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Interconnected Horizons: ASEAN's Journey in the Global Semiconductor Trade Network Amidst the COVID-19 Pandemic

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Abstract: *This paper examines the global semiconductor industry trade network and the place of the Association of Southeast Asian Nations (ASEAN) in it. The network analysis parameters (e.g. degree centrality, eigenvector centrality, and closeness) are calculated for two semiconductor product classifications (i.e. Harmonized System (HS) 8541 and HS 8542) as well as key inputs for the manufacturing process and testing, packaging, and distribution. The study finds that the coronavirus disease (COVID-19) pandemic has a significant adverse effect on the semiconductor trade network. It finds that the central position in the network is determined by Germany, the United States, China, Belgium, India, Italy, Spain, the Netherlands, France, and the United Kingdom. It is also found that Singapore, an ASEAN Member State, occupies the central position in the trade network. Other ASEAN Member States, such as Viet Nam, Malaysia, Thailand, the Philippines, and Indonesia, have been well integrated in the trade network in recent years. However, countries such as Myanmar, Cambodia, Brunei, and the Lao People's Democratic Republic (Lao PDR) are still in the peripheral area of the network. Nonetheless, over the years, these countries have improved their participation in semiconductor trade. The COVID-19 pandemic has impacted trade in key inputs and manufacturing parts of semiconductor production. It has drastically reduced the trade flows, connectivity, and dependence of many countries in the network.*

Keywords: Semiconductor trade; COVID-19; ASEAN; trade network; regional trade

JEL Classification: D85; F14; F15; L63

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1. Introduction

This paper aims to examine the impact of the coronavirus disease (COVID-19) pandemic on the semiconductor industry, with emphasis on the role of the Association of Southeast Asian Nations (ASEAN) region. The semiconductor industry, which produces microchips, has become an integral part of the production of computers, automobiles, and mobile phones. As it is considered the 'brain' of electronic devices, demand for these chips has increased substantially in recent years due to developments in artificial intelligence and machine learning. From 2000 to 2022, global semiconductor sales increased from $200 billion to $574 billion (SIA, 2023). Further, the COVID-19 pandemic increased the demand for these chips for medical devices and to find the solution to numerous public health problems. However, the COVID-19 pandemic and lockdowns led to disruptions in these chips' supply chains and subsequently affected downstream sectors, including cars, consumer electronics, home appliances, industrial robotics, and many other vital goods (SIA, 2021).

The semiconductor production process is considered one of the most complicated manufacturing processes, requiring more than 800 discrete steps (Huethorst, 2011). The overall production process consists of three distinct steps: design, fabrication, and assembly and testing. Due to the increasing complexity and costs, many companies specialise in a single production step. For instance, the company that designs the chips subcontracts fabrication to other companies. After fabrication, the chip is tested, assembled, and packaged to protect it from damage. It is argued that no country has the entire production within its territory (Kleinhans and Baisakova, 2020). However, the industry is dominated by the United States (US); Taiwan; the Republic of Korea (henceforth, Korea); Japan; Europe; and China. The global value chain (GVC) for this industry is quite unbalanced. The high-value core intellectual properties associated with designing the chip are dominated by advanced economies (e.g. the US,[2] Japan, the European Union, and an emerging economy, Korea) whereas the lower value-added processes (e.g. fabrication, assembly and testing) are carried out in Asian countries (e.g. Taiwan, Korea, and China).[3] Due to the disparities in value creation in the production process, the market shares of the US, Japan, the EU, and Korea account for more than 80% of global revenue. This is a clear indication of the lack of ability of Asian and developing economies to participate in the GVC,

[2] Qualcomm, Broadcom, and Nvidia are the top semiconductor companies in the world, headquartered in the US.

[3] Around 87% of semiconductor production takes place in these countries (Trendforce, 2021). For instance, Taiwan Semiconductor Manufacturing Company manufactures semiconductors for companies such as Apple, Qualcomm, Nvidia, and Advanced Micro Devices. Similarly, Samsung in Korea dominates in the production process, with 17% of the global share.

especially in the higher value-added processes, due to lack of capital and high-quality labour, better infrastructure, an improved business climate, and better institutions and policies (Kowalski et al., 2015; Bamber et al., 2014).

The COVID-19 pandemic has exposed the vulnerability of the global production network, prompting companies to strengthen their supply chains. Further, with the increasing presence of China in the semiconductor market and its approach to promoting its own technology, the US has imposed restrictions on its exports of design technologies to China for fabrication[4] (Grimes and Du, 2020). These trade tensions have induced many firms to diversify their production locations away from China. This situation has widened the scope for many countries to participate in the production value chain – including ASEAN. Foreign direct investment in semiconductor production in ASEAN has increased.[5] However, foreign investment in the ASEAN region has largely focused on low value-creation processes such as assembly and testing.[6] Thus, the key challenge for policymakers is how to facilitate the GVC participation of firms in higher value-added processes and thereby improve their well-being by reaping the maximum benefit from the production process. To do this, it is important to understand where each country is located in the trade network. If the country is an export hub, then its trade intensity with other countries would be higher and it would benefit more from participating in the GVC than if it were a local supplier. It is also important to ascertain whether the geographical proximity of ASEAN economies with key trading economies matters for entering the trade network. The semiconductor industry is cyclical and is subject to business cycle shocks, as semiconductor chips have a relatively short life and become obsolete when new and faster applications are developed. Upturns occur during periods of high demand, causing supply shortages, higher prices, and revenue growth. Downturns are caused by inventory build-up, resulting in falling prices and revenue growth (Regions, 2019). Thus, the industry is exposed to slowing world growth due to the pandemic and trade tensions.

Given this context, this study examines the structure of the GVC in the global semiconductor industry, with emphasis on ASEAN. It aims to address the following questions. Where is ASEAN positioned in the semiconductor GVC network? How does the

[4] The US blacklisted the Chinese semiconductor foundry Semiconductor Manufacturing International Corporation (SMIC) in 2020.

[5] US-based semiconductor manufacturer Global Foundries plans to invest $4 billion to expand production in Singapore in 2023.

[6] Intel Corp plans to invest more than $7 billion in building a new chip packaging and testing factory in Malaysia.

COVID-19 pandemic affect the structure and intensity of the trade network? Which countries are central and peripheral in the semiconductor value chain?

The literature does not pay enough attention to the GVC of the semiconductor industry, especially in the context of the COVID-19 pandemic. Existing studies on COVID-19 and trade suggest that the pandemic and its related lockdown adversely impacted various aspects of the global economy, such as the stock market (Narayan, Devpura, and Wang, 2020; Phan and Narayan, 2020; Prabheesh and Kumar, 2021); exchange rates (Iyke, 2020a; Iyke, 2020b; Rai and Garg, 2021; Padhan and Prabheesh, 2021); economic growth and trade (Vidya and Prabheesh, 2020; Vidya, 2022; Zainuddin et al., 2021; Bekkers and Koopman, 2022); and oil prices (Devpura and Narayan, 2020; Narayan, 2020).

Studies have found that COVID-19 adversely affected the GVC and led to the regionalisation of production (Freeman and Baldwin, 2020). Some studies have also found that the protectionist policies adopted by countries during the pandemic led to a reorientation of production towards domestic and neighbouring countries, a shortening of GVCs and their regionalisation, and a fall in foreign direct investment (Kersan-Škabić, 2021; Bonadio et al., 2020). However, few studies deal with semiconductors. Grimes and Du (2020) argued that China's aim to attain autonomy in the semiconductor industry is still far from reality because of its continued dependence on foreign technology. Further, higher value-added activities in the sector in China are dominated by global companies. Thus, the trade tensions with the US will undermine the country's aim to achieve autonomy in the semiconductor industry. Cabegin (2015) argued that ASEAN Member States such as Singapore and Malaysia can upgrade technological intensities and diversify international production linkages through trade integration. However, the Philippines failed to upgrade its technologies, leading to a reduced market share due to increased competition from China. None of these studies discusses the structure of the semiconductor GVC network and the impact of the pandemic on the trade network. Similarly, the position of each country in the production network is unclear from the literature. The role of ASEAN in the network is also unclear. Addressing the research questions proposed here would help to formulate appropriate policies to maximise the benefits of GVC participation for ASEAN.

This study contributes to the literature in the following ways: (i) to our knowledge, it is one of the first attempts to understand the trade network structure of the semiconductor industry; (ii) it may be the first attempt to understand the impact of COVID-19 on the semiconductor industry; (iii) it aims to determine the position of ASEAN in the semiconductor trade network, facilitating a comparative analysis of the economic strengths of these economies and their ability

to derive benefits from participating in GVC; and (iv) the findings may show the resilience of countries to various shocks in the trade network.

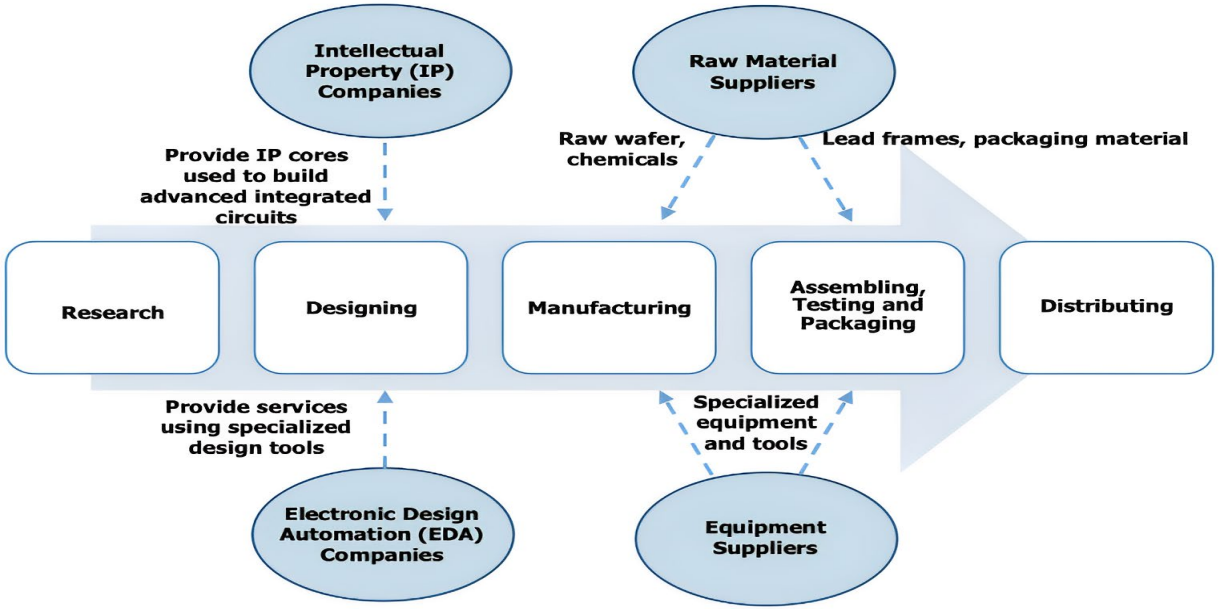
2. Semiconductor Industry: GVC, Global Trends, and Where Does ASEAN Stand?

A semiconductor is a substance that conducts electricity under some but not all circumstances. Manufacturers can customise the conductivity of a semiconductor, such as introducing a sensitivity to heat or light, or altering conductivity based on the direction of the current. Semiconductors are an important component of many commonly used electronic devices, including smartphones, tablets, and PCs.

2.1. Semiconductor Value Chain

Although semiconductor manufacturing is a very complex process, the value chain is simplified in Figure 1. Individual semiconductor chips are designed with the help of advanced software and computer workstations. Semiconductor production begins with research and development (R&D) and ends with distribution. The starting point of GVC is R&D, which is very competitive. Here, companies constantly seek to increase the processing capability and speed of semiconductor devices while reducing their cost. The semiconductor industry is one of the most R&D intensive industries in the world, with industry-wide investment rates at 15%–20% of sales. In the second stage – the design stage – companies consider new products and specifications to meet customer needs, then lay their design foundation. Research outcomes are a key input to the design stage, which relies heavily on highly skilled engineers and human capital. This stage involves several supporting companies, such as those that provide intellectual property to build advanced integrated circuits and those that provide computer-aided design (CAD) and other design services. In this segment, US-based companies Synopsys, Cadence Design Systems, and Siemens EDA sell or licence software services as inputs to many US and foreign chipmakers. The three companies are estimated to supply 85% of the global electronic design automation market (Bown, 2020).

Figure 1: Semiconductor Industry Value Chain



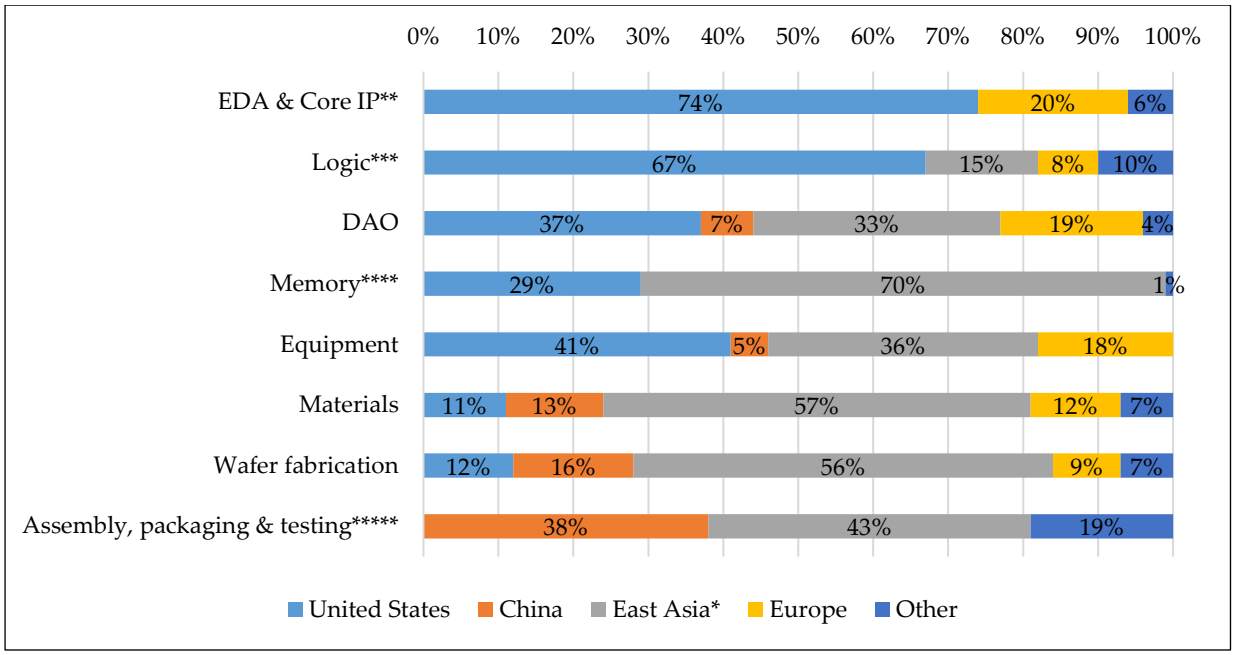
Source: SIA (2016).

The third stage – manufacturing – involves the production of the designed chips. In this stage, the company produces 'wafers' that contain many 'die' or chip. During this stage, raw wafer materials, chemicals, and advanced technology are used. As a first step, a pure semiconductor material, silicon, or germanium ingot is cut into thin round slices. Then, the individual die is cut from fabricated wafers, tested for defects, and assembled into complex packages that combine wire contacts with insulating material to form the finished semiconductor component. Finally, the packaged semiconductor is distributed for end use in electronic products (e.g. smartphones and computers). Higher value creation takes place during the initial stages of this process (R&D and design), whereas assembly, testing, and packaging are at the lower value creation end of the process. Thus, the countries involved in the earlier stages of the process gain more benefits from the production process.

Figure 2 shows that the US leads in most R&D and design activities (e.g. electronic design automation, core intellectual property, chip design, and advanced manufacturing equipment). This is because the US has more advanced technology and skilled labour than any other country. At the same time, East Asia, which includes Korea, Japan, and Taiwan, dominates in manufacturing (e.g. wafer fabrication), which requires massive capital investment supported by government incentives as well as access to robust infrastructure and a skilled workforce. In

contrast, China dominates in assembly, packaging, and testing, which are less skill- and capital-intensive.[7]

Figure 2: Global Semiconductor Supply Chain Based on Geographic Specialisation



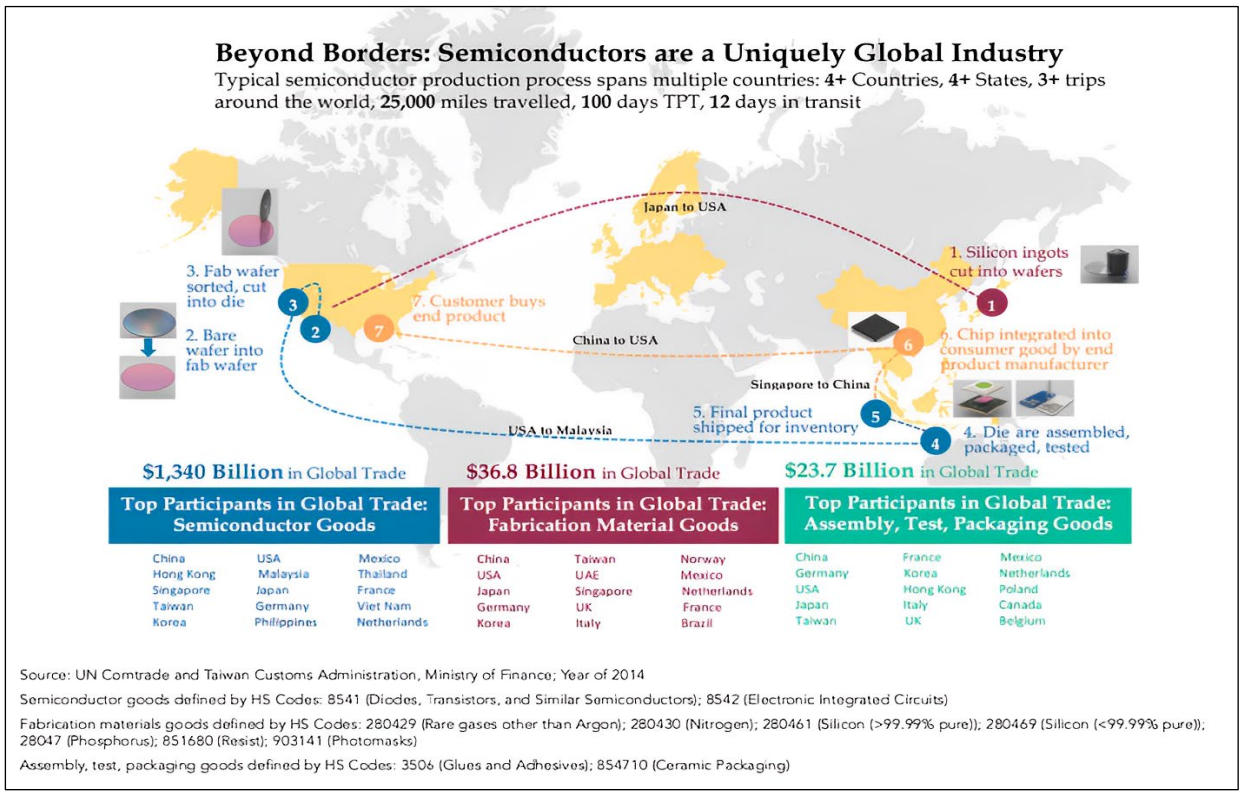
DAO = discrete, analog, and others; EDA = electronic design automation; IP = intellectual property.
* East Asia includes the Republic of Korea, Japan, and Taiwan
** Other includes China and East Asia.
*** Other includes China.
**** Other includes China and Europe.
***** Other includes the United States and Europe.
Source: SIA (2021).

Figure 3 is a simplified representation of the semiconductor GVC. It shows that the silicon wafer is cut into round wafer slices in Japan and exported to the US to be transformed from bare wafer to fab-wafer. It is then cut into 'die'. The die is assembled, tested, and packaged in Malaysia, then shipped to Singapore for inventory. Finally, end product manufacturers in China

[7] Two types of business models exist in the industry: (i) the fabless-foundry model, and (ii) the integrated device manufacturer (IDM) model. Under the fabless-foundry model, production is highly vertically specialised and design companies focus on designing parts and contract out the manufacturing process (fabrication) to other companies. The design companies are called fabless, whereas contract manufacturing companies are called 'foundry'. The third group of companies perform assembly, testing, and packaging and are known as outsourced semiconductor assembly and test companies (Ciani and Nardo, 2022). Fabless companies include AMD, Broadcom, MediaTek, UNISOC and Qualcomm. Foundries include GlobalFoundries, HHGrace, SMIC, TowerJazz, Taiwan Semiconductor Manufacturing Company, and UMC. However, in the case of the IDM model, the company performs all the processes – from design to packaging of semiconductors. IDM model companies include Infineon Technologies, Intel, Micron, Renesas, Samsung, and Texas Instruments.

integrate the chips into consumer goods. The final product is exported to the US for end use. GVC business is considered to have a disproportionate distribution of gain from the value chain process amongst developing and developed countries. As high value creation (e.g. R&D and design) requires significant investment and high-level skill sets, developed countries dominate these stages of production. Since the manufacturing process requires a larger labour force with lower level skills than the earlier stage, this production process is done in developing and emerging markets. This clearly shows a more significant gain from trade via the GVC for developed countries compared with developing and emerging countries.

Figure 3: Global Value Chain of Semiconductors



Source: SIA (2016).

Semiconductors are the fourth most traded product globally, with more than 120 countries involved in their export and import. To understand the level of trade participation of countries in the semiconductor trade supply chain, we took the exports of semiconductor items (Harmonized System (HS) 8541 and HS 8542) by countries and ranked the share of the top countries and ASEAN in terms of global exports (Tables 1 and 2). China, Hong Kong, Singapore, and Japan largely export key high-tech products such as diodes, transistors, and similar semiconductor devices (HS 8541), with China and Hong Kong supplying more than 45% of total global exports in 2021 (Table 1). ASEAN economies like Singapore and Malaysia are in the top 10 exporters,

with Viet Nam, Thailand, and the Philippines contributing more than 1% of global exports. The dominance of Japan and the US has been overtaken by Asian economies like Hong Kong and China, with China's exports increasing from 5.5% in 2002 to 33.0% in 2021.

Table 2 shows that Hong Kong, Taiwan, and China dominate exports of electronic integrated circuits and their parts, accounting for more than 50% of global exports in 2021. ASEAN such as Singapore, Malaysia, Viet Nam, and the Philippines made up around 20% of world exports in the same year. The export market share of the US and Japan has declined from 18% and 11% in 2002 to 5% and 7% in 2021, respectively, due to the emergence of China and Hong Kong. Singapore, Malaysia, and the Philippines have seen a declining trend in their share of world exports, while Viet Nam's exports have improved. Overall, some ASEAN Member States play a significant role in world exports, but their participation has been declining due to the emergence of China and Hong Kong.

Table 1: Trends in Semiconductor Exports (Product HS 8541)

2001			2019			2021		
Rank	**Country**	**Share** (%)	**Rank**	**Country**	**Share** (%)	**Rank**	**Country**	**Share** (%)
1	Japan	19.75	1	China	30.23	1	China	33.50
2	United States	12.53	2	Hong Kong	12.00	2	Hong Kong	12.30
3	**Singapore**	**10.93**	**3**	**Malaysia**	**7.63**	**3**	**Singapore**	**7.70**
4	Hong Kong	7.86	4	Japan	7.53	4	Japan	7.00
5	**Malaysia**	**7.49**	**5**	**Singapore**	**6.43**	**5**	**Malaysia**	**5.60**
6	China	5.71	6	Germany	5.89	6	Germany	5.50
7	Germany	5.47	7	United States	5.86	7	United States	5.10
8	Taiwan	4.76	8	Rep. of Korea	4.58	8	Taiwan	4.40
9	**Thailand**	**4.52**	9	Taiwan	4.11	9	Rep. of Korea	3.50
10	**Philippines**	**3.41**	**10**	**Viet Nam**	**3.20**	10	Netherlands	2.50
22	**Indonesia**	**0.43**	**12**	**Thailand**	**1.67**	**11**	**Viet Nam**	**2.40**
73	**Viet Nam**	**0.00**	**13**	**Philippines**	**1.29**	**12**	**Thailand**	**1.81**
120	**Cambodia**	**0.00**	**28**	**Indonesia**	**0.14**	**13**	**Philippines**	**1.20**
156	**Brunei**	**0.00**	**46**	**Cambodia**	**0.02**	**25**	**Cambodia**	**0.21**
176	**Myanmar**	**0.00**	**81**	**Myanmar**	**0.00**	**30**	**Indonesia**	**0.12**
178	**Lao PDR**	**0.00**	**172**	**Brunei**	**0.00**	**66**	**Myanmar**	**0.00**
			178	**Lao PDR**		**85**	**Lao PDR**	**0.00**
						174	**Brunei**	**0.00**

Note: Product HS 8541 – Diodes, transistors, and similar semiconductor devices; photosensitive semiconductor devices.
Sources: International Trade Centre (2022).

Table 2: Trends in Semiconductor Exports (Product 8542)

2002			2019			2021		
Rank	**Country**	**Share** (%)	**Rank**	**Country**	**Share** (%)	**Rank**	**Country**	**Share** (%)
1	United States	18.68	1	Hong Kong	19.16	1	Hong Kong	20.50
2	**Singapore**	12.44	2	China	14.54	2	Taiwan	15.21
3	Japan	11.10	3	Taiwan	14.30	3	China	15.12
4	Taiwan	7.40	4	Rep. of Korea	11.26	4	**Singapore**	10.91
5	**Malaysia**	7.30	5	**Singapore**	10.95	5	Rep. of Korea	10.60
6	**Philippines**	6.75	6	**Malaysia**	6.38	6	**Malaysia**	5.81
7	Hong Kong	6.47	7	United States	5.68	7	United States	5.13
8	Rep. of Korea	6.00	8	Japan	3.96	8	**Viet Nam**	3.44
9	Germany	4.25	9	**Philippines**	2.71	9	Japan	3.30
10	United Kingdom	4.18	10	Germany	2.13	10	**Philippines**	2.31
14	**Thailand**	1.61	14	**Thailand**	1.08	14	**Thailand**	0.80
27	**Indonesia**	0.10	30	**Indonesia**	0.04	31	**Indonesia**	0.00
45	**Viet Nam**	0.00	62	**Cambodia**	0.00	58	**Cambodia**	0.00
95	**Brunei**	0.00	96	**Myanmar**	0.00	132	**Brunei**	0.00
170	**Cambodia**	0.00	150	**Lao PDR**	0.00	153	**Myanmar**	0.00
198	**Myanmar**	0.00	165	**Brunei**	0.00	207	**Lao PDR**	0.00
203	**Lao PDR**	0.00						

Note: Product HS 8542 – Electronic integrated circuits; parts thereof.
Sources: International Trade Centre (2022).

3. Data and Empirical Approach

This study compares the structure of the trade network of major semiconductor components under HS 8541 (diodes, transistors, and semiconductor devices) and HS 8542 (electronic integrated circuits). Both these categories are high value-added products, which require a high level of R&D and design activities. We also investigate the key inputs and manufacturing part of semiconductor production, i.e. the fabrication material, under HS 280429 (rare gases other than argon), HS 280430 (nitrogen), HS 280461 (silicon (>99.999%pure)) and HS 280469 (silicon (<99.999%pure)), HS 28047 (phosphorous), HS 851680 (electric heating resistors or resistors), and HS 903141 (photomask). Finally, to capture the assembly, testing, and packaging process, we use HS 3506 (glues and adhesives) and HS854710 (ceramic packaging).[8]

The main purpose of the study is to ascertain the position of ASEAN economies in world semiconductor trade. We take the top 50 countries in global semiconductor trade based on their share of global exports. We calculate the cumulative export volume of each country under the specified product code, and then sort the top 50 and include the ASEAN which are not in the top 50. For this purpose, the bilateral trade data for semiconductor products are drawn from the International Trade Centre (2022). The list of sample countries is in the Appendix.

To find the position of ASEAN Member States in the trade network, we adopt the network model proposed by Fagiolo, Reyes, and Schiavo (2010). The network is a mathematical representation of the state of a system at a given point in time in terms of nodes and linkages. In a world trade network map, the countries are represented as nodes and the trade flows are indicated as links. The export values of each product code are constructed in the network, then the network parameters (e.g. degree, eigenvector, betweenness, and closeness centrality) are calculated.

The export value of a given product in the network graph represented for countries i to j is denoted by W_{ij}.

$$Export_i(t) = \sum_{j=1}^{n-1} W_{ij} \qquad (1)$$

where $Export_i(t)$ denotes the export value of a product for country i at time t.

The trade network maps for HS 8541 are constructed from 2002 to 2020. However, because of space constraints, the results of each parameter in the trade network are shown for ASEAN and the top 10 economies in the trade map.

[8] All these classifications of HS codes are taken from SIA (2016).

A) Total degree

The degree of node *i* represents the number of other nodes connected to nodes in the network and involves both in-degree and out-degree. It is the sum of the total in-degree and out-degree. Having a high total degree implies that countries have many trading partners. To calculate the in-degree, out-degree, and total degree, the following equations can be used:

$$d_i^{in} = \sum_{j=1}^{N} a_{ij} \quad (2)$$

$$d_i^{out} = \sum_{j=1}^{N} a_{ji} \quad (3)$$

$$d_i = d_i^{in} + d_i^{out} \quad (4)$$

where *N* in Equation (2) is the sum of the nodes in the network. If country *i* imports commodities from *j*, an edge from *i* to *j* forms and $a_{ij} = 1$. Otherwise, the value will become zero.

B) Eigenvector centrality

This measures the connectivity between a country node and many other central countries. Its size depends on the centrality of its large trading partners. The greater the eigenvector centrality of country *i,* the more central the country nodes it connects, which indicates a closer trade relationship between country *i* and the central countries of the trade network.

$$EC_i = \frac{1}{\lambda} \sum_{j \epsilon N_i} w_{ij} EC_j \quad (5)$$

where λ is a constant, N_i is the set of nodes that link to node *i*, and w_{ij} indicates the total trade volume from *i* to *j*.

C) Closeness centrality

This measures the total distance from other nodes to a given node. The stronger the centrality of one node, the smaller the total distance to the node. A node is the topological centre of the network if its total distance is the smallest. In addition, a weighted distance based on total bilateral trade can be used to capture the centrality of country nodes in the trade network. In the trade network, the higher the closeness centrality of country *i*, the closer its trade connection with other countries in the trade network. The formula is as follows:

$$CL_i = \frac{N-1}{\sum_j d_{ij}} = \frac{1}{d_i} \quad (6)$$

where d_{ij} is the distance or the length of the shortest path between vertices and N represents the number of nodes in the graph.

4. Empirical Findings

In this section, we report the findings obtained from the network analysis. We divide this section into various subsections based on the production process, such as high value added, which includes higher R&D and design; manufacturing, which requires key inputs such as fabrication material; and low value-added processes such as assembly, testing, and packaging.

4.1. Findings from R&D and Design Activities

In this section, we use two semiconductor components – HS 8541 and HS 8542 – which involve a higher level of R&D and design activities. Table 3 provides a summary of the total degree network-level statistics for both products: HS 8541 and HS 8542. For HS 8541, China has the highest total degree, followed by the US and Germany. ASEAN economies such as Singapore, Thailand, and Malaysia have a notable share of world exports, but it has been declining over the years. For HS 8542, the countries with highest trade flows are the US, the Netherlands, China, Spain, the United Kingdom (UK), Italy, Czechia, and Singapore, while France experienced a decline. Despite the COVID-19 pandemic, there was no substantial reduction in trade flows except for Spain and the UK. ASEAN Member States such as Singapore, Thailand, Malaysia, the Philippines, Indonesia, and Viet Nam were active players in the international semiconductor trade, with increasing total degrees over the years. However, Brunei, Myanmar, Cambodia, and the Lao People's Democratic Republic (Lao PDR) had minimal trade participation. It can be observed that the COVID-19 pandemic has reduced the degree of trade in most countries in these products, especially HS 8541.

Table 3: Total Degree Values of Selected Economies

HS 8541 (diodes, transistors, etc.)					**HS 85428** (electronic integrated circuits; memories)				
	2002	**2010**	**2019**	**2021**		**2002**	**2010**	**2019**	**2021**
Top economies									
China	135	225	251	250	**US**	208	221	229	224
US	189	219	223	224	**Germany**	213	193	221	213
Germany	213	200	217	216	**Netherlands**	157	179	188	206
France	176	184	186	186	**China**	132	171	200	202
UK	164	182	183	177	**France**	198	186	188	188
Italy	156	167	191	180	**Spain**	124	159	172	
Spain	144	161	184	179	**UK**	192	204	200	
Netherlands	69	156	181	185	**Italy**	154	157	183	184
Singapore	130	153	158	157	**Czech Republic**	109	148	160	167
Taiwan	131	161	148	135	**Singapore**	153	155	175	178
ASEAN economies									
Singapore	130	153	158	157	**Thailand**	104	129	145	139
Malaysia	104	113	130	125	**Malaysia**	122	120	138	132
Thailand	82	102	128	128	**Philippines**	119	99	118	124
Philippines	79	82	95	92	**Indonesia**	69	72	89	83
Viet Nam	25	56	105	97	**Viet Nam**	41	59	100	101
Indonesia	62	66	75	75	**Brunei**	14	15	13	12
Myanmar	7	12	22	18	**Myanmar**	5	9	20	15
Cambodia	11	8	22	26	**Cambodia**	9	9	27	37
Brunei	9	7	10	10	**Lao PDR**	6	4	10	13

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Note: Red and blue shading indicate a decline and increase in values compared with the previous period, respectively.
Source: Authors' calculation.

Table 4 shows eigenvector centrality values for the trade network in both semiconductor devices from 2002 to 2021. In the case of HS 8541, the values indicate high trade connectivity amongst countries, with France, Germany, the US, the UK, China, Italy, Hong Kong, the Netherlands, and Spain having consistently high values, while ASEAN show varied results. Singapore leads in connectivity, followed by Malaysia, which had consistent values over the years. Thailand and Indonesia also showed increased connectivity, while Myanmar, Cambodia, Brunei, and the Lao PDR had low values, indicating less involvement in the market. Similarly, in the case of HS 8542, the US, the Netherlands, China, France, Germany, Switzerland, Spain, Italy, and Poland have relatively high values. Singapore leads in connectivity, followed by Malaysia, which had consistent values over the years, and Thailand showed increased connectivity. Myanmar, Cambodia, Brunei, and the Lao PDR had low values, indicating less involvement in the market compared with other ASEAN. The figure also shows a reduction in centrality due to the pandemic in the case of HS 8542.

Table 4: Eigen Vector Centrality of Selected Economies

HS 8541 (diodes, transistors, etc.)					**HS 8542** (electronic integrated circuits; memories)				
Country	**2002**	**2010**	**2019**	**2021**	**Country**	**2002**	**2010**	**2019**	**2021**
Top 10 countries									
France	0.96	1.00	1.00	1.00	US	0.98	0.96	1.00	0.99
Germany	1.00	1.00	0.97	0.98	Netherlands	0.98	0.97	0.98	0.95
US	0.99	1.00	0.99	0.99	China	0.95	0.96	0.98	0.99
UK	0.95	1.00	0.97	0.94	France	0.99	0.94	0.98	1.00
China	0.88	1.00	0.98	0.99	Germany	1.00	0.98	0.99	0.98
Italy	0.91	0.96	0.97	0.98	Switzerland	0.86	0.88	0.91	0.95
Hong Kong	0.93	0.98	0.95	0.95	Spain	0.89	0.91	0.93	0.91
Netherlands	0.93	0.96	0.95	0.98	Italy	0.96	0.95	1.00	0.99
Spain	0.94	0.98	0.95	0.98	Poland	0.88	0.85	0.94	0.96
Singapore	0.83	0.95	0.94	0.93	Singapore	0.94	0.93	0.96	0.97
ASEAN Member States									
Malaysia	0.82	0.91	0.89	0.89	Thailand	0.84	0.83	0.90	0.91
Thailand	0.72	0.82	0.88	0.89	Malaysia	0.84	0.90	0.88	0.86

HS 8541 (diodes, transistors, etc.)					HS 8542 (electronic integrated circuits; memories)				
Country	**2002**	**2010**	**2019**	**2021**	**Country**	**2002**	**2010**	**2019**	**2021**
Philippines	0.77	0.79	0.83	0.91	Philippines	0.84	0.87	0.87	0.88
Indonesia	0.56	0.75	0.82	0.75	Viet Nam	0.51	0.77	0.89	0.84
Viet Nam	0.54	0.73	0.83	0.86	Indonesia	0.62	0.83	0.87	0.8
Myanmar	0.18	0.29	0.41	0.36	Brunei	0.25	0.28	0.24	0.25
Cambodia	0.28	0.17	0.31	0.34	Cambodia	0.22	0.20	0.40	0.49
Brunei	0.23	0.15	0.21	0.26	Myanmar	0.13	0.20	0.35	0.31
Lao PDR	0.16	0.10	0.18	0.18	Lao PDR	0.15	0.09	0.18	0.29

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Note: Red and blue shading indicate a decline and increase in values compared with the previous period, respectively.
Source: Authors' calculation.

The closeness centrality parameter is used to interpret trade connectivity in the semiconductor market (Table 5). In the case of HS 8541, China has substantially increased its values over the years (from 0.63 to 0.81), indicating high trade interconnectedness with its partners. In the case of HS 8542, the US, Germany, the Netherlands, and China exhibit high closeness values. Amongst ASEAN Member States, only Malaysia, Thailand, the Philippines, Indonesia, and Viet Nam are active players in the semiconductor market. Most ASEAN economies are integrated into semiconductor trade, but their progress has been slow and stagnant. Further, there is a decline in the closeness parameter in the case of HS 8541 in most countries. However, amongst ASEAN economies, the reduction is found only in the case of Indonesia and Viet Nam.

Table 5: Closeness Centrality of Selected Economies

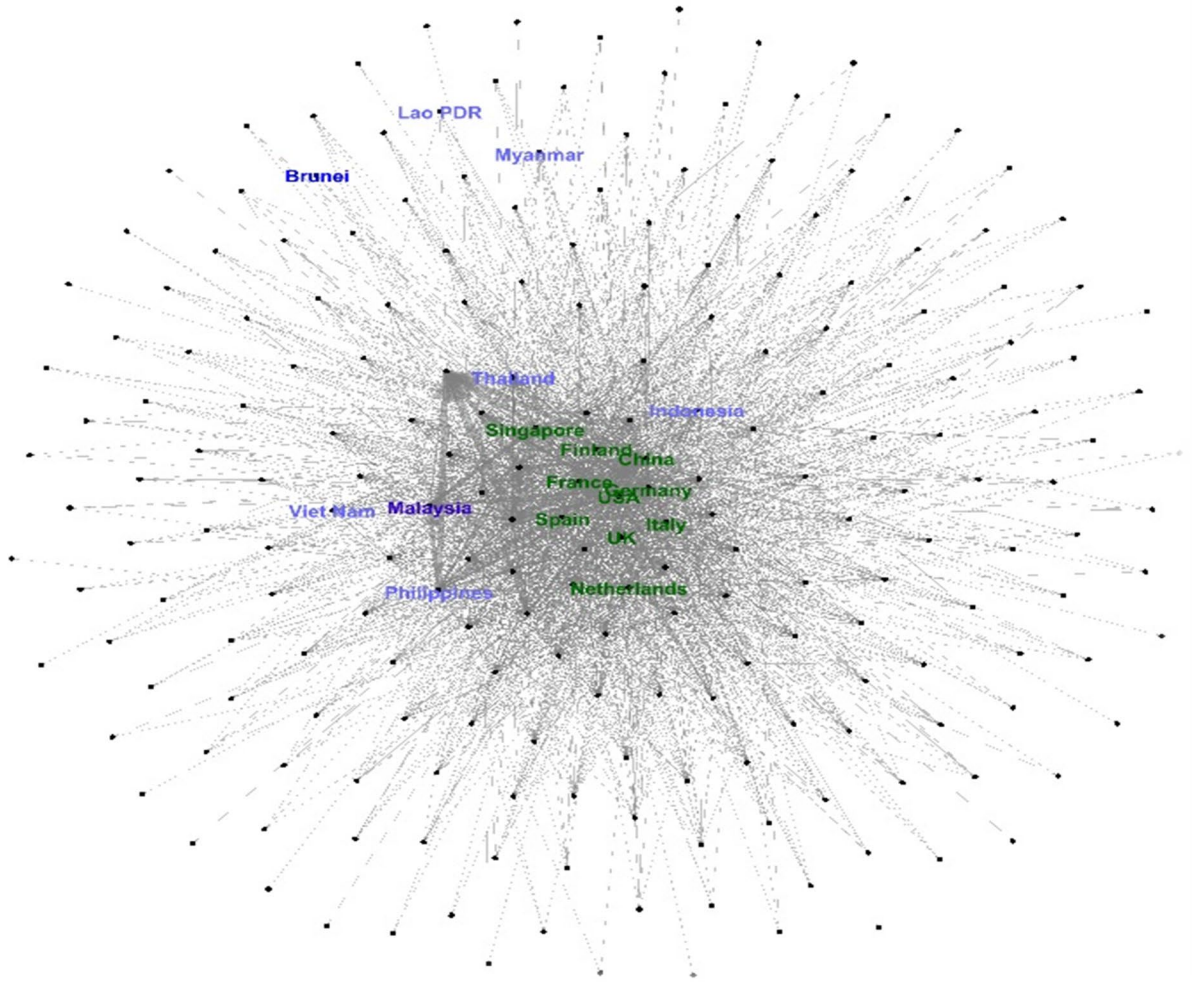
HS 8541 (diodes, transistors, etc.)					HS 8542 (electronic integrated circuits; memories)				
Country	**2002**	**2010**	**2019**	**2021**	**Country**	**2002**	**2010**	**2019**	**2021**
Top 10 countries									
China	0.65	0.84	0.92	0.90	US	0.79	0.85	0.83	0.83
US	0.76	0.82	0.82	0.79	Germany	0.80	0.76	0.81	0.80
Germany	0.83	0.77	0.81	0.80	Netherlands	0.67	0.73	0.73	0.79
France	0.73	0.73	0.72	0.71	China	0.63	0.71	0.76	0.77
UK	0.70	0.72	0.72	0.72	France	0.76	0.75	0.73	0.73
Italy	0.69	0.69	0.74	0.74	Spain	0.62	0.69	0.70	0.71
Spain	0.66	0.68	0.73	0.72	Italy	0.66	0.68	0.71	0.72
Netherlands	0.53	0.67	0.72	0.72	Czech Republic	0.60	0.67	0.67	0.69
Singapore	0.64	0.66	0.67	0.66	Singapore	0.66	0.68	0.70	0.71
Taiwan	0.64	0.68	0.66	0.65	Sweden	0.59	0.68	0.65	0.66
ASEAN Member States									
Malaysia	0.59	0.60	0.62	0.63	Thailand	0.59	0.64	0.65	0.64
Thailand	0.57	0.59	0.62	0.61	Malaysia	0.62	0.61	0.64	0.63
Philippines	0.56	0.56	0.57	0.58	Philippines	0.61	0.58	0.60	0.61
Indonesia	0.54	0.54	0.55	0.54	Indonesia	0.55	0.54	0.54	0.55
Viet Nam	0.41	0.52	0.59	0.57	Viet Nam	0.51	0.53	0.57	0.58
Brunei	0.00	0.39	0.38	0.40	Brunei	0.45	0.47	0.42	0.42
Cambodia	0.00	0.40	0.50	0.50	Cambodia	0.00	0.00	0.49	0.51
Lao PDR	0.00	0.00	0.00	0.38	Myanmar	0.00	0.00	0.43	0.39
Myanmar	0.00	0.00	0.47	0.51	Lao PDR	0.00	0.00	0.37	0.00

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Note: Red and blue shading indicate a decline and increase in values compared with the previous period, respectively.
Source: Authors' calculation.

Data visualisation of the trade network graph for the semiconductor devices (HS 8541) is provided in Figures 4–6. We analysed and constructed network maps for 2012 to 2021. However, due to space restrictions, we only present 3 years here (2005, 2019, and 2021). The last 2 years (2019 and 2021) are to analyse the impact of the pandemic on semiconductor exports, with 2019 representing the pre-pandemic period and 2021 representing the pandemic period. The connection between countries is represented in the nodes and edges format. For better visualisation, the top countries are in green and ASEAN Member States are in blue. The characteristics of the network can be interpreted as macro-level because it is characterised as a core–periphery structure.

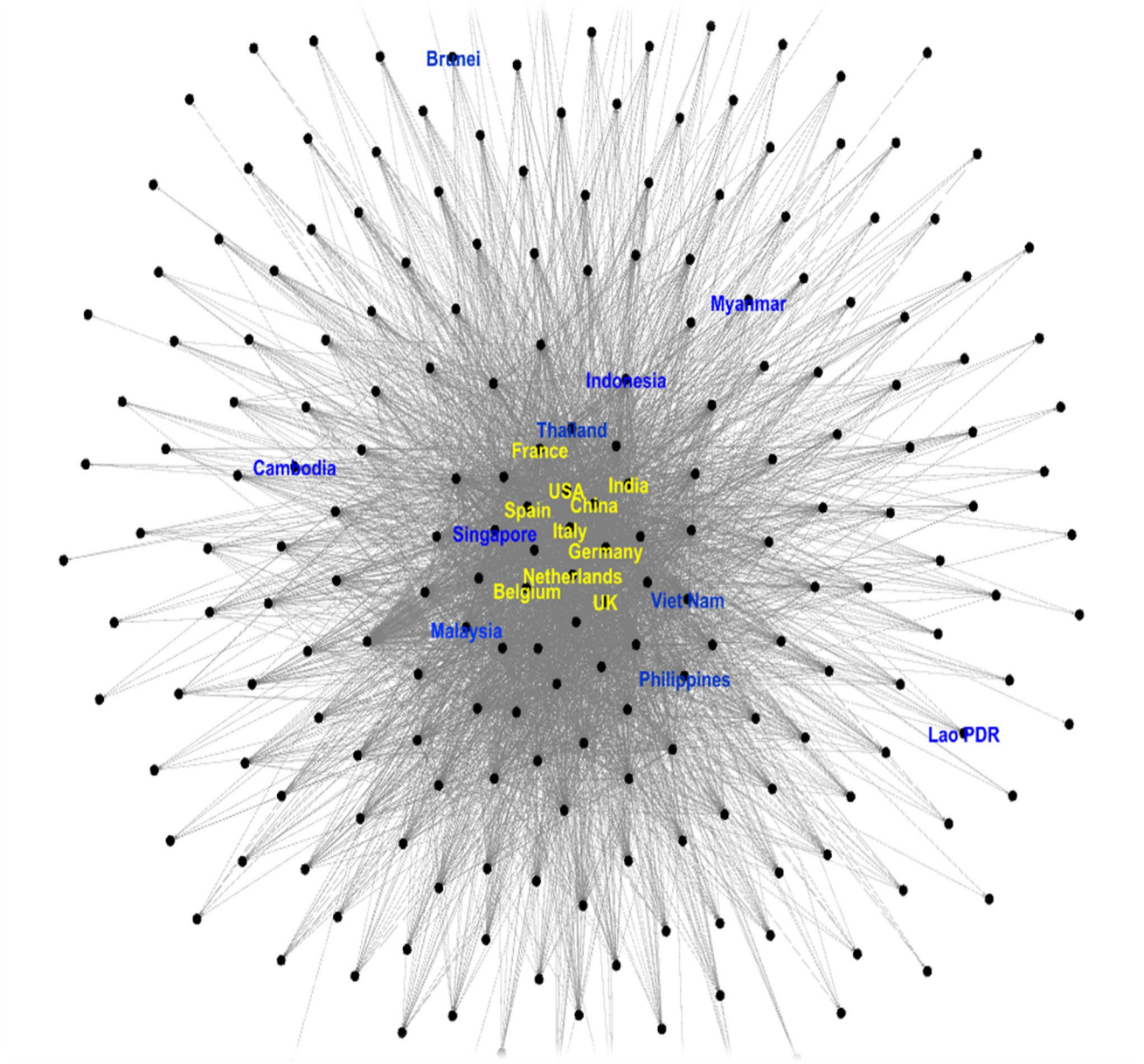
From Figure 4, it can be observed that France, the US, and Germany are the top countries as they are at the centre of the network. Finland, China, Italy, Spain, and the UK are the other countries that are presented in the central network. The Netherlands and Singapore are also concentrated in the centre. Singapore is the only ASEAN Member State that occupied the central position in the network in 2005. Thailand, Viet Nam, Malaysia, the Philippines, and Indonesia also have a significant position in the trade network. Brunei, the Lao PDR, and Myanmar occupy peripheral places in the network. Figure 5 represents the network in 2019, which shows the entry of India and Belgium to the centre, along with the US, China, France, Spain, the Netherlands, and Italy. It can also be observed that China occupies the middle position in the network. Further, the network became thicker and stronger in 2019 compared with 2005, indicating strong participation of countries in semiconductor trade. However, in 2021, after the COVID-19 crisis (Figure 6), the network became thinner and more scattered compared with the pre-COVID-19 period (2019). The central position is still occupied by Germany, the US, China, Belgium, India, Italy, Spain, the Netherlands, France, and the UK. ASEAN Member States – Singapore, Malaysia, Thailand, Viet Nam, and the Philippines – occupied the central position in the network in 2021. Brunei, the Lao PDR, Myanmar, and Cambodia are on the periphery of the network.

Figure 4: Trade Network Graph – HS 8541 Exports, 2005



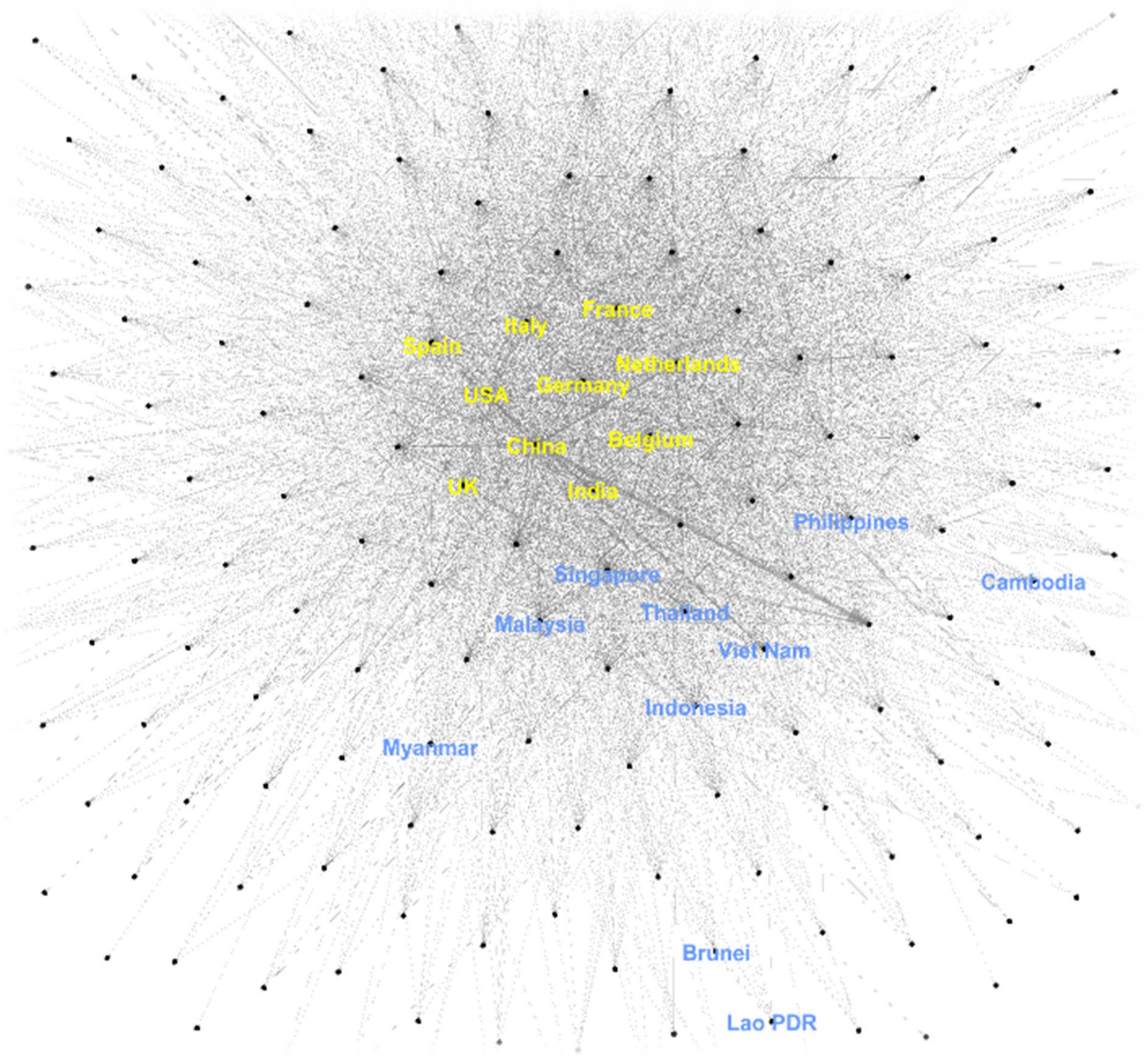
HS = Harmonized System, UK = United Kingdom, USA = United States of America.
Source: Authors' own representation using Gephi tool.

Figure 5: Trade Network Graph – HS 8541 Exports, 2019



HS = Harmonized System, UK = United Kingdom, USA = United States of America.
Source: Authors' own representation using Gephi tool.

Figure 6: Trade Network Graph – HS 8541 Exports, 2021



HS = Harmonized System, UK = United Kingdom, USA = United States of America.
Source: Authors' own representation using Gephi tool.

The pandemic has had a significant impact on international trade flows, including semiconductor trade. Several factors may have contributed to the differences in trade inflows experienced by different countries during the pandemic. Firstly, countries that had a strong domestic semiconductor industry and a diversified supply chain were better positioned to weather the disruptions caused by the pandemic. For example, countries such as Taiwan, Korea, and the US have strong semiconductor industries and supply chains, which helped them maintain their semiconductor trade during the pandemic. In contrast, countries that rely heavily

on imports of semiconductors, such as China, experienced a drop in trade inflows due to disruptions in the global supply chain caused by the pandemic.

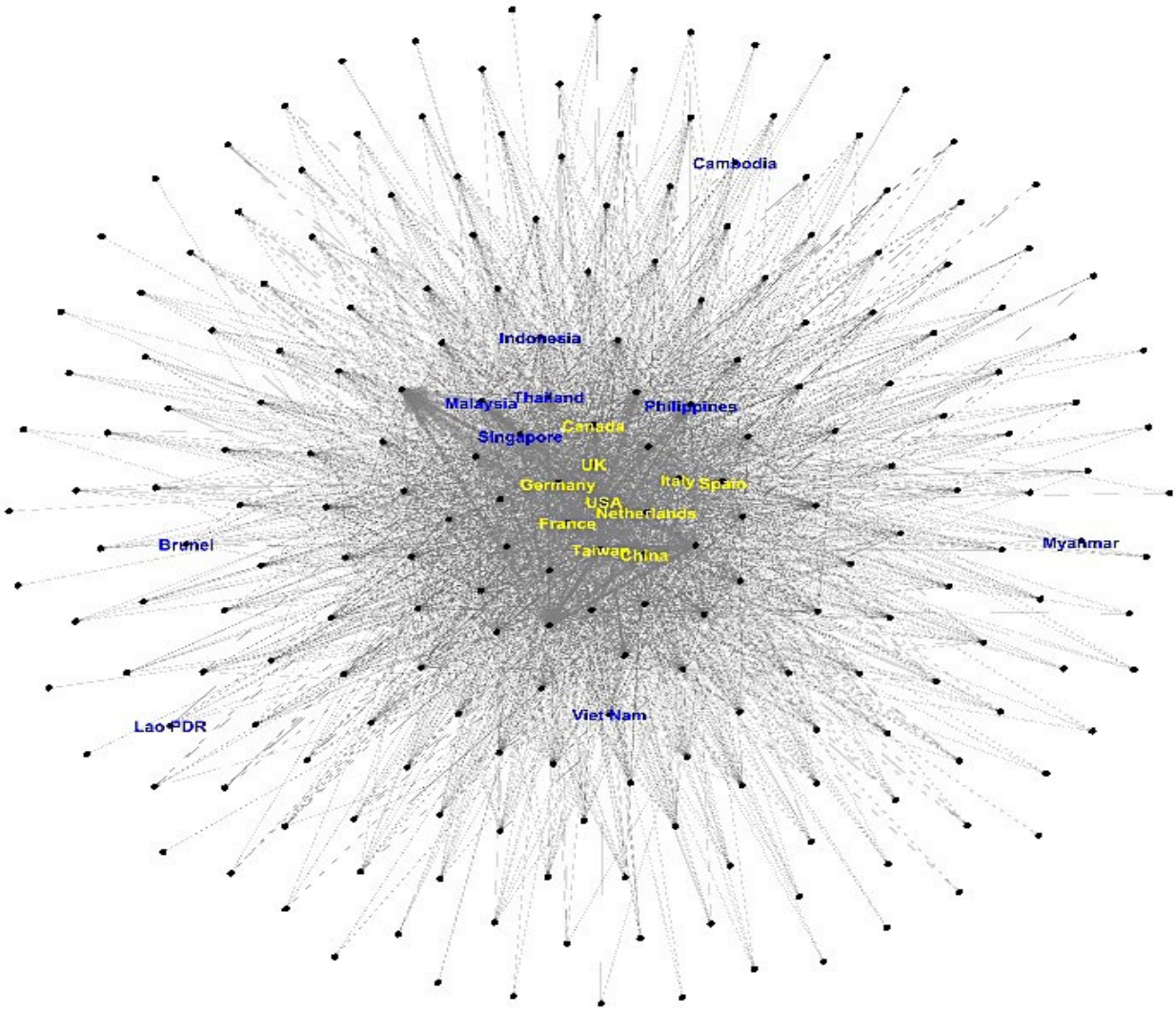
Secondly, the pandemic has resulted in changes in consumer behaviour, with increased demand for electronic devices and other digital products as people stayed at home. This has led to an increase in demand for semiconductors, and countries that were able to ramp up their production and exports of semiconductors were able to benefit from this trend. For example, Taiwan and Korea experienced a surge in semiconductor exports during the pandemic, driven by the high demand for electronic devices and home appliances.

Thirdly, the pandemic has led to changes in global trade policies and regulations, which have had a significant impact on semiconductor trade. For example, trade tensions between the US and China have resulted in restrictions on semiconductor trade between the two countries, which may have affected the trade inflows of these countries. Similarly, changes in export control regulations in some countries may have affected the flow of semiconductors to other countries, leading to a drop in trade inflows. Overall, the impact of the pandemic on semiconductor trade inflows has been complex and varied, and different countries have experienced different outcomes based on a range of factors, such as their domestic semiconductor industry, supply chain resilience, and changes in global trade policies and regulations.

Similarly, the data visualisation of the trade network graph for HS 8542 (electronic integrated circuits, parts thereof, and most advanced chips and memories) is presented in Figures 7–9**.** From Figure 7, it can be observed that in 2005, France, the US, the Netherlands, the UK, and Germany were the top countries as they were at the centre of the network. Canada, China, Italy, Spain, and Taiwan are the other countries that are presented in the central network. Singapore is the only ASEAN Member State that occupied a near-central position in the network in 2005. Thailand, Malaysia, and the Philippines also have a significant position in the trade network. However, the positions of Indonesia and Viet Nam are slightly far from the centre of the network, but they are well connected. Brunei, the Lao PDR, and Myanmar occupy peripheral places in the network. Figure 8 represents the network in 2019, which shows that Singapore moved to a more central position compared with 2005. Further, the figure shows the dominance of European counties in the middle, aligned with the US. Compared with 2005, the network became denser and more concentrated in 2019. However, Figure 9 shows that during the COVID-19 crisis (2021), the network became thinner and more scattered compared with the pre-COVID-19 period (2019). The key highlight is the position of Singapore in the network. Singapore became the centre of the network in 2021. Further, Cambodia improved its

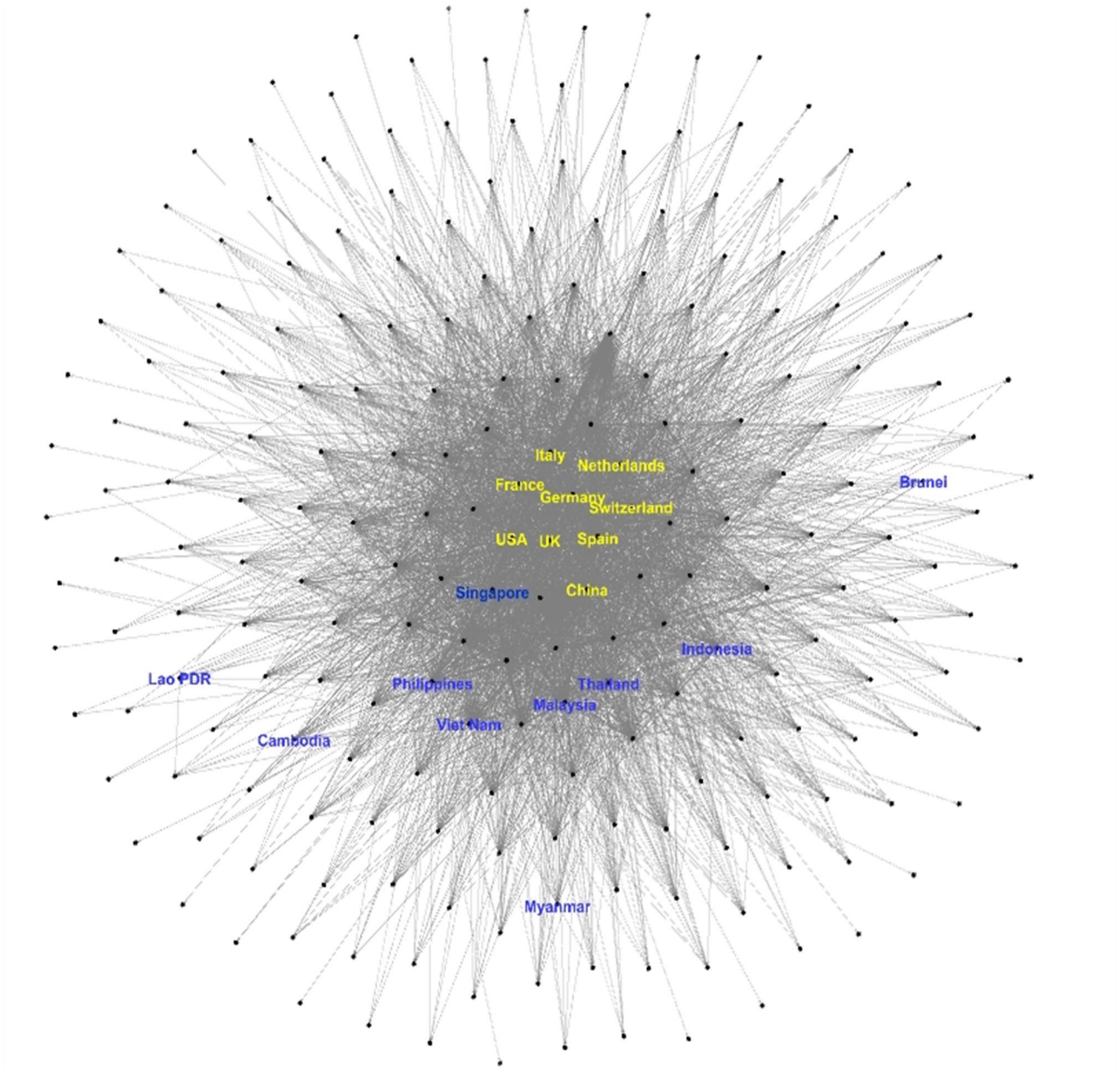
position by moving from the periphery to closer to the centre of network. However, Brunei, the Lao PDR, and Myanmar occupy peripheral places in the network.

Figure 7: Trade Network Graph – HS 8542 Exports, 2005



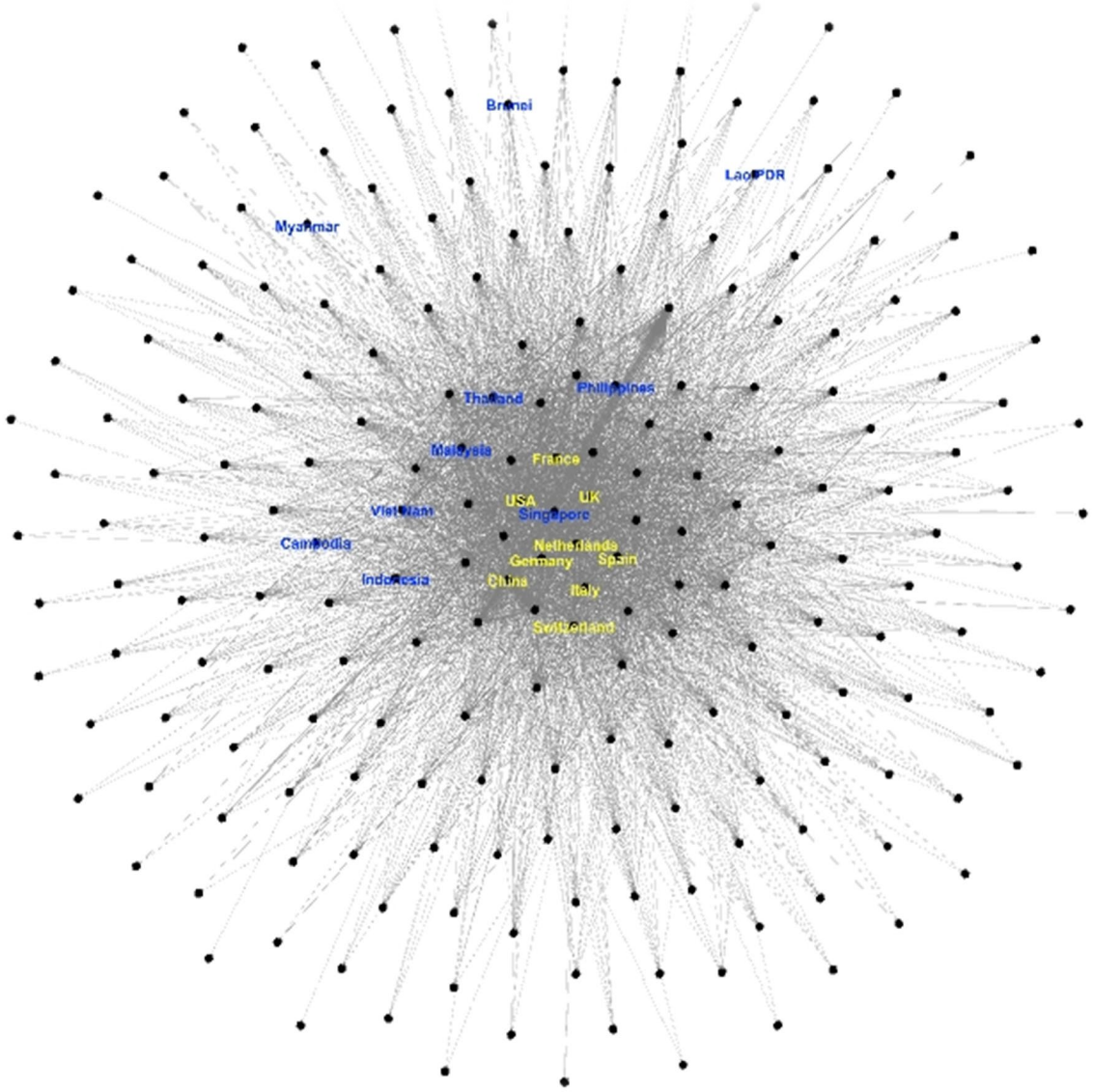
HS = Harmonized System, UK = United Kingdom, USA = United States of America.
Source: Authors' own representation using Gephi tool.

Figure 8: Trade Network Graph – HS 8542 Exports, 2019



HS = Harmonized System, UK = United Kingdom, USA = United States of America.
Source: Authors' own representation using Gephi tool.

Figure 9: Trade Network Graph – HS 8542 Exports, 2021



HS = Harmonized System, UK = United Kingdom, USA = United States of America.
Source: Authors' own representation using Gephi tool.

4.2 Manufacturing Activities

We also investigate the key inputs and manufacturing part of semiconductor production, i.e. the fabrication material, defined by HS 280429 (rare gases other than argon), HS 280430 (nitrogen), HS 280461 (silicon (>99.999%pure)) and HS 280469 (silicon (<99.999%pure)), HS 280470 (phosphorous), HS 851680 (resistors), and HS 903141 (photomask). The total degree measures for each product from 2010, 2019, and 2021 are reported in Table 6. It can be observed that, in most cases, there is a decline in the number of trade flows in 2021 compared with 2019, as there are more red cells than blue cells, indicating that the pandemic adversity affected the trade network.

Table 6: Total Degree Values of Selected Economies

HS-280429				HS-280430				HS-280461				HS-280469				HS-280470				HS-851680				HS-903141			
Country	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**
US	**109**	**110**	**109**	US	82	**110**	109	US	85	**110**	109	China	71	**92**	86	China	53	**34**	32	Germany	180	**209**	192	Germany	53	**75**	69
Germany	**101**	**93**	**91**	Germany	65	**93**	91	Germany	53	**93**	91	Netherlands	46	**55**	65	India	18	**30**	28	China	170	**207**	211	US	58	**57**	50
France	**83**	**88**	**93**	France	56	**88**	93	France	30	**88**	93	US	62	**48**	52	Germany	8	**21**	18	Italy	142	**178**	173	UK	45	**57**	52
UK	**82**	**73**	**72**	UK	73	**73**	72	UK	34	**73**	72	Germany	23	**64**	60	Japan	16	**19**	20	France	142	**162**	151	Singapore	39	**41**	47
Italy	**57**	**65**	**77**	Italy	43	**65**	77	Italy	33	**65**	77	UK	50	**57**	46	US	22	**20**	17	US	130	**168**	153	Japan	43	**48**	47
Belgium	**56**	**65**	**57**	Belgium	42	**65**	57	China	48	**76**	76	Japan	38	**33**	31	Netherlands	10	**29**	9	Turkey	117	**151**	164	China	45	**62**	60
China	**30**	**76**	**76**	China	18	**76**	76	Belgium	13	**65**	57	Italy	39	**40**	34	Viet Nam	11	**20**	19	Netherlands	107	**155**	159	Netherlands	24	**60**	52
Netherlands	**44**	**72**	**67**	Netherlands	47	**72**	67	Netherlands	18	**72**	67	Brazil	30	**31**	31	Belgium	9	**13**	12	Belgium	129	**145**	132	Rep. of Korea	34	**39**	45
Singapore	**48**	**55**	**55**	Singapore	41	**55**	55	Singapore	29	**55**	55	Spain	27	**41**	37	Poland	9	**12**	4	Austria	124	**140**	149	Italy	40	**34**	30
Russia	**11**	**70**	**77**	Russia	9	**70**	77	Russia	5	**70**	77	Norway	24	**28**	36	Kazakhstan	6	**11**	11	Spain	123	**141**	143	Malaysia	32	**40**	32
ASEAN																											
Malaysia	**13**	**28**	**29**	Malaysia	13	**28**	29	Malaysia	10	**28**	29	Malaysia	14	**30**	32	Singapore	7	**5**	2	Singapore	84	**106**	100	Thailand	18	**19**	21
Thailand	**16**	**21**	**21**	Thailand	15	**21**	21	Thailand	7	**21**	21	Singapore	29	**17**	17	Malaysia	8	**2**	4	Thailand	68	**78**	80	Philippines	10	**16**	11
Indonesia	**14**	**19**	**13**	Indonesia	12	**19**	13	Philippines	6	**19**	14	Thailand	17	**18**	22	Indonesia	4	**2**	2	Viet Nam	39	**72**	73	Viet Nam	6	**11**	12
Philippines	**7**	**19**	**14**	Philippines	4	**19**	14	Indonesia	4	**19**	13	Viet Nam	8	**6**	6	Philippines	3	**2**	2	Malaysia	55	**67**	60	Indonesia	8	**11**	5
Viet Nam	**8**	**12**	**14**	Viet Nam	8	**12**	14	Viet Nam	4	**12**	14	Philippines	11	**4**	6	Thailand	5	**1**	0	Indonesia	38	**50**	50	Cambodia	1	**4**	3
Brunei	**6**	**4**	**4**	Brunei	3	**4**	4	Brunei	0	**4**	4	Indonesia	9	**6**	6	Myanmar	1	**1**	0	Philippines	25	**39**	38	Brunei	1	**2**	0
Myanmar	**2**	**7**	**3**	Myanmar	3	**7**	3	Myanmar	1	**7**	3	Lao PDR	5	**5**	4	Lao PDR	1	**0**	0	Myanmar	5	**9**	10	Myanmar	0	**1**	2
Cambodia	**1**	**1**	**2**	Cambodia	1	**1**	2	Cambodia	1	**1**	2	Myanmar	0	**2**	1	Brunei	0	**0**	0	Brunei	8	**14**	8	Lao PDR	0	**0**	2
Lao PDR	**1**	**1**	**1**	Lao PDR	1	**1**	1	Lao PDR	0	**1**	1	Brunei	1	**1**	1					Cambodia	6	**11**	11				
												Cambodia	0	**1**	1					Lao PDR	2	**3**	5				

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Notes: HS 280429 (rare gases other than argon), HS 280430 (nitrogen), HS 280461 (silicon (>99.999%pure)), HS 280469 (silicon (<99.999%pure)), HS 280470 (phosphorous), HS 851680 (resistors), and HS 903141 (photomask). Highlighted in Red and blue shading indicate a decline and increase in the Eigen value compared with the previous period, respectively.
Source: Authors' calculation.

Analysing the situation from 2010 to 2019, the presence of ASEAN economies has improved significantly in most cases, indicating better trade connectivity within these goods. Amongst ASEAN Member States, the highest increase in degree took place in product HS 851680 (resistors) during 2010–2019. However, in the case of HS 280470 (phosphorous), the trade is very weak and decreasing. During the pandemic (2021), we can see that almost all non-ASEAN economies (except France, Italy, and Russia) reduced their trade flows for rare gases other than argon (HS 280429), nitrogen (HS 280430), and silicon (HS 280461). However, for products such as phosphorous and photomask, there is a drastic reduction in these countries. This could be due to:

(i) Supply chain disruptions – causing delays and shortages of raw materials and finished goods, which could have affected the production and export of semiconductor manufacturing products, leading to a reduction in trade flows.

(ii) Decreased demand – the pandemic caused an economic slowdown, which could have reduced the demand for semiconductor manufacturing products. With businesses and consumers cutting back on spending, there may have been less need for these products, resulting in lower trade flows.

(iii) Trade restrictions – some countries may have imposed trade restrictions or tariffs on these products, which could have reduced their export and import. This could have been in response to geopolitical tensions or efforts to protect domestic industries.

(iv) Shifts in production – some countries may have shifted their production of semiconductor manufacturing products to meet local demand or reduce their reliance on imports. This could have led to a decrease in trade flows as they produced more for domestic consumption rather than export.

We also analysed the Eigen vector centrality for the selected economies for the manufacturing activities. Products such as rare gases other than argon (HS 280429), nitrogen (HS 280430), and silicon (HS 280461) show very high connectivity over 2010–2019. Most non-ASEAN economies, such as the US, Russia, Korea, and Japan, showed a very high jump in connectivity, indicating that these countries had become highly interdependent in the network by 2019. ASEAN such as Thailand, the Philippines, Malaysia, Viet Nam, and Singapore also showed an increase in the Eigen vector centrality connectivity measure (Table 7). During the pandemic (2021), almost all non-ASEAN economies (except France and Singapore) reduced their trade connectivity substantially. In the case of products such as silicon, another important ingredient (HS 280469) saw substantial changes over the years.

Countries such as Germany, the US, France, China, the UK, Poland, and India saw a huge increase in connectivity from 2010 to 2019. Italy, the Netherlands, and Japan showed almost no change in their connections.

Considering another set of ingredients – the resistors and photomask components of the semiconductor business – we see quite a different trend. Unlike the previous products, these products (HS 851680 and HS 903141) show an increase in trade connections for the US, Germany, Korea, and Italy; and a fall in connectivity for others.

In sum, we can say that the pandemic has affected the manufacturing products of semiconductors to a large extent. Especially after 2019, we see that most of the trade connectivity networks have been affected due to the reduction in trade flows for both non-ASEAN economies and ASEAN Member States.

Table 7: Eigen Vector Centrality of Selected Economies

				HS-280430				HS-280461				HS-280469				HS-280470				HS-851680				HS-903141			
Country	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**	**Country**	**2010**	**2019**	**2021**
US	1.00	1.00	1.00	US	0.86	1.00	1.00	US	0.97	1.00	1.00	Germany	1.00	1.00	1.00	US	1.00	0.99	1.00	Germany	1.00	1.00	1.00	US	1.00	1.00	1.00
Germany	0.96	0.83	0.82	Germany	1.00	0.83	0.82	Germany	0.91	0.83	0.82	US	0.72	0.91	0.85	Germany	0.77	0.85	0.96	US	0.94	0.97	0.95	Germany	0.80	0.82	0.77
France	0.91	0.75	0.84	France	0.83	0.75	0.84	France	0.56	0.75	0.84	Netherlands	0.80	0.80	0.88	Rep. of Korea	0.84	1.00	0.88	France	0.83	0.92	0.96	China	0.79	0.85	0.82
Singapore	0.86	0.87	0.88	Singapore	0.52	0.87	0.88	Singapore	0.47	0.87	0.88	France	0.61	0.77	0.73	China	0.98	0.83	0.56	UK	0.86	0.93	0.88	Singapore	0.60	0.82	0.74
Russia	0.65	0.80	0.70	Russia	0.58	0.80	0.70	China	1.00	0.90	0.71	Italy	0.78	0.72	0.75	Italy	0.42	0.50	0.61	China	0.86	0.88	0.91	Japan	0.75	0.61	0.62
China	0.64	0.90	0.71	China	0.52	0.90	0.71	Rep. of Korea	0.57	0.73	0.79	China	0.54	0.67	0.60	Netherlands	0.62	0.84	0.27	Italy	0.86	0.89	0.86	Rep. of Korea	0.67	0.72	0.73
Rep. of Korea	0.62	0.73	0.79	Rep. of Korea	0.31	0.73	0.79	UAE	0.37	0.80	0.70	UK	0.64	0.84	0.55	Taiwan	1.00	0.86	0.62	Russia	0.81	0.83	0.85	Taiwan	0.70	0.69	0.53
Belgium	0.71	0.66	0.62	Belgium	0.80	0.66	0.62	Japan	0.84	0.70	0.79	Japan	0.58	0.58	0.62	Japan	0.47	0.77	0.41	Netherlands	0.81	0.81	0.85	Netherlands	0.52	0.68	0.68
Netherlands	0.76	0.55	0.73	Netherlands	0.83	0.55	0.73	Taiwan	0.85	0.72	0.79	India	0.52	0.69	0.65	Belgium	0.30	0.98	0.85	Poland	0.81	0.77	0.84	UK	0.56	0.74	0.62
Japan	0.51	0.70	0.79	UK	0.95	0.56	0.68	Belgium	0.58	0.66	0.62	Poland	0.62	0.59	0.67	Brazil	0.65	0.94	0.54	India	0.76	0.84	0.84	Hong Kong	0.62	0.57	0.54
ASEAN																											
Thailand	0.61	0.65	0.55	Thailand	0.38	0.65	0.55	Thailand	0.33	0.65	0.55	Singapore	0.40	0.34	0.22	Indonesia	0.61	0.23	0.27	Singapore	0.85	0.77	0.76	Malaysia	0.56	0.60	0.54
Philippines	0.43	0.70	0.55	Malaysia	0.44	0.63	0.58	Philippines	0.28	0.70	0.55	Thailand	0.29	0.32	0.43	Malaysia	0.70	0.19	0.42	Thailand	0.73	0.74	0.74	Thailand	0.43	0.49	0.49
Malaysia	0.43	0.63	0.58	Philippines	0.2	0.70	0.55	Malaysia	0.29	0.63	0.58	Malaysia	0.35	0.50	0.33	Viet Nam	0.24	0.59	0.42	Malaysia	0.68	0.75	0.73	Philippines	0.42	0.58	0.39
Viet Nam	0.44	0.56	0.48	Viet Nam	0.28	0.56	0.48	Viet Nam	0.23	0.56	0.48	Viet Nam	0.45	0.22	0.24	Singapore	0.12	0.35	0.11	Indonesia	0.51	0.69	0.66	Viet Nam	0.23	0.46	0.35
Indonesia	0.57	0.42	0.36	Indonesia	0.42	0.42	0.36	Indonesia	0.23	0.42	0.36	Indonesia	0.42	0.21	0.19	Philippines	0.45	0.23	0.27	Viet Nam	0.56	0.69	0.67	Indonesia	0.18	0.39	0.23
Myanmar	0.16	0.36	0.14	Myanmar	0.21	0.36	0.14	Myanmar	0	0.36	0.14	Philippines	0.37	0.16	0.24	Thailand	0.60	0.16	0.00	Philippines	0.62	0.67	0.67	Cambodia	0.06	0.15	0.14
Brunei	0.16	0.17	0.14	Brunei	0.11	0.17	0.14	Brunei		0.17	0.14	Myanmar	0.00	0.08	0.03	Myanmar	0.03	0.16	0.00	Myanmar	0.14	0.21	0.2	Myanmar	0.00	0.06	0.08
Cambodia	0.05	0.04	0.07	Cambodia	0.04	0.04	0.07	Cambodia	0	0.04	0.07	Cambodia	0.00	0.03	0.03	Brunei	0.00	0.00	0.00	Cambodia	0.15	0.22	0.25	Lao PDR	0.00	0.00	0.08
Lao PDR	0.05	0.04	0.04	Lao PDR	0.04	0.04	0.04	Lao PDR		0.04	0.04	Brunei	0.04	0.04	0.02	Lao PDR	0.15	0.00	0.00	Brunei	0.15	0.26	0.16	Brunei	0.00	0.12	0.00
												Lao PDR	0.03	0.03	0.03					Lao PDR	0.05	0.07	0.11				

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Notes: HS 280429 (rare gases other than argon), HS 280430 (nitrogen), HS 280461 (silicon (>99.999%pure)), HS 280469 (silicon (<99.999%pure)), HS 280470 (phosphorous), HS 851680 (resistors) and HS 903141 (photomask).
Highlighted in Red and blue shading indicate a decline and increase in the Eigen value compared with the previous period, respectively.
Source: Authors' calculation.

4.3. Assembly, Testing, and Packaging Activities

We also look at the last activities of semiconductor products, such as assembly, testing, and packaging. These activities are very difficult to capture as they are not well defined in the context of the semiconductor industry. However, these activities can be proxied through the various ingredients used in the process. Following SIA (2016), we choose HS 3506 (glue and adhesives) and HS 854710 (ceramic packaging) to analyse the process. The total degree measures for each product from 2010, 2019, and 2021 are reported in Table 8. It can be observed that in most cases, there is a decline in trade flows in 2021 compared with 2019, in the case of HS 3506 (glue and adhesives) as compared with HS 854710 (ceramic packaging). Further, the degree has increased substantially in glues and adhesives in the case of ASEAN economies over the years, indicating active trade in these goods.

We also analysed the Eigen vector centrality for the selected economies for the assembly and testing and packaging activities (Table 9). It can be observed that in the context of HS 3506 (glues and adhesives), many ASEAN economies are found to have a higher centrality value, e.g. in the case of Malaysia, Viet Nam, and Singapore in 2021. Over the years, there has been a significant improvement in the connectivity of trade in this product category in ASEAN economies. As assembly, testing, and packaging are less technically intensive than other production stages for semiconductors, the high Eigen values also indicate more involvement of ASEAN economies in low value-creation activities.

Table 8: Total Degree Values of Selected Economies

HS 3506				**HS 854710**			
	2010	**2019**	**2021**		**2010**	**2019**	**2021**
Country	**Total degree**			**Country**	**Total degree**		
China	197	211	204	China	104	128	124
Germany	178	180	176	Germany	73	86	82
US	161	172	173	US	56	70	75
Italy	160	174	170	Italy	54	64	66
Netherlands	142	172	164	UK	72	49	45
France	148	161	153	France	38	45	47
UK	151	156	149	Spain	31	29	33
Spain	128	145	147	Netherlands	27	34	26
ASEAN							

HS 3506				HS 854710			
	2010	2019	2021		2010	2019	2021
Country	Total degree			Country	Total degree		
Singapore	94	106	108	Singapore	24	29	31
Malaysia	109	121	102	Viet Nam	14	21	30
Thailand	95	110	91	Malaysia	17	15	17
Indonesia	77	99	73	Thailand	10	16	17
Viet Nam	49	60	69	Indonesia	5	5	8
Philippines	32	50	55	Philippines	3	6	7
Cambodia	10	22	24	Myanmar	1	4	4
Brunei	10	11	12	Lao PDR	1	1	2
Myanmar	8	16	10	Cambodia	1	2	1
Lao PDR	7	5	6	Brunei	2	1	0

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Notes: HS 3506 (glues and adhesives) and HS 854710 (ceramic packaging). Highlighted in Red and blue shading indicate a decline and increase in values compared with the previous period, respectively.
Source: Authors' calculation.

Table 9: Eigen Vector Centrality of Selected Economies

HS 3506						HS 854710					
2010		2019		2021		2010		2019		2021	
Hong Kong	1.000	China	1.000	China	1.000	Germany	1.000	Japan	1.000	US	1.000
Rep. of Korea	0.980	India	0.981	Malaysia	0.995	China	0.883	Germany	0.952	Germany	0.919
Japan	0.980	Taiwan	0.928	India	0.964	Czech Republic	0.880	Rep. of Korea	0.929	Japan	0.916
India	0.970	New Zealand	0.928	Viet Nam	0.937	Poland	0.880	US	0.899	India	0.856
Malaysia	0.970	US	0.928	Australia	0.937	Netherlands	0.862	Czech Republic	0.850	Singapore	0.847
Singapore	0.970	France	0.928	Hong Kong	0.937	India	0.790	Switzerland	0.842	France	0.836
China	0.958	Myanmar	0.928	Japan	0.937	Belgium	0.789	Netherlands	0.833	Poland	0.835
Taiwan	0.953	Australia	0.928	Rep. of Korea	0.937	Finland	0.789	Australia	0.789	Italy	0.830
Thailand	0.924	Hong Kong	0.928	New Zealand	0.937	UK	0.789	Finland	0.789	Malaysia	0.784
Indonesia	0.924	Japan	0.928	US	0.937	Japan	0.788	Turkey	0.789	Australia	0.776
Viet Nam	0.924	Rep. of Korea	0.928	Taiwan	0.937	Singapore	0.780	Singapore	0.764	Thailand	0.760
Philippines	0.924	Viet Nam	0.910	Singapore	0.863	Malaysia	0.724	Malaysia	0.631	Viet Nam	0.694
Cambodia	0.672	Singapore	0.906	Indonesia	0.863	Indonesia	0.568	Thailand	0.560	Indonesia	0.599
Myanmar	0.602	Malaysia	0.862	Tailand	0.863	Thailand	0.470	Philippines	0.499	Philippines	0.588
Brunei	0.602	Indonesia	0.862	Philippines	0.863	Viet Nam	0.362	Viet Nam	0.420	Myanmar	0.398
Lao PDR	0.446	Thailand	0.862	Bruei	0.789	Philippines	0.362	Indonesia	0.378	Lao PDR	0.180
		Philippines	0.862	Combodia	0.739	Myanmar	0.120	Myanmar	0.329	Cambodia	0.090
		Cambodia	0.672	Myanmar	0.671	Brunei	0.106	Cambodia	0.163		
		Bruei	0.614	Lao PDR	0.376	Lao PDR	0.064	Brunei	0.079		
		Lao PDR	0.350								

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, UK = United Kingdom, US = United States.
Notes: HS 3506 (glues and adhesives) and HS 854710 (ceramic packaging). Highlighted in Red and blue shading indicate a decline and increase in values compared with the previous period, respectively.
Source: Authors' calculation.

4.4. ASEAN in the Semiconductor Production Process: A Snapshot

Table 10 presents data on the total degree of trade connections in the three production stages of the semiconductor industry amongst ASEAN Member States. From the table, it is evident that the total degree of trade connections has increased in the high value-added process amongst ASEAN during 2010–2021. This trend can be observed in economies such as Singapore, Malaysia, Thailand, the Philippines, Viet Nam, and Indonesia.

Moreover, there has been a significant increase in the trade degree in the assembly and testing as well as packaging stages amongst these economies. However, the number of trade connections in the manufacturing process is relatively low compared with the other two production stages. Only Singapore shows a reasonable number of trade connections (51) in the manufacturing process in 2021. On the other hand, the trade connections in other ASEAN Member States, such as Cambodia, Myanmar, Brunei, and the Lao PDR, are low across all the production stages.

Table 10: Total Degree in Semiconductor Production Process of ASEAN – A Snapshot

High Value Added			Manufacturing			Assembly, Testing, and Packaging		
Country	**2010**	**2021**	**Country**	**2010**	**2021**	**Country**	**2010**	**2021**
Singapore	154	166	Singapore	40	51	Singapore	59	70
Malaysia	117	132	Thailand	21	33	Thailand	53	49
Thailand	116	130	Malaysia	21	30	Viet Nam	32	47
Philippines	91	114	Viet Nam	12	25	Indonesia	41	41
Viet Nam	58	98	Indonesia	13	16	Malaysia	63	59
Indonesia	69	78	Philippines	9	16	Philippines	18	23
Cambodia	9	31	Myanmar	2	4	Cambodia	5	8
Myanmar	11	22	Cambodia	2	4	Myanmar	5	7
Brunei	11	12	Brunei	3	3	Brunei	6	6
Lao PDR	4	11	Lao PDR	1	2	Lao PDR	4	4

Note: Highlighted in Blue shading indicates an increase in values compared with the previous period.
Source: Authors' calculation.

5. Conclusions

This study highlighted the significance of the semiconductor industry in the global economy and its evolution in recent years, as well as the impact of the COVID-19 pandemic on trade in semiconductor products. It is evident that developed markets, such as the US, Japan, and European countries, have traditionally dominated the industry network, but China has emerged as a core player in recent years. Our findings suggest that the COVID-19 pandemic adversely affected the overall trade network of the semiconductor industry. The number of trade connections amongst countries has decreased due to the pandemic. The trade network became thinner and scattered in 2021 compared with the pre-COVID-19 period (2019). However, the key central players' positions have not changed in the network. Amongst ASEAN Member States, Singapore has emerged as the central economy in the trade network in recent years. Similarly, Viet Nam, Malaysia, Thailand, the Philippines, and Indonesia have been well integrated with the trade network in recent years, including high-value production processes.

Amongst the ASEAN economies, trade participation in the various production processes also varies. The study found a noticeable increase in the total degree of trade connections in high value-added processes amongst Singapore, Malaysia, Thailand, the Philippines, Viet Nam, and Indonesia. The assembly, testing, and packaging stages also saw a significant increase in trade connections amongst these countries. However, the manufacturing process has lower trade connections compared with the other two stages. Singapore is the only country that showed a reasonable number of trade connections in the manufacturing process. Additionally, the trade connections in Cambodia, Myanmar, Brunei, and the Lao PDR are relatively low across all the production stages.

Overall, the semiconductor industry in ASEAN has potential for further growth, particularly in the high value-added and assembly/testing/packaging stages. Policymakers need to focus on increasing trade connections and promoting the semiconductor industry's growth and integration into the global network, especially in countries with low trade connections. The COVID-19 pandemic has significantly impacted the semiconductor industry, highlighting the need for policymakers to focus on creating robust supply chains and promoting trade resilience.

Policymakers should invest in infrastructure, R&D, and human capital; reduce supply chain disruptions and trade restrictions; promote industry diversification; and prioritise environmental sustainability. By doing so, ASEAN Member States can enhance their participation in the

semiconductor industry and create a more vibrant and sustainable semiconductor industry in the region. While the study's limitations include the focus on gross trade data and a macro view, addressing these issues in future research could lead to country-specific policy solutions.

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Appendix

Sample Countries Used in the Network Analysis

Sample Countries – HS 8541		Sample Countries – HS 8542	
Australia	China	Germany	Indonesia
Finland	India	Greece	Ireland
Israel	Japan	Hungary	Italy
Japan	Latvia	Indonesia	Rep. of Korea
Luxembourg	Malta	Ireland	Lao PDR
Malaysia	Romania	Israel	Lithuania
Netherlands	Sweden	Italy	Mexico
Romania	Switzerland	Rep. of Korea	Morocco
Turkey	Thailand	Lao PDR	Myanmar
UK	US	Malaysia	New Zealand
Africa	Viet Nam	Mexico	Philippines
Austria	Australia	Morocco	Poland
Belgium	Austria	Myanmar	Portugal
Brazil	Belarus	Netherlands	Russian Federation
Brunei	Belgium	Norway	Serbia
Cambodia	Brazil	Philippines	Singapore
Canada	Brunei	Poland	Slovakia
China	Bulgaria	Portugal	Slovenia
Croatia	Cambodia	Russian Federation	Spain
Czech Republic	Canada	Serbia	Sweden
Denmark	Costa Rica	Singapore	Switzerland
France	Czech Republic	Slovakia	Taiwan
Germany	Denmark	Spain	Thailand
Greece	Estonia	Taiwan	UAE
Hungary	Finland	Tunisia	US
India	France	UAE	Viet Nam
		UK	

HS = Harmonized System, UAE = United Arab Emirates, UK = United Kingdom, US = United States.
Source: Authors.

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