Analysis of Korean Import and Export in the Semiconductor Industry: A Global Supply Chain Perspective*

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Abstract

Purpose – Semiconductors are a significant export item for Korea that is expected to continue to contribute significantly to the Korean economy in the future. Thus, the semiconductor industry is a critical component in the 4th Industrial Revolution and is expected to continue growing as the non-face-to-face economy expands as a result of the COVID-19 pandemic. In this context, this paper aims to empirically investigate how semiconductors are imported and exported in Korea from a global supply chain perspective by analysing import and export data at the micro-level.

Design/methodology – This study conducts a multifaceted analysis of the global supply chain for semiconductors and related equipment in Korea by examining semiconductor imports and exports by semiconductor type, year, target country, mode of transportation, airport/port, and domestic region, using import/export micro-data. The visualisation, flow analysis, and Bayesian Network methodologies were used to compensate for the limitations of each method.

Findings – Korea is a major exporter of semiconductor memory and has the world's highest competitiveness but is relatively weak in the field of system semiconductors. The trade deficit in 'semiconductor equipment and parts' is clearly growing. As a result, continued investment in 'system semiconductors' and 'semiconductor equipment and parts' technology development is necessary to boost exports and ensure a stable supply chain.

Originality/value – Few papers on semiconductor trade in Korea have been published from the perspective of the global supply chain or value chain. This study contributes to the literature in this area by focusing on import and export data for the global supply chain of the Korean semiconductor industry using a variety of approaches. It is our hope that the insights gained from this study will aid in the advancement of SCM research.

Keywords: Bayesian Network, Flow Analysis, Semiconductor Industry, Supply Chain, Trade, Visualisation

JEL Classifications: D85, F14, L63

1. Introduction

Semiconductors are being called 'industrial rice' or 'magic stones' since they play a part that goes into all electronic products. In the early days, the U.S. and Japan took the lead in the semiconductor market when Korea was centered on subcontracting in the form of simple assembly plants in the 1970s. Now, the semiconductor industry plays a vital role in Korea. The industry ranked second in market share after the U.S., while industrial technology competitiveness ranked third, after the U.S. and Japan. The exports hit $126.7 billion in 2018,

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the country’s highest-ever; and in 2020, we saw semiconductor exports hit $99.2 billion despite the COVID-19 pandemic and U.S. sanctions against Huawei (Lee, June-Myeong, and Shim, Hye-Jeong, 2021).

The semiconductor industry is considered to be a key industry in the era of the 4th Industrial Revolution and is expected to grow continuously. In the future, artificial intelligence is expected to fundamentally change life, industry, economy, and society. In particular, self-driving cars, intelligent robots, bio/healthcare, and the Internet of Things will emerge as key technologies. It is predicted that various application markets that utilise semiconductor technologies, such as artificial intelligence, autonomous vehicles, IoT, AR/VR, intelligent robots, and sensors, will grow. In particular, various semiconductor markets based on artificial intelligence will be the new growth engines.

However, the industry in Korea may face a crisis due to the efforts of the U.S., China, and Europe to reorganise their semiconductor supply chains. The U.S. is making every effort to create a semiconductor supply chain centered within the country. Besides, global ICT (Information and Communication Technology) companies, such as Apple, Google, Facebook, and Tesla, have started to make efforts to design semiconductor chips. Also, the semiconductor industry operates as a global supply chain. This characteristic necessitates that semiconductor manufacturing processes take into account the entire global supply chain (Lee et al., 2006).

On the other hand, Korea faces a number of challenging issues related to the semiconductor industry. The industrial base in Korea is unstable and exposed to risks in overseas supply chains due to the low localisation rates of equipment, materials, and components, which are the foundation of semiconductors. Also, due to a lack of self-sufficiency in core equipment and materials, Korea’s semiconductor industry is vulnerable to overseas supply chain risks. As of 2019, the semiconductor industry showed the highest export volume which accounted for 17.9% of Korea’s exports. This is the highest of any industry in the country. Besides, the semiconductors’ share of total exports has risen by 8.9% since 2009. Such increase is more than any other industry (Business Korea official website). Also, Korea’s competitiveness in system semiconductors, despite its status as a memory semiconductor major player, is relatively low. On the other hand, the system semiconductor market, which is already nearly three times the size of the memory semiconductor market, is expected to continue growing (The Export-Import Bank of Korea, 2021). Thus, this study examined the global supply chain of semiconductors and related equipment in Korea using import/export micro-data by semiconductor type (semiconductor memory and system semiconductor), year, target country, mode of transportation, airport/port, and domestic region.

The structure of this study is as follows. Section 2 reviews the literature on the supply chain of the semiconductor industry. Section 3 introduces the three methodologies employed in this study. Section 4 presents the process of collecting and filtering the data and includes descriptive statistics with the extracted dataset. Section 5 presents the results, and Section 7 concludes the paper and suggests future research.

2. Literature Review

In global technological developments, the semiconductor manufacturing industry has been considered one of the largest contributors for a long time. Advanced technology that enhances economic, technological, and military competitiveness requires semiconductors. Policies concerning semiconductors and the necessary inputs, therefore, have a significant impact on national and international security (Khan, 2020). Not surprisingly, there has been extensive research conducted in the field of semiconductors and their manufacturing. The
history of semiconductor research goes back quite a long time. Such research began quite inconspicuously about 200 years ago with some observations on the electrical properties of silver sulfide. Progress was very slow for the next 50 years, but then, in about 1885, a mild interest developed with the discovery of point contact rectifiers. These devices were used as detectors until they were displaced by the vacuum tube in around 1915 (Pearson and Lansberg, 1955).

In more recent years, researchers, in general, have been active in analysing the industry competitiveness between countries, along with building strategic plans to effectively operate complex supply chains. This is because securing competitiveness is the first priority for all businesses in order to improve their ability to be flexible and responsive to meet changing market requirements (Gunasekaran and Ngai, 2004). In this regard, supply chain management (SCM) is well-known to play an important role.

There have been various research approaches proposed in regards to SCM and semiconductor manufacturing. Jang Jung-Hwan and Kim Ho (2017) examined changes in semiconductor packaging technology in the context of industrial innovation regimes and analysed innovators and networks in the industry from a supply chain perspective. Since SCM plays a vital role in the industry, there has been much research on optimisation under uncertainty, such as stochastic programming (Gupta et al., 2000), and research using a scenario-based approach (Shah and Pantelides, 1992). Ryu (2006) summarised some of the lessons learned from the introduction, construction, and stabilisation of SCM by leading domestic semiconductor manufacturers, discussing how they can be extended to the establishment of SCM systems in enterprises and how process system engineering can contribute to this. Ryu and Lee (2008) also investigated the issues in semiconductor manufacturing supply chain management. Based on personal industrial experience and research progresses, relevant research and information were introduced to address the key issues and challenges. The work by Shin Hyun-Joon and Ryu Jae-Pil (2011) established realistic production and transport strategies for the supply chain by reflecting on various constraints when making decisions about the semiconductor manufacturing supply chain. This research developed two approaches: the ‘stochastic model with consideration of various cases’ and the ‘deterministic model considering replanning cost and proposal of efficient solution methods’ in order to take volatilities into account.

In addition, the subject of semiconductor industry-related SCM research has been expanded and diversified, including semiconductor equipment (Cohen et al., 2003; Terwiesch et al., 2005), semiconductor equipment manufacturers (Zhang et al., 2010), the semiconductor component supply chain (Pai and Yeh, 2016), e-SCM (Hwang and Lu, 2013), the green supply chain in the semiconductor industry (Hwang et al., 2016), and semiconductor supply chain companies (Wang and Chen, 2019).

In terms of methodology, SCM studies on the semiconductor industry have also been conducted through various types of analyses. It is divided into qualitative and quantitative research methodologies as follows. First, the semiconductor industry’s SCM was investigated using a case study (Hwang et al., 2008; Zhang et al., 2010; Jang and Kim, 2017), literature reviews (Mönch et al., 2018a; Mönch et al., 2018b; Uzsoy et al., 2018), and providing concepts (Ryu and Lee, 2008) and frameworks (Seitz et al., 2016) based on qualitative analysis methods. Second, there are mathematical models, such as stochastic and optimisation models (Denton et al., 2006; Lee et al., 2006; Chiang et al., 2007; Wang et al., 2007; Wang et al., 2009; Shin and Ryu, 2011; Sun et al., 2011; Degbotse et al., 2013), that have been used as quantitative analysis methods to study the semiconductor industry and conduct SCM analyses. There is also a study that used questionnaires to analyse the supply chain in the semiconductor industry (Hsiao et al., 2008; Pai and Yeh, 2016), as well as a study that used regression (Rasiah and
Analysis of Korean Import and Export in the Semiconductor Industry: A Global Supply Chain Perspective

Shan, 2017; Wang and Chen, 2019; Nam and Wang 2020), the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method (Hwang et al., 2016), time-series models (Wang and Chen, 2019), multivariate cointegration tests and error-correction models (Wong and Tang, 2011), group discussions with experts and Fuzzy analytic hierarchy process (FAHP) approaches (Hwang and Lu, 2013), hybrid analytic hierarchy process–fuzzy logic model (AHP–FLM) approaches (Bahinipati et al., 2009), and hybrid MTS-MTO (make-to-stock and make-to-order) modes (Lin et al., 2018) used to analyse the supply chain in the semiconductor industry.

The following is a study that examines the SCM of the semiconductor sector focusing on Taiwan (Hsiao et al., 2008; Hwang et al., 2008; Hwang and Lu, 2013), Malaysia (Wong and Tang, 2011), Singapore (Rasah and Shan, 2016), and China (Grimes and Du, 2020). However, to our knowledge, there are very few papers with a view of the global supply chain or the global value chain except for Grimes and Du (2020).

This paper differs from previous works in the following aspects: i) Using import and export trade data, this study examines Korea’s semiconductor industry from the perspective of the global supply chain; ii) The majority of previous research did not divide and analyse semiconductors in detail, but this study does so, and iii) As a result, the analysis of the global supply chain for the Korean semiconductor industry must be approached in a manner that is distinct from previous studies.

This study contributes to the existing literature on the global supply chain of the semiconductor industry in Korea, and it is our hope that the insights gained from the present study will help further SCM research.

3. Methodology

3.1. Visualisation

In this study, a visualisation method (using Tableau software, a data visualisation tool) was used to examine the import and export status of two types of semiconductors and semiconductor equipment and parts in order to gain insight into the semiconductor industry’s global supply chain based in Korea. By visualising the import/export volume ($) of semiconductors and related equipment on a map, it was possible to quickly assess the current status of major import/export countries and major domestic import/export regions, as well as the growth and decline in imports and exports by year (5-year period from 2010 to 2020). However, this mapping allows for the visualisation of a single step in a process. On the other hand, the Sankey diagram enables the representation of multiple steps regarding import/export in terms of the volume ($) of flows in the complexity of trade paths (Soundararajan et al., 2014).

3.2. Flow Analysis

A Sankey diagram is a graphical representation of flows, e.g., those of energy, money, and supply and demand (Soundararajan et al., 2014). Also, this diagram is a visual representation of value flows, including of energy, materials, and costs, within systems at the operational level or across global value chains (Schmidt, 2008).

Fig. 1 shows the representation in a Sankey diagram. In the case of import, it shows the import link from one country (node) to a specific region (node) in Korea (and vice versa). The thickness of the link directly reflects the relative flow volume ($)
This study develops and presents a Sankey diagram-based analytical framework with the goal of identifying and characterising structural aspects of the global supply chain of semiconductors and related manufacturing machines, devices, and parts in Korea. The purpose of this study is to visualise the trajectory of import/export flows and to provide useful insight into opportunities for the value volume ($), thereby informing policymakers about trade trends and supply chain prospects by using a Sankey diagram.

3.3. Bayesian Network

A Bayesian network (BN) approach has been applied in a variety of fields and is a highly effective tool for risk detection, prediction, probabilistic reasoning, and decision support. Also, the advantage of BN over other methodologies is that it enables the modeling of dependencies between influential factors (Baksh et al., 2018) and the BN has been shown to be a highly effective method for enabling inferences and expressing uncertain knowledge (Lee et al., 2020).

The BN model makes use of a graphical representation (Directed Acyclic Graph, DAG) composed of nodes and arcs, in conjunction with mathematical inference calculation representing the conditional dependencies (Das and Ghosh, 2020). Any node \(X_i\), given its parents, is conditionally independent of its child node in the Bayesian network (see Fig. 2).

According to Das and Ghosh (2020), each node \(X\) in the Bayesian network is associated with a conditional probability distribution \(P(X_i|\text{Parents}(X_i))\). In the Bayesian network, any node \(X_i\), given its parents, is conditionally independent of its child node.

\[
P(x_1, x_2, x_3, ..., x_n) = \prod_i P(X_i | \text{Parents}(x_i)) \quad (1)
\]

If a BN has \(n\) parent nodes, then any value in the joint distribution can be represented by \(P(X_1 = x_1, X_2 = x_2, X_3 = x_3, ..., X_n = x_n)\). The joint probabilities can be factorised using the chain rule of probability theory as follows:

\[
P(X_1 = x_1, X_2 = x_2, X_3 = x_3, ..., X_n = x_n) = P(x_1)P(x_2|x_1)(x_3|x_1,x_2) ... = \prod_i P(x_i|x_1, x_2, ..., x_{i-1}) \quad (2)
\]

While numerous authors have examined various Bayesian network-based techniques for analysing detection, prediction, and probabilistic reasoning in a variety of fields, there is a
lack of research on the trade field using real import/export data. Also, Netica (Norsys Software Corp., https://www.norsys.com) was used in this study to develop the BN model and to generate the graphical interfaces that facilitate the comprehension of network occurrences.

4. Data

This study’s analysis relied on annual import and export data for all items obtained from the Trade Statistics Service (TRASS). In this regard, import data include import date, import origin, import items (10-digit HS code), port of import, import destination, and the weight and price of each imported product. Export data has been correspondingly obtained. Notwithstanding the various types, this study categorises semiconductors by memory and system and further analyses equipment and parts required for semiconductor manufacturing. Accordingly, HS codes corresponding to each memory and system semiconductor, equipment, and parts for semiconductor manufacturing were investigated (see Appendix Table 1), and corresponding import and export data extracted.

This classification is based on several assumptions. Notably, only those classified as semiconductor-related goods with semiconductor HS codes (in the HS code-harmonised system) were considered. Furthermore, equipment and goods that are universally classified in other industries, such as a microscope (9011.80-9000), scope (9011.80-9000), recorder, gas regulator (8481.10-0000), AC servo motor (8501.40-2000) and an air valve (8481.80-1090), were omitted.

The data were extracted in approximately four to five-year periods from 2010, 2015, and 2019. In addition, the research period was extended to the first year of the COVID-19 pandemic in 2020. A sample of several item categories was extracted from the obtained semiconductor-related import/export data and verified by comparing it with annual import/export data provided by the Korean Customs Service (https://unipass.customs.go.kr/ets). Finally, the final extracted data was analysed using the three methodologies discussed in Section 3 (see Fig. 3).

Fig. 3. Process of Data Pre-processing and Data Analysis
Table 1 shows the import/export costs and balance of trade by semiconductor type and year. Furthermore, the figures for each semiconductor type below show the proportion of imports and exports by year.

Examining imports and exports of semiconductor memory reveals steadily increasing exports and that this industry contributes to the Korean economy in terms of its trade balance. Furthermore, system semiconductors also show an increase in exports. Overall, the rate of exports is higher than imports.

System semiconductors have a higher proportion of imports than memory conductors. The proportion of imports of semiconductor manufacturing equipment and parts is higher than that of such exports.

### Table 1. Import/Export Value and Proportion of Each Semiconductor Type

<table>
<thead>
<tr>
<th>Year</th>
<th>Import (a)</th>
<th>Export (b)</th>
<th>Total (a)+(b)</th>
<th>Trade balance (b)-(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Semiconductor memory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>6,048</td>
<td>28,470</td>
<td>34,518</td>
<td>22,422</td>
</tr>
<tr>
<td>2015</td>
<td>8,430</td>
<td>33,785</td>
<td>42,215</td>
<td>25,356</td>
</tr>
<tr>
<td>2019</td>
<td>19,307</td>
<td>62,995</td>
<td>82,302</td>
<td>43,687</td>
</tr>
<tr>
<td>2020</td>
<td>18,887</td>
<td>63,929</td>
<td>82,816</td>
<td>45,041</td>
</tr>
<tr>
<td><strong>System semiconductor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>18,443</td>
<td>16,094</td>
<td>34,537</td>
<td>-2,349</td>
</tr>
<tr>
<td>2015</td>
<td>24,075</td>
<td>23,134</td>
<td>47,209</td>
<td>-941</td>
</tr>
<tr>
<td>2019</td>
<td>20,629</td>
<td>25,676</td>
<td>46,305</td>
<td>5,047</td>
</tr>
<tr>
<td>2020</td>
<td>24,489</td>
<td>30,227</td>
<td>54,716</td>
<td>5,737</td>
</tr>
<tr>
<td><strong>Manufacturing equipment and parts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>7,824</td>
<td>2,319</td>
<td>10,142</td>
<td>-5,505</td>
</tr>
<tr>
<td>2015</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2019</td>
<td>10,582</td>
<td>6,224</td>
<td>16,806</td>
<td>-4,358</td>
</tr>
<tr>
<td>2020</td>
<td>17,173</td>
<td>6,682</td>
<td>23,855</td>
<td>-10,491</td>
</tr>
</tbody>
</table>

**Notes:**

1. Semiconductor optical devices are not included in the statistics.
2. The import and export data of manufacturing machines and parts in 2015 recorded very small amounts, even in the raw data.
In terms of the trade balance, semiconductor memory has maintained a surplus, while system semiconductors have also achieved a surplus since 2010, as the trade deficit has been reduced. However, it is clear that the semiconductor manufacturing and parts trade deficit is growing. In the next section, the current status of semiconductor imports and exports in Korea are examined through visualisation and flow analysis. Also, the advantage of BN over other methodologies is that it enables the modeling of dependencies between influential factors; therefore, the changes and distribution of domestic import and export regions are investigated using Bayesian network analysis.

5. Results

5.1. Visualisation of Import and Export Status

5.1.1. Import/Export of Semiconductor Memory

The main importing countries of semiconductor memory were centered around Asia (based on $ million). China was the largest market in Korea for both imports and exports. Semiconductor memory were being exported to many countries, with most exports being made to Asia. Furthermore, many exports were made to the U.S., Europe, and Brazil. While imports of semiconductor memory from the U.S. decreased, exports to the U.S. gradually increased (see Fig. 4).

Fig. 4. Import and Export of Memories (2010, 2015, 2019, and 2020)
According to the volume ($) of semiconductor memory imported and exported in 2020, the top three importers were China, Taiwan, and the Philippines, while the top three exporters (to South Korea) were China, Hong Kong, and the United States.

5.1.2. Import/Export of System Semiconductors

Unlike semiconductor memory, the proportion of imports and exports of system semiconductors by country were similar. In particular, there were no notable changes in the exports of system semiconductors from 2010–2020 (see Fig. 5). Based on the import and export volume ($) in 2020, system semiconductor imports from Taiwan were highest, and imports from the United States, China, Japan, and Singapore were also high. In the case of exports, Vietnam, China, Hong Kong, and Singapore were the highest, in that order.

Fig. 5. Import and Export of System Semiconductors (2010, 2015, 2019, and 2020)
5.1.3. Import/Export of Semiconductor Manufacturing Equipment and Parts

The biggest importers of equipment and parts required for semiconductor manufacturing were the U.S. and Japan. Imports of semiconductor equipment and parts from Europe increased in 2019 and 2020, compared to 2010. The high volume ($) of imports from the Netherlands is particularly noticeable.

**Fig. 6.** Import and Export of Manufacturing Machine and Parts (2010, 2019, and 2020)

Note: Because there was insufficient information in the raw data for 2015, the graph does not include data on semiconductor equipment and parts imports and exports.
According to the 2020 import data, ‘machines and apparatus[es] for the manufacture of semiconductor devices or electronic integrated circuits’ (HS code: 848620) accounted for 89.7% of total imports from the Netherlands. This item was an ‘extreme ultra-violet (EUV) lithography machine’, which is primarily manufactured by ASML of the Netherlands and is a critical piece of equipment in the semiconductor process. The Netherlands is the only country that manufactures this equipment on a global scale. As illustrated in Fig. 6, production equipment imported from the Netherlands has a high price-to-weight ratio. Export target countries included China, Taiwan, Japan, the U.S., and Singapore. In particular, ‘machines and apparatus[es] for the manufacture of semiconductor devices or of electronic integrated circuits’ (HS code: 848620) and ‘machines and apparatus[es] specified in Note 9 (C) to this chapter’ (HS code: 848640) accounted for 67.2 percent of the total semiconductor equipment and parts exports to China.

Fig. 7 illustrates the number of import and export destinations from a supply chain perspective. As previously stated, semiconductor exports and related equipment and parts continue to grow. The number of countries exporting semiconductor memory has increased from 64 in 2010 to 61 in 2015, 63 in 2019, and 73 in 2020. While exports of system semiconductors increased, the number of export destinations decreased from 110 in 2019 to 98 in 2020. Along with increased exports, there is a need to expand exporting countries.

Additionally, the volume ($) of system semiconductors imported and the countries from which they were imported increased. This can be interpreted in one of two ways. While various items from various countries are required to secure a system semiconductor, in the long run, it is critical to reduce reliance on system semiconductor imports and establish the most reliable and stable supply chain through domestic production.

**Fig. 7. Import and Export of Manufacturing Machines and Parts (2010, 2015, 2019, and 2020)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Export</th>
<th>Import</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>[63]</td>
<td>[82]</td>
</tr>
<tr>
<td>2015</td>
<td>[102]</td>
<td>[114]</td>
</tr>
<tr>
<td>2019</td>
<td>[107]</td>
<td>[110]</td>
</tr>
<tr>
<td>2020</td>
<td>[107]</td>
<td>[114]</td>
</tr>
</tbody>
</table>

Note: The numbers in [ ] in the figure above denote the number of countries.

### 5.2. Import/Export of Semiconductors by Domestic Region

Fig. 8 shows that the domestic regions of origin for semiconductor memory used in Korea (Fig. 8(a)) and system semiconductor (Fig. 8(b)) exports are centered around Gyeonggi-do. The domestic dispersion of imports and exports show that imports are from more diverse regions than exports for both memory and system semiconductors. In addition, the import and export status of semiconductor manufacturing equipment and parts shows that imports are concentrated in Gyeonggi-do, where semiconductors are manufactured.

Examining annual trends reveals a clear increase in export volume ($) of memory and system semiconductors, as well as import volume ($) of equipment and parts in some areas of Gyeonggi-do.
Fig. 8. Import and Export of Semiconductor by Type (2010, 2015, 2019, and 2020)  
(Unit: $ million)
5.3. Flow analysis: Origin/Destination (O/D)

The previous Sections 5.1 and 5.2 presented the national and domestic import and export origins and destinations but did not show the correlations between two special regions. Thus, this section examines the trade flow (based on volume ($) in 2020) between semiconductor import and export origins and destinations centered on Korea by conducting an origin/destination (O/D) analysis. Such an O/D analysis has been visualised using the Sankey diagram. This visualised approach is a subtype of flow diagram in which the arrows' width is proportional to the size of the represented flow. The flow quantities in this study correspond to the trade flow of import and export.

Imports have been presented in order of foreign countries, transport modes (air or sea), domestic airports, seaports, and domestic regions, while exports have been presented in order of domestic regions, domestic airports and seaports, transport modes (air or sea), and foreign countries. Fig. 9-11 show that semiconductor imports and exports are transported mainly by air, for which Incheon International Airport is the primary airport.

5.3.1. Imports and Exports of Semiconductor Memory

As shown in Fig. 9, semiconductor memory was mainly imported from China to Suwon-si and Icheon-si (in Gyeonggi-do), and to Jung-gu (in Incheon-si) via Incheon International Airport. Exports are higher than imports, and semiconductor memory was mainly exported from regions with semiconductor production bases (Asan-si, Icheon-si, Yongin-si, Pyeongtaek-si and Cheongju-si) to the U.S. and countries centred around Asia, including China, Hong Kong, Vietnam and the Philippines, as mentioned above. A sankey diagram is a type of diagram that is used to depict the flow of values from one set to another. The objects that are connected are referred to as nodes, while the connections are referred to as links. Sankey diagrams are most effective when illustrating a many-to-many mapping between various routes through a series of stages. Rectangles or text are used to represent various entities (nodes). Their connections are denoted by arrows or arcs with a width proportional to the magnitude of the flow.

Fig. 9. Import and Export of Semiconductor Memory in 2020

(a) Import
5.3.2. Imports and Exports of System Semiconductors

Fig. 10 represents imports and exports of system semiconductors in 2020. The imports of system semiconductors were from Taiwan, the U.S., China, Japan, and Singapore (this result is consistent with Fig. 5) to Suwon-si, Jung-gu of Incheon-si, Seoul (Yeongdeungpo-gu, Gangnam-gu), and Gwangju-si. As mentioned above, domestic regions of import for system semiconductors were diversely distributed. The reason that the proportion of other cities is greater than that for semiconductor memory is that, as previously stated, it is used in a variety of industries and is in high demand throughout Korea.

System semiconductors were mainly exported by air from Asan-si, Incheon-si (Jung-gu, Yeonsu-gu), and Gwangju-si, to countries including China, Vietnam, Hong Kong, Taiwan, Singapore, and Malaysia.

Note: ‘ZZZ’ and ‘ZZZZ’ stands for an unknown port.
5.3.3. Imports and Exports of Semiconductor Equipment and Parts

Imports of semiconductor equipment and parts were mainly from the U.S. and the Netherlands. In particular, imports from Japan were mainly by sea via the Busan Port (‘machines for depositing membrane or sputtering metal on semiconductor wafers’ (HS code: 8486204000) and ‘for dry-etching patterns on semiconductor materials’ (HS code: 8486208410) account for a higher proportion than other imported items). Fig. 11 illustrates the transportation of semiconductor equipment and parts from the Busan Port to Gyeonggi-do Province.

Exports of semiconductor equipment and parts were very low compared to memory and system semiconductor export volume ($) but were mainly from the Gyeonggi-do region, and approximately half of the exports to China were by sea via the Busan Port.
5.4. Bayesian Network Analysis

Using visualisation and the Sankey diagram above, the analysis has limitations in simultaneously showing the changes in the variable distribution according to their different conditions (e.g., item, year, countries). In other words, while it presents semiconductors by type and year, as shown in the previous section, it is challenging to simultaneously check each country and domestic region’s import and export status by type and by year. Thus, this study’s analysis uses a Bayesian network to overcome these limitations.

A Bayesian network is an analytical tool that supports comprehensive decision-making by using graph theory to show variability according to the changes in each variable linked by causal relationships. In addition, the changes in variables (variants) according to the changes in a single variable or variant are observable in real-time by obtaining inverse distributions. Furthermore, Bayesian networks can be analysed with limited data using Bayesian theory and can ‘learn’ to estimate parameters with more data. It possesses the advantage of increasing the accuracy of the estimate through the updating or learning process, which reflects the entered data.

This section examines the changes and distribution of domestic import and export regions by year, import and export, type of semiconductor, country of import and export, transportation modes, and port or seaport. In this regard, the import and export supply chain status will be determined and examined from various perspectives.

5.4.1. Bayesian Networks Model with ‘Type’, ‘Import/Export’, and ‘Year’

Each Bayesian network comprises nodes and links. The figure below shows three nodes, each representing the semiconductor type, import and export, and year. These nodes are connected by arrows. Fig. 12(a) shows the distribution of the data used in this study. For
example, the distribution of import and export costs for memory and system semiconductors and semiconductor equipment and parts for four years (2010, 2015, 2019 and 2020) are shown in the table below, and Figure 10(a) shows this distribution in the 'type' node. The import and export and year distributions for all data are shown in a similar manner (see Table 2). The data have been organised to show how the yearly import and export cost distribution changes by semiconductor type, as well as by import and export.

**Table 2. Import and Export Volume ($) by Semiconductor Type over Four Years**

<table>
<thead>
<tr>
<th></th>
<th>Memory (unit: $ million)</th>
<th>System (unit: $ million)</th>
<th>Manufacturing (unit: $ million)</th>
<th>Total (unit: $ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of imports and exports</td>
<td>241,851 (50.9%)</td>
<td>50,805 (38.4%)</td>
<td>182,767 (10.7%)</td>
<td>475,423 (100.0%)</td>
</tr>
</tbody>
</table>

The direction of the arrow expresses the change in the distribution of the connected nodes under given conditions. For example, in Fig. 12(b), the distribution of the import and export node (arrow endpoint 1) and year node (arrow endpoint 2) changed under the condition that the semiconductor type was semiconductor memory (the node has turned grey; the arrow points out the direction). In other words, for the semiconductors and related equipment and parts considered in this study, the proportion of all exports (for the four years) (78.2%) was higher than that of imports (21.8%) (Fig. 12(b)), while the proportion of imports and exports of system semiconductors was similar (Fig. 12(c)), and the proportion of imports (70%) was higher than that of exports (30%) for semiconductor equipment and parts (Fig. 12(d)).

The figures also show an increasing trend of import and export costs by year for semiconductor memory, system semiconductors, and semiconductor equipment and parts.

**Note:** 'Memory' stands for semiconductor memory, 'system' refers to system semiconductors, and 'manufacturing' denotes manufacturing equipment and parts for semiconductors.

Fig. 13 shows the addition of a 'transportation mode' node to the previous model. While a large proportion of memory and system semiconductor imports and exports are transported...
by air (Fig. 13(a) and (b)), the proportion of sea transportation modes are relatively higher for semiconductor equipment and parts compared to semiconductors (Fig. 13(c)). Further examining the ‘exports’ of semiconductor equipment and parts shows a higher proportion of sea transportation (Fig. 13(d)).

**Fig. 13. Bayesian Network Model with ‘Type’, ‘Import/Export’, ‘Year’, and ‘Transportation Mode’**

It is also possible to consider a reverse situation for the results presented above using inverse probabilities by evaluating the conditional probability changes in the order of ‘transportation mode’, ‘type’, ‘import and export’, and ‘year’. However, as mentioned above, the amount of data included for 2015 is small and has a narrow distribution, as shown in Fig. 13(a). In this regard, the following Bayesian network has been designed by selecting the year to eliminate the limitation of a lack of data for one year.

Figure 14 shows the revised prior probabilities under the conditions of ‘2020’ for the year and ‘aviation’ and ‘maritime’ for the transportation modes. Fig. 14(a) represents the prior probabilities (‘type’ and ‘import/export’) of semiconductor memory (53.8%) and exports (63.5%) for ‘aviation’ transportation mode in 2020. Fig. 14(b) represents the prior probabilities of manufacturing equipment and parts (87.7%) and imports (56.5%) for the ‘maritime’ transportation mode in 2020. In other words, while the original model showed the proportion of transportation modes by air or by sea when the conditions ‘type’ and ‘import/export’ were selected, inverse probabilities can be used to examine the distribution of ‘type’ and ‘import/export’ in 2020 for the ‘aviation’ and ‘maritime’ transportation modes in reverse.
5.4.2. Model Based on Bayesian Networks with Connections Between Countries and Regions.

First, the distribution of domestic regions of import and export by country (P(County | Type, Country, and Airport/Seaport)) can be examined when the distribution of countries is established by year, import and export, transportation mode, and semiconductor type (P(Country | Year, Import/Export, Transportation mode, and Type)). In this regard, the analysis was conducted under the assumption that ‘type’ and ‘airport/seaport’ directly impact the distribution of domestic imports and exports. Notably, ‘year’ and ‘import/export’ affect ‘country’, which is reflected in ‘county’, so it can be assumed that this also indirectly impacts the distribution of domestic imports and exports.

Only major countries and regions with high import and export costs were considered for ‘country’ and ‘county’. Jung-gu in county represents Jung-gu, Incheon, while other Jung districts of Seoul, Busan, Ulsan, Daegu and Daejeon were included as ‘other counties’ due to low import and export costs. Buk-gu also only included the northern district of Gwangju, while other northern districts of Daegu, Busan and Ulsan were included as ‘other counties’.

Similarly, ‘airport/seaport’ only included Incheon International Airport and the Busan Port, as shown in the Sankey diagram above, since not all domestic airports and seaports could be included. The remaining airports and seaports were categorised as ‘other ports’.

Fig. 16 shows P(County | Import/Export=Import, Type=Memory, Year=2020, Country=all, Airport/Seaport=all).

The highest volume ($) of semiconductor memory imports was from China in 2020, to the counties Suwon-si, Icheon-si, and Jung-gu (Incheon) (Fig. 16(a)). This network graph is identical to the O/D analysis results presented above. Fig. 16(b) shows the status of exports.
However, the disadvantage of the Bayesian network is that it cannot present results in the size of the Sankey diagram as it only shows proportions. Thus, it would be better to examine the results by supplementing the strengths and weaknesses of each analytical tool.

6. Conclusions

As the non-face-to-face economy continues to grow as a result of the spread of COVID-19, it is critical to examine the supply chain in order to ensure stable semiconductor production in an environment where the semiconductor market is expected to grow. The semiconductor industry is one of Korea's most important export fields, and semiconductors are a key...
commodity for the domestic economy. This study conducted a multifaceted analysis by considering semiconductor imports and exports by semiconductor type, year, target country, mode of transportation, airport/port, and domestic region using import/export micro-data to examine the global supply chain of semiconductors and related equipment in Korea. The methodologies of visualisation, flow analysis, and Bayesian networks were used to supplement the limitations of each method, and the following research findings were derived as a result of this work.

Since 2010, the pattern of change in the trade of semiconductor memory and system semiconductors has remained almost constant. Semiconductor memory has maintained a surplus in the trade balance, and system semiconductors have also achieved a surplus following a reduction in the trade deficit since 2010. However, it is clear that the trade deficit in ‘semiconductor equipment and parts’ continues to grow. In advanced technology countries, such as the United States, the Netherlands, Japan, and Singapore, semiconductor production equipment and parts account for a large proportion of total imports. It is necessary to have production roses and parts made in the same area. Especially, the ‘extreme ultra-violet (EUV) lithography machine’, which is critical for semiconductor production, is the only piece of equipment that can be supplied by the Netherlands.

As is widely known, Korea is a major exporter of semiconductor memory and has the best competitiveness in the world; however, it is relatively weak in the field of system semiconductors. Therefore, as various experts have stated, investment in system semiconductors and continuous technology development are required, as is manpower training.

This study determined that the volume ($) of system semiconductors exported continues to grow. The number of export destinations, on the other hand, decreased from 110 in 2019 to 98 in 2020. Along with increasing export volume ($), it is necessary to diversify exporting countries.

Additionally, the volume ($) of system semiconductors imported and the countries from which they are imported have increased. This development can be interpreted in one of two ways. While various items from various countries are required to secure a system semiconductor, in the long run, it is critical to reduce reliance on system semiconductor imports and establish the most reliable and stable supply chain through domestic production.

Korea has developed a ‘K (Korea) semiconductor strategy’ and set the goal of developing the world’s best semiconductor supply chain by 2030. The ‘K semiconductor belt’, in particular, is intended to stabilise the supply chain via domestic demand. It is critical to maintain a stable supply chain by analysing the current state of the supply chain from overseas to ensure the uninterrupted supply of equipment and parts to Korea. This study contributes to the literature in this regard by focusing on import and export data of the Korean semiconductor industry’s global supply chain.

However, some limitations are noted in the research. The supply chain for semiconductors as intermediate goods was not considered in this study, nor were factors affecting the location of semiconductor production failures by semiconductor country taken into account. From a methodology standpoint, a more in-depth analysis of Bayesian networks should be conducted, but given the scope of this study, a more in-depth analysis should be conducted in subsequent studies. Additionally, a more detailed analysis of each semiconductor item would benefit a future revision of the Bayesian network model. Finally, using import/export microdata, this study examined the global supply chain for domestic semiconductors and related equipment from the perspective of import and export flows. However, a more detailed analysis is necessary for more specific causes, which we will leave to future research.
Acknowledgements

The authors are grateful to the editor and anonymous referees for their insightful comments and suggestions on improving the manuscript.

Appendices

Appendix Table 1. Classification Semiconductor HS code

<table>
<thead>
<tr>
<th>Semiconductor</th>
<th>HS code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory (n=14)</td>
<td>8473304060, 8542321010, 8542321020, 8542321030, 8542321090, 8542322000, 8542323000, 8542324010, 8542324020, 8542324030, 8542324040, 8542324050, 8542324060, 8542324090</td>
</tr>
<tr>
<td>System (n=25)</td>
<td>8542331000, 8542332000, 8542333000, 8542334010, 8542334020, 8542334030, 8542334040, 8542334050, 8542334060, 8542334090, 8542339000, 8542391000, 8542392000, 8542392010, 8542393000</td>
</tr>
<tr>
<td>Manufacturing machines and parts (n=127)</td>
<td>8414090100, 8419391000, 8421293010, 8421293090, 8421399021, 8421399029, 8421999031, 8424891000, 8424909010, 8443325010, 8443391010, 8447903000, 8479904000, 8486101000, 8486102000, 8486103011, 8486103019, 8486103020, 8486103090, 8486104011, 8486104019, 8486104021, 8486104029, 8486105010, 8486105020, 8486105030, 8486109000, 8486201000, 8486202100, 8486202210, 8486202290, 8486202310, 8486202390, 8486203000, 8486204000, 8486205110, 8486205190, 8486205910, 8486205990, 8486206010, 8486206020, 8486206091, 8486206099, 8486207000, 8486208110, 8486208120, 8486208190, 8486208410, 8486208420, 8486208490, 8486209110, 8486209120, 8486209190, 8486209200, 8486209310, 8486209321, 8486209329, 8486209390, 8486209400, 8486209500, 8486209600, 8486209900, 8486401010, 8486401020, 8486401030, 8486401040, 8486401090, 8486402010, 8486402020, 8486402031, 8486402039, 8486402040, 8486402050, 8486402070, 8486402080, 8486402091, 8486402092, 8486402093, 8486402094, 8486402095, 8486402099, 8486403010, 8486403020, 8486403090, 8486901010, 8486901020, 8486902010, 8486902020, 8486904010, 8486904020, 8514401000, 8514901000, 8539491010, 8541902000, 8541903000, 8541909000, 8542901000, 8542902000, 8542903000, 8542904010, 8542904020, 8542904030, 8542904040, 8542904050, 8542904060, 8542904090, 8543901000, 8548901000, 9002909010, 9002909100, 9005001000, 9010901010, 9010901090, 9017809010, 9021909010, 9031411000, 9031412000, 9031491000, 9031494010, 9031809091, 9031901010, 9031901090, 9032812091</td>
</tr>
</tbody>
</table>

Source: HS code list.
Appendix Fig. 1. Import ($) Flow of System Semiconductors in 2020

Note: 'ZZZ' and 'ZZZZ' stands for an unknown port.
Appendix Fig. 2. Export ($) Flow of System Semiconductors in 2020
References


Economics, 107(1), 56-77.