher out-degree than in-degree. Conversely, China's higher in-degree indicates a greater role as a consumer. China also has a noteworthy number of out-degrees due to the significant growth of its semiconductor manufacturing equipment industry over the last two decades, with multinational companies based in China exporting manufacturing equipment produced in the region to other nations.

As depicted in Figure 7, six regions other than the United States and China have nodes of a similar size. It is evident, however, that these nodes are considerably smaller than those of the United States and China. Furthermore, the value of betweenness centrality in the United States and China is notably high, demonstrating that these two regions are significant SME hubs, and have a major role in the global semiconductor manufacturing equipment supply chain. Moreover, the arrows in Figure 7, which signify the magnitude of imports and exports between regions, illustrate that there is a significant import and export relationship between the United States and China. Notably, the arrow heading to China (U.S. exports to China) is remarkably strong, and the arrow heading to the United States from China (China exports to the United States) is also remarkably dark. Table 7 further confirms this by showing that the betweenness centrality value in the Netherlands is 34.13, which is substantially lower than 220.86 in the United States and greater than 9.60 in Japan.

THREE QUESTIONS

The United States has been imposing export controls on certain semiconductor manufacturing equipment in China (logic semiconductors 16/14nm or less, NAND 128 layers or more, and DRAM 18nm or less) since October 2022. This has resulted in a significant decrease in China's imports of semiconductor manufacturing equipment. Comparing imports from January to September 2022 to those from October 2022 to February 2023, China's imports of semiconductor manufacturing equipment fell by about 22%. This is in stark contrast to the 2% drop in equipment imports by Korean companies operating in China, which have been suspended for a year, and highlights the impact of the sanctions (Kim et al., 2023).

The strength of the sanctions and their implementation will ultimately determine the extent of the global impact. If stronger sanctions are imposed on the entire China semiconductor industry, this could lead to a decrease in global semiconductor production, resulting in price increases in home appliances and a disruption in the manufacturing industry. Korea and Japan, which are highly reliant on trade with China, could suffer immensely and have far-reaching ramifications for the global economy, including the United States.[5] As a result, it is difficult to institute comprehensive sanctions on China's semiconductor industry. It is, therefore, important to revisit the three questions posed at the onset of this study and offer answers based on the network analysis above.

Can China overcome U.S. sanctions?

The first question we raised in the introduction was, "Can China overcome U.S. sanctions and continue to develop the semiconductor industry?" Our answer to this question is that China will not be able to overcome the U.S. sanctions on its semiconductor industry in the next 10 years, but, in the longer run, China has the potential to become more independent.

If the goal of the U.S. sanctions on China is to impede the acquisition of state-of-the-art semiconductor production technology and impede the development of technology in the field, then the sanctions will be successful. Nevertheless, they will not impede China from obtaining advanced semiconductor technology permanently. Despite their frequent application, U.S. economic sanctions often fail to achieve U.S. foreign policy objectives and often harm American economic interests without changing the target's behavior in any meaningful way (Haass, 1998). Ultimately, sanctions are no match for market forces.

Short-run Considerations

The U.S. sanctions will make it difficult for China to secure technical personnel, semiconductor manufacturing equipment, and advanced semiconductor production, significantly hampering the China semiconductor industry in the short term.[6] Furthermore, equipment from the Dutch company ASML is essential to produce state-of-the-art semiconductors and the United States imposes sanctions not only on its semiconductor manufacturing equipment but also on Dutch ASML's exports to China. Domestic and foreign semiconductor companies operating in China will have difficulty producing high-end semiconductors in the short term.

All of the competitiveness indices we calculated earlier are based on import and export data of individual region's semiconductor industries, including export and import data of foreign companies. The Chinese semiconductor industry's reliance on foreign regions is a major impediment to its ability to stand independently. The improvement in the competitiveness of the China semiconductor industry confirmed earlier is largely due to foreign companies. Since the mid-2000s, global semiconductor companies' investment in China has increased exponentially. According to Bloomberg data, 286 multinational semiconductor companies made investments in Mainland China from 2003 to October 2022, with an amount of 104,088.4 million dollars.[7] Global semiconductor companies have invested heavily in the OSAT process in China.

China’s imports also reflect a heavy reliance on Korea and Taiwan, China. Demand for semiconductors in China continues to increase, with China's deficit in the sector reaching -296.0 billion dollars (semiconductors -$260.8 billion, semiconductor manufacturing equipment -$35.2 billion) in 2021. Without these foreign semiconductor companies, the development of China's semiconductor industry would be difficult.

China’s individual semiconductor companies' influence in the global supply chain is relatively weak. According to the network analysis based on companies’ profits data by Jeong (2021c),[8] the global semiconductor supply chain is centered on U.S. companies and Chinese companies’ influence is relatively weak. Likewise, China's Hi-Silicon (design and manufacturing) and SMIC (foundry) companies are not influential in the global semiconductor supply chain. In addition, major China semiconductor companies were found to have high external dependence.

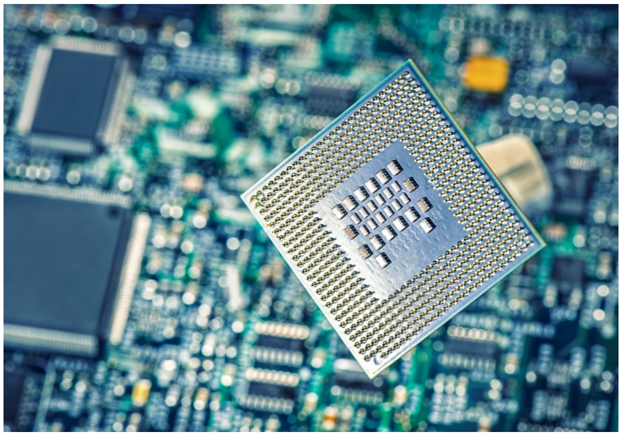
According to Eikon's database, U.S. companies account for about 1/3 of the companies supplying goods to SMIC, while European companies from such regions as the United Kingdom, Germany, and the Netherlands account for a high proportion. Huawei, which is not a semiconductor producer but occupies an important position in the supply chain, is also highly dependent on the outside world. U.S. companies account for 43% of the companies that supply goods to Huawei, and U.S. companies account for about 20% of the vendors (Jeong, 2021c).

U.S. companies account for the largest portion of Huawei's suppliers and sellers. On the other hand, the proportion of China companies was found to be about 15% and 10% of suppliers and sellers, respectively. Since most Chinese companies are highly dependent on foreign regions, it is difficult for China’s semiconductor industry to become independent. Once again, it is no exaggeration to say that the fate of the China’s semiconductor industry in the future depends on global semiconductor companies that have invested in China.

China has the capability to develop low-end semiconductors, such as those used in automobiles, but is unable to produce high-end Graphics Processing Units (GPUs) used for AI and machine learning. Despite significant investments, this challenge remains due to a lack of skilled professionals. Generally, estimates place China's semiconductor technology level approximately 10 years behind that of leading technology holders (Agrawal, 2022).

The Long Run

In the long run, however, China's environment for fostering the semiconductor industry is much



more advantageous than when Samsung or TSML fostered the semiconductor industry in the 1990s. As seen in the previous analysis, China and Hong Kong are already serving as hubs for global semiconductor production and trade. This is also a very important asset for China to develop the semiconductor industry in the future. Considering the various constraints faced by China's semiconductor industry, the China government has invested astronomically in the sector, selecting it as one of its strategic development areas in the 14th Five-Year Plan and 2035 Mid-to-Long-term Goals in March 2021 (Jeong, 2022c, p. 114). This has included the development of design software, high-purity materials, important manufacturing equipment and manufacturing technologies, and advanced memory technology. The Chinese government has invested heavily in its semiconductor industry in recent years and has set a goal of being self-sufficient in semiconductor production.[9]

The Chinese government has also launched several initiatives to attract foreign investment in the sector, such as the China Integrated Circuit Industry Investment Fund and the national integrated circuit industry base, and to spur innovation. China is also fostering the semiconductor industry with the national semiconductor fund, various tax support measures, and through the Star market, (the Chinese version of the NASDAQ (Jeong, 2022c, pp. 116-123)). The Chinese government's substantial financial backing for the semiconductor industry is a major driving force in accelerating the self-sufficiency of the Chinese semiconductor industry.

Despite China's high reliance on foreign semiconductor firms and production, China's existing semiconductor industry ecosystem has the potential to significantly aid the Chinese government's goal of strengthening China's semiconductor industry in the long run. China's significant progress in the semiconductor industry may have laid the groundwork for technological independence.

Global Effect of U.S. sanctions?

The second question raised in the introduction is "How might U.S. sanctions on the China semiconductor industry affect the global semiconductor supply chain?" As China is a key hub in this supply chain, any additional sanctions imposed on its production could have a negative impact in the short term.

The formation of the global semiconductor supply chain over the past 30 years has been based on a commercial division of labor, with China serving as a hub, and East Asia has solidified its status as a semiconductor manufacturing region. The attempt by the United States to reorganize this supply chain through sanctions against China is likely to have a significant impact on the global semiconductor industry, as well as the United States itself. Global semiconductor companies, including those from the United States, are already feeling the effects of these sanctions in their sales. As many experts have warned, any artificial intervention in the semiconductor supply chain is sure to disrupt its market-driven character. The United States has justified its actions in the name of security, but it is clear that nationalistic interests are a strong factor in this policy. It is overly ambitious to expect foreign semiconductor companies who have chosen to build semiconductor production plants in the United States to provide financial details and relinquish a significant portion of their profits to the U.S. government.

In order to exclude China's semiconductor industry from the global semiconductor supply chain, cooperation from global semiconductor producers is absolutely essential. Although some companies are already participating in the sanctions, it is uncertain how far these companies will be willing to go in order to abide by the sanctions and continue to suffer from declining sales. Moreover, since regions such as Japan and Germany export semiconductor equipment to China, it is also important to consider whether these regions will continue to adhere to the sanctions. Additionally, some European regions prioritize economic cooperation with China over sanctions.

At the same time, the U.S. administration is at odds with its allies concerning the Inflation Reduction Act of 2022 and its subsidies. Anger is escalating among allies in response to the United States' extraterritorial trade approach. Quoting Emily Weinstein of Georgetown University's Center for Security and Emerging Technology, "the more the United States continues to rely on unilateral—and especially extraterritorial—controls, the harder it will be to work with allies" (Mark & Roberts, 2023). Ultimately, strong U.S. leadership in the international community is essential for successful sanctions, but the conflicting economic interests of different regions will ultimately be a determining factor in the outcome of U.S. sanctions on the China semiconductor industry.

Analysis of the global semiconductor industry has shown that China's role in the industry has grown significantly since 2000, while China, Taiwan; Korea; and the Netherlands have also seen their shares and rankings in the global market increase. It is unlikely, however, that the market-based supply chain can be successfully reorganized, as Mainland China's semiconductor industry currently accounts for too much of the global supply chain. Furthermore, any attempts to reorganize this chain may have serious consequences for the global economy. The United States' various support programs for attracting foreign semiconductor companies to their own region are widely seen as politically motivated, and their lack of authenticity and sustainability has caused investors to become increasingly uncertain. In the future, the U.S. government's additional sanctions on the semiconductor industry in Mainland China will act as a source of greater uncertainty for companies that have already committed to investing in the United States.

U.S.-China Hegemonic Competition and Policy Implications for the United States

The third question we asked in the introduction is "what will be the outcome of the U.S.-China semiconductor hegemonic competition, and what policy implications will arise from it?" The Biden administration may wish to exclude China from the semiconductor supply chain, yet it is immensely challenging for semiconductor companies to find a region that can produce semiconductors as cost

-effectively and proficiently as China. The semiconductor ecosystem that has been in place for the past three decades is unlikely to be supplanted by India or any other East Asian nation. This is further demonstrated by surveys of companies (Jeong, 2021a). Considering this reality, U.S. sanctions on China semiconductors are likely to incur serious repercussions at the corporate level in the future.

Furthermore, the U.S. sanctions on the semiconductor industry in could have a detrimental impact on the global semiconductor industry, including the American semiconductor sector. U.S. companies that have traditionally relied on corporate profits to develop and innovate cutting-edge technologies will not only suffer a loss of corporate profits but will also lose the driving force for future technological development should they be excluded from the Chinese market. As U.S. semiconductor companies rely heavily on the Chinese market, the negative impact on U.S. companies will be very large. For example, China accounts for 29.6% of U.S. semiconductor exports, and 67% of Qualcomm, 57% of Micron, and 49% of Broadcom sales (van Hezewijk, 2019). Applied Materials, one of the world's largest semiconductor equipment companies, has predicted a significant decline in sales of approximately $1.5-$2 billion in fiscal 2023 due to U.S. export controls to China, with a $490 million drop expected in the first quarter of the same year (Applied Materials, 2022). Additionally, Lam Research has suggested that sales could plummet by up to $2.5 billion in 2023 due to similar restrictions (Reuters, 2022), while the KLA has warned that export controls could result in a decrease of up to $900 million (Nikkei Asia, 2022).

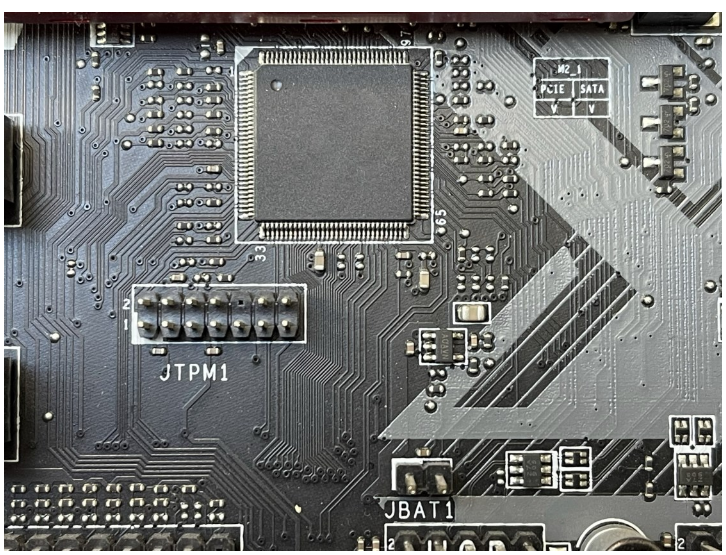
Consequently, reducing trade with China's semiconductor industry could have a detrimental impact on the U.S. semiconductor industry's competitiveness in the mid-to-long term. The U.S. Chamber of Commerce estimates that if China were to impose sanctions on U.S. chipmakers, the worst-case scenario would result in U.S. semiconductor sales plummeting to zero, leading to a potential loss of $83 billion in annual revenue and 124,000 jobs. Moreover, the available revenue for research and development (R&D) is projected to decrease by $12 billion over the next 28 years (U.S. Chamber of Commerce, n.d.).

It is essential that the United States strengthens the semiconductor industry to increase its competitiveness, which means that companies should develop more cooperative and strategic relationships than current supply chains based on international division of labor. Additionally, the U.S. government should take stronger steps to prevent the illegal outflow of advanced semiconductor technology to China, as well as the outflow of technology and other professional personnel. To this end, the United States should collaborate with its allies to control the export of semiconductor technology and hinder unwanted technology transfers, while ensuring that export controls are limited to specific security purposes and do not become a more far-reaching protectionist initiative. Furthermore, export controls should be designed in a targeted manner to prevent unintended damage to the industries. The United States should also strengthen its foreign investment screening function and use multinational forums to lead the aforementioned issues, including stabilizing global semiconductor supply chains.

Along with the implementation of policies to prevent technological theft in China, it is also essential for the United States to create an environment conducive to high-tech manufacturing, including the semiconductor industry, developing at home. China has made great strides in the past few decades to bolster its production capacity with economic growth. As revealed in a recent Foreign Affairs article, back in 2007, China was in charge of assembling Apple's iPhone using cheap labor but accounted for less than 4% of the total added value produced by Apple. Yet, by 2018, this had grown to over 25% (Wang, 2023).

CONCLUSIONS

China has become a competitive global manufacturing superpower and has been actively pursuing innovation in the manufacturing sector. This has enabled it to proudly develop cutting-edge technologies such as high-speed trains, 5G, and AI. Chinese companies are innovating and multinational companies are innovating through competition. The subsidy policy of the United States, such as the Chips and Science Act, has limitations in enabling the U.S. semiconductor manufacturing industry to compete with China, which is rapidly advancing in emerging technologies. To compete with China, the United States and its allies need to focus on creating a conducive environment for innovation in manufacturing, in addition to the aforementioned measures to prevent technological theft. By doing so, it will be possible to spur innovation within its own industry, enabling the development of more innovative future technologies.



NOTES

[1] UN Comtrade Database. https://comtrade.un.org/.

[2] In Bloomberg's survey of global semiconductor companies, 46.7% reported that proximity to markets or customers was the primary motivation for investing abroad. Data was collected on foreign companies investing in the semiconductor sector between January 2003 and October 2022. (Bloomberg DB, January 3, 2023).

[3] The United States restricts the capacity of Americans (including citizens, green card holders, and foreigners residing in the United States) to contribute to the growth or fabrication of ICs at advanced semiconductor production facilities based in China without obtaining a license. Furthermore, it prohibits the provision of equipment and tools to all fabrication facilities in China that manufacture and develop logic chips with non-planar transistor architectures of 16nm or smaller; DRAM memory chips of 18nm half-pitch or smaller; NAND flash memory chips with 128 layers or greater.

[4] The potential implications of this are significant. Producing advanced Si logic ICs is impossible without sophisticated manufacturing equipment, software, and technical assistance from the supplier's skilled personnel. According to some equipment manufacturers, even if the maintenance and installation personnel of foreign equipment factories are China nationals, the equipment technology must not originate from the United States and must not fall within any of the three categories specified above, in order for it to be allowed to operate in China.

[5] Recently, Samsung reported its lowest profit in 14 years due to waning chip demand. https://www.reuters.com/technology/samsung-quarterly-profit-set-hit-14-year-low-amid-chip-glut-2023-04-04/. Accessed April 10, 2023.

[6] A number of experts in the United States, most notably Bateman, a Senior Fellow in the Technology and International Affairs Program at the Carnegie Endowment for International Peace, have expressed this opinion. https://foreignpolicy.com/2022/11/02/united-states-China-semiconductor-imports/. Accessed March 3, 2023.

[7] Bloomberg DB. Accessed Jan, 3 2023.

[8] We analyzed the global supply chain using trade data in this paper, as the U.S. sanctions on the China semiconductor industry had far-reaching impacts on the foreign semiconductor industry invested in China. This study thus had a different purpose from that of the network analysis conducted by Jeong in 2021 which utilized corporate data.

[9] Despite investing $20 billion in semiconductor development through the first National Integrated Circuit Industry Investment Fund in 2014, China has since then allocated around $150 billion to the domestic semiconductor industry—twice the amount the global semiconductor industry has spent on R&D annually—in an effort to create its own semiconductor manufacturing ecosystem. https://foreignpolicy.com/2021/02/16/semiconductors-us-china-taiwan-technology-innovation-competition/. Accessed March 6, 2023.

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Appendix A: Defining Semiconductors in Trade Data

Semiconductors are divided into discrete and integrated circuits (ICs). Discrete refers to a small electronic semiconductor component that has a single function within a product. Examples include diodes, transistors, condensers, and the like. An IC, on the other hand, is a collection of circuit components such as transistors, condensers, and diodes that are combined on a substrate in an inseparable form to perform a specific function in an electrical circuit. The semiconductor industry encompasses not only discrete and ICs, but also the materials, parts, production equipment, and design necessary to produce them. This study, however, focuses only on the semiconductor manufacturing industry. Network analysis is based on data from 2021.

To comprehensively analyze semiconductor trade, we must first identify which industrial classifications capture the relevant trade flows. The MTI code is an industrial classification code created in 1988 by the Korean Ministry of Trade, Industry, and Energy and the Korea International Trade Association (KITA). The MTI system combines Harmonized System (HS) codes of similar types, providing codes and item names, and is used to classify individual items in accordance with the industrial classification. Through the Kita.net, users can access import and export statistics by item based on the MTI classification criteria, which consists of a five-stage classification system of one digit, two digits, three digits, four digits, and six digits. Using these codes, we divide the semiconductor industry into twelve fields, including semiconductors and semiconductor manufacturing equipment, and describe these fields in Table A-1. The semiconductor equipment industry is divided into two main categories: equipment and parts. Semiconductors can be further divided into Integrated Circuits, Integrated Circuit components, Discrete component parts, silicon wafers, and Integrated Circuits, with Discrete components themselves being sub-divided into four sub-fields.

Table A-1: Classification of Semiconductor Industries

Classifications	Types	Classification Fields
Semiconductor Manufacturing Equipment (SME)	SME Parts	1) SME Part
Semiconductors	Integrated Circuits	2) Memory
		3) Process Controller
		4) Amplifier
		5) Other Integrated Circuit
	Integrated Circuit Parts	6) Integrated Circuit Part
	Discrete Components	7) Transistor
		8) Diode
		9) Other Discrete Component
		10) Component
	Discrete Component Parts	11) Discrete Component Part
	Silicon Wafers	12) Silicon Wafer

Source: Korean Ministry of Trade, Industry, and Energy / Korea International Trade Association.

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VOLUME 3 | ISSUE 1 | REVISED VERSION
JANUARY 2024
https://bush.tamu.edu/mosbacher/white-papers/

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