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# Dynamics of Trade Characteristics, Competition Networks, and Trade Fragility in ASEAN Economies

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**Abstract**: *This paper analyses the trade characteristics, competition networks, and fragility of global trade in goods in the Association of Southeast Asian Nations (ASEAN) economies, particularly in the context of the coronavirus disease (COVID-19). The study covers the 10 ASEAN Member States and 110 trade partners, using the Harmonized System (HS) 6-digit product classification from 2010 to 2021. The findings reveal that ASEAN dominates with trade complementarity. Dense and intense competition networks are found. The electrical and machinery imports from central players are highly sensitive to shocks, with electronics also becoming susceptible to shocks after the pandemic. The study also shows that liquefied natural gas products and countries such as Singapore, Indonesia, Brunei, and Myanmar experienced increased shocks. The research underscores the importance of policymakers prioritising their understanding of trade linkages and potential spillover effects when formulating policies to mitigate the impact of shocks. The findings have implications for policymakers, highlighting the need for them to take a holistic approach when devising policies and strategies to mitigate the adverse effects of global shocks.*

**Keywords:** Export similarity, trade complementarity, competition trade networks, trade fragility, ASEAN

**JEL Classification**: F14, F15, L14

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# 1. Introduction

This research paper investigates the trade characteristics, competition networks, and fragility of global trade in goods in the Association of Southeast Asian Nations (ASEAN) economies, particularly in the context of the coronavirus disease (COVID-19) pandemic's unprecedented impact on the global economy. One of the most significant impacts of the pandemic has been the reduction in international trade due to supply chain disruptions. As economies are heavily interdependent through global value chains, the resulting fragmentation caused by the pandemic has deepened trade relations amongst nations.

Trade and development depend on competitiveness and complementarity amongst countries. Trade liberalisation can lead to trade competition if two countries' exporting structures are similar, limiting their potential for inter-country trade. However, if the product similarity increases over time, the export structures of the two countries or regions converge, making them more competitive in the third market (Finger and Kreinin, 1979; Pearson, 1994). Conversely, when the exporting structure of one country is similar to the importing structure of another, strong complementarity exists between them, providing better opportunities for trade cooperation (Liu, Xu, and Zhang, 2020). The ASEAN economies, in particular, depend heavily on China, their largest external trade partner, and are well integrated into global supply chains (ASEAN, 2022). The COVID-19 outbreak in China and subsequent lockdown measures disrupted connectivity between ASEAN Member States (AMS) and their trading partners. As a result, these economies have been exposed to risks of supply chain disruptions, which have adversely affected their productivity and economic recovery from the COVID-19 induced recession. In the aftermath of the crisis, policymakers have become increasingly concerned about countries' vulnerability to external sector shocks and their ability to build resilience against future supply chain disruptions (Golan, Jernegan, and Linkov, 2020).

ASEAN has emerged as a leading bloc promoting trade liberalisation and regionalism, with all 10 ASEAN increasing their trade in goods over the years. In 2020, the region's total exports were valued at $1,356.89 billion, while imports were valued at $1,234.34 billion. ASEAN economies are integrated with the international market and serve as the main manufacturing hub for electronics, machinery, automobile parts, and components. However, recent trade tensions and rising production costs in China have led multinational companies to shift their operations to some ASEAN, creating Asian supply chains that exclude China. Although Japan, China, and the Republic of Korea (henceforth, Korea) dominate Asian supply chains, Viet Nam's emergence in the supply chain creates opportunities for other

AMS. However, these economies remain vulnerable to trade shocks due to their reliance on China and supply chain disruptions.

This paper emphasises the importance of ASEAN economies strengthening their resilience to external shocks, which can be achieved by diversifying their trade partners, analysing the fragility of specific product groups, and identifying competition patterns in trade networks. The study will provide a reference for quantifying the fragility of trade in goods in ASEAN. Moreover, in the policy domain, mitigating the risks of fragility and strengthening resilience may help in the long run.

Furthermore, understanding competition patterns in trade networks can provide valuable insights into the dynamics of trade and how they may impact the fragility of global trade in goods. By identifying potential competition clusters, policymakers can develop appropriate strategies to enhance their competitiveness and reduce their vulnerability to external shocks.

Second-generation[2] trade models theoretically support trade interconnectedness and competition patterns through networks, i.e. the new trade theory, which assumes the existence of product differentiation, increasing returns to scale, and imperfect competition (Krugman, 1980; Helpman and Krugman, 1985). Due to the complexity and interdependence of trade, the trade competition patterns call for complex network analysis (Liu, Xu, and Zhang, 2020). As consumers' demand for variety increases, it impacts market size and trade openness, fostering product variety and intra-industry trade. The premise of the assumption that industry consists of homogenous producers was reconsidered in Bernard and Jensen (1995) and Bernard et al. (2003). Meanwhile, Melitz (2003) discussed the role of trade in intermediates in determining trade patterns. He showed that trade in intermediates can reallocate resources amongst firms, with the most productive firms expanding their exports and the least productive firms exiting the market. This reallocation of resources leads to increased productivity and economic growth. Many studies have examined the competitiveness and complementarity of trade patterns in sector-specific cases such as global wheat trade (Dong et al., 2018); global oil trade networks (Zhang, Ji, and Fan, 2014); liquefied natural gas (Chen et al., 2016); iron ore (Hao et al., 2018); and agri-trade (Liu, Xu, and Zhang, 2020).

[2] First-generation trade models emphasised the basic assumptions of the neo-classical trade theory of comparative advantage. However, the neo-classical trade theory failed to explain the nature of trade patterns amongst countries, product varieties, locations, and industrial clusters. The answer is found in the second-generation models, i.e. new trade theory.

Most of the above studies are on sector-specific cases and do not cover a region to reveal its trade dynamics. Moreover, they do not cover the COVID-19 period. Nguyen, Pham, and Vallée (2017) investigated export similarity amongst ASEAN+3 countries using similarity index analysis from 1990 to 2014. The study was confined to intra-regional trade patterns and did not cover potential partners from extra-regional trade. As ASEAN's extra-regional trade is far ahead of intra-regional trade, there is scope for further research. Identifying such characteristics would help policymakers understand the pattern of multilateral trade relationships. Until recently, studies on trade network analysis based on the competitiveness and complementarity of goods have been scarce. In particular, product-wise spatial distribution based on competitiveness and complementarity has not been researched (Liu, Xu, and Zhang, 2020). Studies on the fragility of the trade network are also relatively scarce in the literature. However, the pioneering work of Korniyenko, Pinat, and Dew (2017) analysed supply shock risks in the highly interconnected global system. Their study used highly disaggregated international trade data to assess the spillover effects of supply shocks from the import of goods.

In this context, this paper discusses the following questions: (i) Does competitiveness or complementarity dominate trade in goods amongst ASEAN and its partners? (ii) Has the pattern of trade in goods changed, in terms of competitiveness and complementarity? (iii) Which inter-regional and intra-regional country pairs are the most competitive? (iv) Have competition patterns in the networks changed since COVID-19? (v) Which products are considered risky, and how sensitive are the import baskets in the trade networks in ASEAN? and (vi) Is there a role for central players in spreading the riskiness and vulnerability of trade in goods networks?

To complement the existing literature, this paper empirically analyses the changes in trade characteristics and trade competition patterns in terms of trade networks in ASEAN. The study explores intra-regional and inter-regional trade patterns in the region. It also attempts to measure the fragility of trade networks.

The approach of the study delves into the trade dynamics between ASEAN member states and their 110 global partners, focusing on the competitiveness and complementarity of manufactured goods. We employ the Export Similarity Index (ESI) and the Trade Complementarity Index (TCI) at the Harmonized System 6-digit level, covering the years 2010 to 2021, to gauge intra-regional and inter-regional trade patterns. Further enriching our analysis, we construct trade network models to identify competition network patterns, highlighting product-wise leading country pairs on intra and inter-regional scales. This framework illuminates the central players, the depth of connectivity, the extent of interconnectedness, and trade density within and beyond the region. Finally, the study delves into the fragility of these trade networks, employing metrics like central players and the clustering coefficient to measure product-wise vulnerabilities.

The study highlights the dominance of trade complementarity in the ASEAN region, particularly for products such as bituminous minerals, natural gas, and electrical items, leading to increased competitiveness and efficiency. Trade networks in goods are dense and complex, varying across different product categories. Electrical products, especially those related to telecommunications, are vulnerable, particularly since the pandemic, emphasising the importance of effective risk management strategies for supply chain resilience. The study also identified potential spillover risks amongst active trade partners, with products like bituminous minerals, liquefied natural gas, and telephones for cellular networks having high clustering coefficients, indicating a higher likelihood of spillover risks.

The major contributions of the study are the following: This study examines the trade dynamics in the ASEAN region by uniquely encompassing the impacts of the COVID-19 era. Unlike much of the current literature, which often zeroes in on sector-specific scenarios, this study broadens its scope to encapsulate intra- and inter-regional ASEAN trade patterns. It bridges critical gaps in existing studies and analyses the product-wise spatial distribution based on competitiveness and complementarity and the fragility of trade networks. Rich empirical analyses reveal nuanced insights, such as dominant patterns of trade complementarity and the pronounced vulnerabilities of certain products since the pandemic. The elucidation of central players and sensitive products from the fragility analysis provides policymakers with valuable information for developing targeted policies to improve resilience and mitigate the negative effects of shocks. Furthermore, the paper accentuates the imperative of synchronised policy interventions and regional collaboration amongst ASEAN Member States, underscoring the significance of cooperative approaches in mitigating shared challenges. Overall, this study’s findings and policy implications offer valuable insights for policymakers and researchers interested in understanding the vulnerability and resilience of interconnected economies in the ASEAN region and beyond.

### 1.1. Literature Review

The global trade landscape has changed dramatically over the past few decades (IMF, 2011). Seminal studies on the determinants of exports and imports include Goldstein and Khan (1978) and Arize (1987). There is also substantial literature on the supply and demand of trade and competitiveness (Farole, Guilherme Reis, and Wagle, 2010; Bayoumi, Saito, and Turunen, 2013), as well as research on the structure and patterns of global trade based on the world trade network approach (Fagiolo, Reyes, and Schiavo, 2010). However, there is a lack of studies measuring export similarity and trade complementarity and their competition networks. Moreover, the fragility of this competition network is also less explored.

The concept of competitiveness and complementarity amongst countries has received significant attention in scholarly research. Overall trade has emerged as a key indicator of the dynamic relationships amongst nations. Researchers have extensively explored the various aspects of trade and its effects on economic growth, development, and globalisation. For instance, Rodrik (1999) found that overall trade openness has a positive impact on economic growth, while Sachs and Warner (1995) argued that it can lead to increased income inequality. Furthermore, trade complementarity, which refers to the degree of complementarity between the goods or services produced by different countries, has also received significant attention in scholarly research. Grubel and Lloyd (1975) demonstrated that countries with high levels of trade complementarity tend to engage in more trade and have more stable trade relationships. As for relevant research methods, traditional analysis of trade competitiveness and complementarity has mainly been done using the revealed comparative advantage (RCA) index (Balassa, 1965). Later, the export similarity index (ESI) was developed by Finger and Kreinin (1979) and the trade complementarity index (TCI) was developed by Drysdale (1969) and Kojima (1964). Finger and Krenin (1979) developed the ESI to identify regions that are likely to be engaged in trade competition – the higher the ESI, the more intense the competitive relationships between the two regions.

Trade liberalisation has been found to promote increased competition, spur innovation and productivity growth, and provide opportunities for growth and diversification. Trade can foster complementarity amongst countries by promoting the exchange of goods and services that are complementary in nature, leading to specialisation and increased efficiency. For example, a country that excels in producing capital-intensive goods can benefit from importing labour-intensive goods from another country. Numerous studies have explored the impact of trade on competitiveness and complementarity. Similarly, Hummels and Klenow (2005) showed that trade can lead to complementarity by promoting the exchange of goods that complement each other. Empirical research studies by Lingzhi (2021); Liu, Xu, and Zhang, 2020); and Dong et al. (2018) used the ESI and the TCI to quantify the competitiveness and complementarity of different country pairs. The study, which focused on the cocoon silk trade, revealed that China’s silk trade with Southeast Asia is highly complementary. In recent years, studies have been extended to examining the competitiveness and complementarity of the construction of the dynamic network approach. For example, Dong et al. (2018) examined the competitiveness of global wheat trade by creating a trading competitiveness network, while Liu, Xu, and Zhang (2020) analysed the competitiveness and complementarity of agricultural trade amongst 65 countries in the Belt and Road Initiative (BRI) from 2005 to 2016. The study revealed that network ties amongst sample countries increased over time. The trade density of the ESI and TCI- networks also increased over time, but the complementarity was greater than the competitiveness. Similarly, several other studies on trade complementarity between China and BRI countries have found that complementarity is higher than competitiveness (Han, Luo, and Zou, 2015; Wang, 2017; Chen, Chen, and Yao, 2020).

Research on sector-specific competition patterns offers essential insights into global market dynamics. Chen (2016) used network analysis to examine the competitive landscape of the global liquefied natural gas (LNG) trade. The study found that competitive relationships amongst LNG exporters increased significantly from 2005 to 2014, shifting from regional to more globalised competition. Similarly, Hao, An, Sun, and Zhong (2018) used complex network analysis to explore competition patterns in global iron ore trade. Their findings revealed a core-periphery structure in the iron ore import competition network, with intensifying competition over the years. The study further found that core countries exhibited higher competition intensity than peripheral countries, with competition intensity correlating positively with GDP and steel production and inversely with geographic distance between trade partners.

In conclusion, the literature on trade and competitiveness emphasises the crucial role that trade plays in enhancing the economic performance of countries. By understanding the intricacies of trade relationships, policymakers can make better decisions to promote economic growth and stability.

Another strand of literature is on the trade networks in a competition pattern. There are many strands within network literature in the context of international trade. In a complex network model, the world is considered a set consisting of many vertices (i.e. countries) and edges between these vertices (countries). The evolution of the world trade network or the World Trade Web has been studied as a binary network, where an edge between any two countries is considered interconnected depending on whether the trade flow is larger than a given threshold (De Benedictis and Tajoli, 2011; Serrano and Boguná, 2003). However, in a binary network, all the interconnections are taken as equal, which may misestimate the impact of trade relationship heterogeneity. Hence, the works of Garlaschelli and Loffredo (2004) and Fagiolo, Reyes, and Schiavo (2008) adopted weighted network approaches to compare the degrees and patterns of trade integration.

One strand is based on a positional analysis of the trade and integration patterns of each country (Kali and Reyes, 2010; Vidya,2022; Vidya and Prabheesh, 2020), while another comprises studies centred on the sector-specific analysis of international trade networks (Amighini and Gorgoni, 2014; Vidya, Mummidi, and Adarsh, 2023). Advanced testing of complementarity and competitiveness in a network is carried out by a few studies in specific commodity contexts (Liu, Xu, and Zhang, 2020; Zhang, Ji, and Fan, 2014; Chen et al., 2016; Dong et al., 2018). The third strand of literature analyses the shocks and fragility in a model. Although several studies measure and analyse the shocks in an economic system by applying econometric approaches (Kose and Riezman, 2001; Frankel and Rose, 1998; Imbs, 2004), the literature is largely silent on measuring the vulnerabilities and shocks in intermediate trade and supply shocks.

Global shocks – in the form of wars, economic recessions, and pandemics – severely disrupt the interconnections and generate cascading consequences from the local to the global scale (Viña and Liu, 2023). The impact of a shock can be increased through interconnectedness of the global economy. For example, the COVID-19 pandemic originated in China but has had a significant impact on countries all over the world. Research by Barbero, de Lucio, and Rodríguez-Crespo (2021) and Dudek and Śpiewak (2022) supports this view. They found that global shocks can have a significant impact on the global economy, which can be amplified by the interconnectedness of the global economy. They noted that policymakers need to be aware of the potential impact of global shocks and take steps to mitigate the impact of such shocks. Studies by Guerrieri et al. (2020), Abbas et al. (2021), and Gruszczynski (2020) discuss the large disruptions to labor supply, supply chains, the tourism industry, and international trade caused by the pandemic. The disruptions caused by the pandemic have led to a decrease in the flow of goods and services, negatively impacting the global economy. A pioneering work in the field of supply shock risks in the highly interconnected global system was conducted by Korniyenko, Pinat, and Dew (2017). They found that a shock to a highly interconnected economy exposes other economies in the network to equal risk, as each economy is dependent on the others.

Following the work of Korniyenko, Pinat, and Dew (2017), we assess the sensitivity of import baskets to supply-side shocks using network analysis parameters. We analyse individual commodity characteristics, such as quality, cyclicality, and complexity, to estimate the riskiness and vulnerability of import baskets. This is done by considering the presence of central players and clustering tendencies. Our methodology helps identify vulnerable products in global trade baskets by categorising them as top exporters and importers of these products.

First, we aim to analyse the trade competitiveness and complementarity between ASEAN and their trade partners. To achieve this, we measure the ESI and TCI for the Harmonized System (HS) 6-digit level manufacturing products of ASEAN, and analyse the competitiveness and complementarity of AMS and their trade partners using trade network analysis.

Second, we aim to analyse the fragility of the trade networks and propose effective mitigation policy measures for ASEAN. To achieve this, we measure the riskiness of products and the intensity of shocks before and after the COVID-19 pandemic. We also analyse the vulnerability of specific sectors in different countries and investigate how these sectors responded to external shocks.

Based on our findings, we provide suggestions and propose effective mitigation policy actions to improve the resilience of the trade networks and enhance the competitiveness of the ASEAN.

## 2. Data and Methodology

The study uses the bilateral goods trade data of ASEAN from 2010 to 2021 from the International Trade Centredatabase. The HS 6-digit level goods are applied. The sample consists of the 10 ASEAN and the 110 leading partners of ASEAN. The HS codes and classifications are given in Table 1.

**Table 1: Top 10 Exports of Goods by HS 6-Digit Code – ASEAN**

| HS Code | Short Product Name | Detailed Product Name |
|---|---|---|
| HS 854231 | Electronics – integrated circuit – processors | Electronic integrated circuits as processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits |
| HS 854239 | Electronics – integrated circuits | Electronic integrated circuits |
| HS 271019 | Bituminous minerals without biodiesel | Petroleum oils and oils from bituminous minerals, not containing biodiesel, not crude, not waste oils; preparations n.e.c. containing by weight 70% or more |

| HS Code | Short Product Name | Detailed Product Name |
|---|---|---|
| | | of petroleum oils or oils from bituminous minerals; not light oils and preparations |
| HS 851712 | Telephones for cellular networks | Telephones for cellular networks or for other wireless networks |
| HS 851770 | Electrical parts of telephone | Telephone sets and other apparatus for the transmission or reception of voice, images, or other data, via a wired or wireless network; parts |
| HS 854232 | Electronics – memories | Electronic integrated circuits as memories |
| HS 271012 | Bituminous minerals | Petroleum oils and oils from bituminous minerals, not containing biodiesel, not crude, not waste oils; preparations n.e.c. containing by weight 70% or more of petroleum oils or oils from bituminous minerals; light oils and preparation |
| HS 847170 | Storage units for data processing | Units of automatic data processing machines; storage units |
| HS 271111 | Natural gas, liquefied | Petroleum gases and other gaseous hydrocarbons; liquefied, natural gas |
| HS 851762 | Electrical communication apparatus | Communication apparatus (excluding telephone sets or base stations); machines for the reception, conversion and transmission or regeneration of voice, images, or other data, including switching and routing apparatus |

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, n.e.c. = not elsewhere classified.
Notes: The short product names are created by the author to make the discussion clear and specific. The detailed product names are taken from the United Nations Statistics Division.
Source: United Nations Statistics Division (n.d.), Classifications on Economic Statistics. http://unstats.un.org/unsd/classifications/Econ (accessed 10 August 2022).

## Empirical methodology

**Export Similarity Index (ESI):** is employed to measure the degree of similarity between two countries concerning their export product compositions to a shared target market. The formula for its calculation is as follows:

$$ESI_{ab} = \left[\frac{1}{2}\left(\frac{x_a^i}{x_a} + \frac{x_b^i}{x_b}\right) \times \left(1 - \left|\frac{\left(\frac{x_a^i}{x_a} - \frac{x_b^i}{x_b}\right)}{\left(\frac{x_a^i}{x_a} + \frac{x_b^i}{x_b}\right)}\right|\right)\right] \times 100 \qquad -(1)$$

In Equation (1), $x_a^i$ denotes the export value of a product $i$ in a country $a$; $x_a$ signifies the total export value of country $a$ as to the global market. Similarly, $x_b^i$ indicates the export value of product $i$ in a country $b$, $x_b$ represents the total export value of country $b$ as to the world market. ESI measures the trade competitiveness by calculating the exports of two countries relative to global markets. ESI values range from 1 to 100. A higher ESI indicates greater congruence in exports between the two nations, signifying heightened trade competition.

**Trade Complementarity Index (TCI):** The TCI measures the degree of similarity between a country's export supply and one of its trade partners' import demand. The index is calculated as follows:

$$TCI_{ab} = (1 - (\left|\frac{\sum_w m_{iwd}}{\sum_w M_{wd}} - \frac{\sum_w x_{isw}}{\sum_w X_{sw}}\right|) \div 2) \times 100 \qquad - \qquad (2)$$

Equation 2 depicts the trade complementarity between two countries: *d* (the importer of interest) and *s* (the exporter of interest). In this context, $d$ the importing country of interest is, $s$ is the exporting country of interest. $w$ is the set of the all countries in the world. $i$ is the total of all industries.$x$ is the commodity export flow, $X$ is the total export flow.$M$ is the total import flow and $m$ is the commodity import flow. In words, it is the sum of the absolute value of the difference between the commodity import share of one country and the commodity export share of the other. This equation is based on the works of Mikic and Gilbert (2009). The value of index ranges between 0 and 100. It takes the value zero when there is no compatibility between exports of country $S$ and imports of country $d$. On the other hand, the index takes the value 100 when exports of country $S$ and imports of country $d$ are in perfect alignment with each other implying the perfect complementarity between two countriesThe study also tries to analyse the fragility of the trade networks[3] and proposes effective policy measures for mitigating trade fragilities in ASEAN economies. To achieve this objective, the study utilises network analysis. We use HS 6-digit product classification, and fragility is calculated on these products and their trade networks. Product fragility can be calculated using three different components: (i) central players, and (ii) clustering tendency,

***Central players*:** The centrality/influential capability for each country in a certain product is calculated as:

$$C_i^{out} = \sum_{j=1}^{n-1} \frac{w_{ij}}{\langle w_j \rangle} \qquad (3)$$

where $C_i^{out}$ is the weighted out-degree centrality of country $i$ and $n$ is the total number of nodes in the specific trade network. Similarly, $w_{ij}$ denotes the value of exports of country $i$ to $j$, and $\langle w_j \rangle$ is the average value of country $j$'s imports.

[3] The methodology is based on Korniyenko, Pinat, and Dew (2017).

To arrive at each product's risk arising from central exporters, we use the following version of standard deviation:

$$Centrality_k = \sqrt{\frac{C_{ik}^{out} - \overline{C_k^{out}}}{n-1}} \quad (4)$$

Here, $\overline{C_k^{out}}$ is the average influential value of countries trading product $k$.

In theory, countries with many trading partners and a high intensity of exports are more likely to experience negative spillovers in the event of a negative supply shock. They are frequently referred to as *influential*. The existence of few key actors distinguishes star-shaped networks. The standard deviation of weighted out-degree centrality is determined for each product network to assess the product's procyclicality to have a few extremely central exporters; the bigger the standard deviation, the more likely the star shape and the higher the potential danger (Korniyenko, Pinat, and Dew, 2017).

***Clustering tendency*:** One of the risks of having clusters of interconnected countries is a spillover of shocks. If a cluster is destabilised by a short-term supply shock in its central country, importers in the cluster will have a low probability of finding an exporter within the same cluster. This is calculated by using two methods: a) weighted average local clustering and b) network diameter.

**a) Weighted average local clustering:** The weighted average local clustering coefficient assesses how near a country's partners are to one another. The higher the clustering coefficient, the more likely nations are to cluster.

The local clustering coefficient, $CC_i$, for a country/node $i$ is given by the proportion of linkages of $i$ and its neighbours compared with the total possible linkages within the network. This is given by the equation:

$$CC_i^w = \frac{1}{k_i(k_i-1)} \sum_{j,k} \frac{1}{\langle w_i \rangle} \frac{w_{ij}+w_{ik}}{2} T_{ij} T_{ik} T_{jk} \quad (5)$$

Here, $k_i$ is the number of linkages country $i$ has with other nodes. The variable $w_{ij}$ is the value of the total trade that takes place between country $i$ and $j$. Additionally, $\langle w_i \rangle$ is the average weight of all ties connected with country $i$.

**b) Network diameter:** This is the maximum distance between the two most distant countries within a network. It is calculated as the number of steps required to reach the farthest node from the selected country in the cluster.

For a specific set of countries, the tendency to cluster is then calculated using the following formula:

$$Cluster_k = CC_i^w \times Diameter \quad (6)$$

## 4. Results and Interpretations

### 4.1. Results of ESI and TCI

#### 4.1.1. ESI

Table 2 provides details on the ESI values for various products in the ASEAN region over 2010–2021. The ESI is a measure of the degree of similarity in the export baskets of two countries, with higher values indicating greater similarity. In this case, the ESI values represent the degree of similarity in the export baskets of ASEAN.

**Table 2: Export Similarity Indices of ASEAN**

| Product name | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bituminous minerals (HS 271012) | NA | NA | 2.05 | 2.13 | 2.07 | 1.31 | 0.99 | 1.15 | 1.13 | 1.17 | 0.75 | 1.42 |
| Bituminous minerals without biodiesel (HS 271019) | 2.81 | 4.05 | 3.92 | 3.36 | 3.54 | 2.14 | 2.04 | 2.71 | 2.53 | 2.53 | 1.79 | 1.87 |
| Natural gas, liquefied (HS 271111) | 3.10 | 2.90 | 2.99 | 2.95 | 7.86 | 8.54 | 6.61 | 5.84 | 4.32 | 5.03 | 1.10 | 1.03 |
| Storage units for data processing (HS 847170) | 2.15 | 1.70 | 2.20 | 2.04 | 1.75 | 1.97 | 1.95 | 1.77 | 1.55 | 1.58 | 1.51 | 1.49 |
| Telephones for cellular networks (HS 851712) | 0.62 | 1.51 | 2.15 | 3.32 | 3.27 | 2.84 | 2.79 | 2.54 | 2.16 | 2.40 | 2.02 | 1.75 |
| Electrical communication apparatus (HS 851762) | 0.21 | 0.23 | 0.29 | 0.35 | 0.43 | 0.51 | 0.56 | 0.58 | 0.52 | 0.70 | 1.10 | 1.14 |
| Electrical parts of telephone (HS 851770) | 0.14 | 0.17 | 0.55 | 0.47 | 0.41 | 0.83 | 1.01 | 1.70 | 1.34 | 1.24 | 1.22 | 1.22 |
| Electronics – integrated circuit – processors (HS 854231) | 3.04 | 3.08 | 3.56 | 3.03 | 3.19 | 3.60 | 3.68 | 3.50 | 5.79 | 5.77 | 5.36 | 6.84 |
| Electronics – memories (HS 854232) | 0.71 | 0.57 | 0.55 | 0.62 | 0.65 | 0.78 | 0.76 | 1.13 | 1.27 | 1.29 | 1.49 | 1.82 |
| Electronics – integrated circuits (HS 854239) | 3.27 | 2.50 | 2.47 | 2.31 | 2.35 | 2.54 | 2.78 | 2.73 | 2.68 | 3.34 | 4.44 | 3.98 |

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, NA = not applicable.
Source: Author's calculations based on analysis.

Overall, the product-wise analysis shows that the ESI values are fairly low – below 5 for the ASEAN. This indicates that there is very little export similarity within the ASEAN. In other words, the countries in the region tend to export different types of products, which could reflect their different economic structures, levels of development, and specialisation patterns.

When looking at specific products, the results are varied. The export similarity for bituminous minerals, storage units, natural gas, and electrical items such as cellular electrical telephones has declined over time, with a particularly sharp drop from 2012 to 2021. This decline is likely due to a number of factors, including changes in demand owing to the rise in renewable energy sources; changes in competition, such as the emergence of new competitors like China, which has become a major producer of electrical items in recent years; and, above all, the impact of COVID-19 (ASEAN, 2022; Kato, 2022).

The commodities such as natural gas liquefied, electronics integrated circuit and electronics integrated circuit processors possess high ESI values. This could be because ASEAN expanded its export baskets and capacities in these areas. It could be also due to the growing worldwide demand for electronics and telecommunication products and components and the integration of technologies into different sectors. Overall, the table provides a useful snapshot of the export similarity patterns in the ASEAN region, which could help policymakers, businesses, and researchers understand the dynamics of regional trade and identify opportunities for cooperation, diversification, and innovation.

#### 4.1.2. TCI

Table 3 shows the values of the TCI for various product codes over 2010–2021. The TCI measures the degree of complementarity or similarity between the export structures of two countries. A TCI value of 100 indicates that the two countries have identical export structures, while a value of 0 indicates that the two countries' export structures are completely dissimilar. This is applicable for all the products in the study, hence the values range from 99.18 to 99.43, indicating a high degree of complementarity between the countries' export structures for this product code. Notably, bituminous minerals (HS 271012 and HS 271019), natural gas liquefied (HS 271111), storage units for data processing (HS 847170), electrical products such as electrical–communication apparatus (HS 851762), electrical parts of telephone (HS 851770), electronics–integrated processors (HS 854231), electronics–memories (HS 854232), and electronics–integrated circuits (HS-854239) had consistently high TCI values throughout the years, ranging from 96.52 to 99.87, indicating a high degree of complementarity between the countries' export structures for these product codes.

**Table 3: Trade Complementarity Indices of ASEAN**

| Product Name | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bituminous minerals (HS 271012) | NA | NA | 98.49 | 98.43 | 98.43 | 98.78 | 98.89 | 98.62 | 98.54 | 98.62 | 98.77 | 98.21 |
| Bituminous minerals without biodiesel (HS 271019) | 97.17 | 96.44 | 97.15 | 97.06 | 97.21 | 98.13 | 98.26 | 97.87 | 97.76 | 97.97 | 97.95 | 97.78 |
| Natural gas, liquefied (HS 271111) | 95.69 | 96.02 | 95.88 | 95.69 | 95.20 | 95.19 | 96.13 | 96.12 | 96.27 | 96.60 | 97.71 | 98.26 |
| Storage units for data processing (HS 847170) | 99.18 | 99.34 | 99.25 | 99.26 | 99.24 | 99.28 | 99.30 | 99.30 | 99.33 | 99.38 | 99.41 | 99.43 |
| Telephones for cellular networks (HS 851712) | 99.56 | 99.30 | 99.07 | 98.62 | 98.64 | 98.50 | 98.55 | 98.70 | 98.82 | 98.81 | 98.90 | 99.03 |
| Electrical communication apparatus (HS 851762) | 99.71 | 99.78 | 99.82 | 99.84 | 99.81 | 99.77 | 99.74 | 99.74 | 99.72 | 99.72 | 99.55 | 99.54 |
| Electrical parts of telephone (HS 851770) | 99.87 | 99.80 | 99.56 | 99.49 | 99.54 | 99.34 | 99.24 | 98.90 | 98.98 | 99.08 | 98.91 | 98.99 |
| Electronics – integrated circuit – processors (HS 854231) | 98.40 | 98.38 | 98.37 | 98.17 | 98.07 | 97.93 | 97.90 | 97.97 | 97.20 | 97.08 | 96.67 | 96.52 |
| Electronics – memories (HS 854232) | 99.62 | 99.69 | 99.71 | 99.67 | 99.63 | 99.57 | 99.59 | 99.34 | 99.17 | 99.18 | 99.03 | 98.89 |
| Electronics – integrated circuits (HS 854239) | 97.88 | 98.31 | 98.26 | 98.25 | 98.27 | 98.09 | 97.91 | 97.96 | 98.04 | 97.96 | 97.59 | 97.75 |

ASEAN = Association of Southeast Asian Nations, HS = Harmonized System, NA = not applicable.
Source: Author’s calculations based on analysis

The reason for the consistently high TCI values amongst ASEAN could be attributed to several factors. One possible reason is the presence of a high degree of intra-regional trade, with ASEAN having similar economic structures and similar levels of development. This similarity in economic structures results in a higher degree of complementarity between the countries' export structures for certain product codes. Another possible reason is the existence of regional integration efforts such as the ASEAN Free Trade Area and the ASEAN Economic Community, which have facilitated increased trade amongst ASEAN. These regional integration efforts have reduced barriers to trade and investment, and have facilitated the development of regional value chains, leading to a higher degree of complementarity between the countries' export structures. The high TCI values can also be attributed to the specialisation of ASEAN in certain product categories. For example, some ASEAN may have specialised in the production of certain electrical products or certain types of minerals, leading to a higher degree of complementarity in their export structures for these product codes.

Overall, the consistently high TCI values for the mentioned product codes amongst ASEAN indicate that there are promising prospects for successful trade in these product categories within the region. These findings suggest that there is potential for further integration and cooperation amongst ASEAN to enhance the complementarity of their export structures and further promote intra-regional trade.

### 4.2. Results of Network Analysis of ESI and TCI

#### (a) Leading Country Pairs following the TCI: Intra-Regional

The study also analyses the inter-regional TCI for ASEAN in different product categories from 2010 to 2021 (Appendix I). For bituminous minerals (HS 271012), Singapore, Thailand, and Viet Nam have been the main trading partners. There has been a consistent increase in the TCI between Singapore and Thailand, indicating growing complementarity in their trade in bituminous minerals.

For bituminous minerals with biodiesel (HS 271019), Brunei Darussalam, Cambodia, and Indonesia have been the primary trading partners for ASEAN. The TCI has shown a consistent increase between all these pairs, indicating growing complementarity in their trade in bituminous minerals with biodiesel. In the case of liquefied natural gas (HS 271111), Indonesia, Malaysia, and Singapore have been the main trading partners with each other and Myanmar. The TCI has increased between Indonesia and Myanmar, as well as between Singapore and Malaysia, indicating growing complementarity in their trade in liquefied natural gas. In the case of storage and data processing (HS 847170), Brunei, Cambodia, Indonesia, Malaysia, Singapore, Thailand, and the Philippines have been the main trading partners within the ASEAN region. The TCI has consistently increased between all these pairs, indicating growing complementarity in their trade of storage units for data processing. For telephones for cellular networks (HS 851712) trade take place between Myanmar–Viet Nam–Philippines. Similarly, for electrical communication apparatus (HS 851762), Singapore and Viet Nam are the main trading partners within the ASEAN region. The TCI has increased consistently between all ASEAN pairs, indicating growing complementarity in their trade in electrical communication apparatus. For electronics, including integrated circuits (HS 854231), memories (HS 854232), and microprocessors (HS 854239), Brunei, Cambodia, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Viet Nam have been the primary trading partners within the ASEAN region. The TCI between all ASEAN pairs in the electronics trade (integrated circuits, memories, and microprocessors) has increased consistently over the past 5 years, indicating growing complementarity in their trade. This indicates that the trade between these countries is becoming more specialised and that each country is focusing on producing the products that it is best at making. In summary, the analysis shows that intra-regional trade complementarity between AMS has been growing in various product categories. The increasing TCI indicates a shift towards more complementarity in trade within the ASEAN region. This shift may be due to factors such as improved trade infrastructure, reduced trade barriers, and increased regional cooperation.

**b) Leading country pairs following the TCI: inter-regional**

The TCI within the ASEAN and its trade partners within the region (intra-regional) and across the regions (inter-regional) is detailed in Appendixes I and II

The trade complementarity for ASEAN and their trade partners (intra-regional) for several product categories from 2010 to 2021 are given in Appendix II. The TCI is an essential measure of the degree of complementarity between the exports and imports of a specific product category between two trading partners.

For bituminous minerals (HS 271012), Indonesia has mainly traded with Japan and India, while Singapore has traded with Korea and Australia. The increasing TCI between Singapore and Australia suggests that the two countries have developed more significant complementarity in their trade in bituminous minerals. In contrast, the TCI between Indonesia and Japan appears to be decreasing.

For bituminous minerals with biodiesel (HS 271019), Singapore has traded with a variety of countries, including China, Italy, Japan, Mozambique, and Taiwan and recently with Canada, Denmark, and France. The significant increase in the TCI between Singapore and Mozambique indicates that there is growing complementarity in their trade in bituminous minerals with biodiesel.

The TCI for liquefied natural gas (HS 271111) suggests that Indonesia, Malaysia, and Singapore have mainly traded with Myanmar and each other. The increasing TCI between Singapore and Malaysia indicates growing complementarity in their trade in liquefied natural gas.

The high complementarity indices apply to the storage units for data processing products trade. For storage units for data processing (HS 847170), Malaysia, Singapore, and Thailand have mainly partnered with Hong Kong, North Korea, and the United Kingdom. The other notable country pairs are Singapore, Viet Nam, Mauritius, and Macao for electrical items. This highlights the growing complementarity of trade with ASEAN. For electrical communication apparatus (HS 851762), Singapore has mainly traded with China, Denmark, France, Hong Kong, Korea, and Australia. The significant increase in the TCI between Singapore and Hong Kong indicates growing complementarity in their trade in electrical communication apparatus.

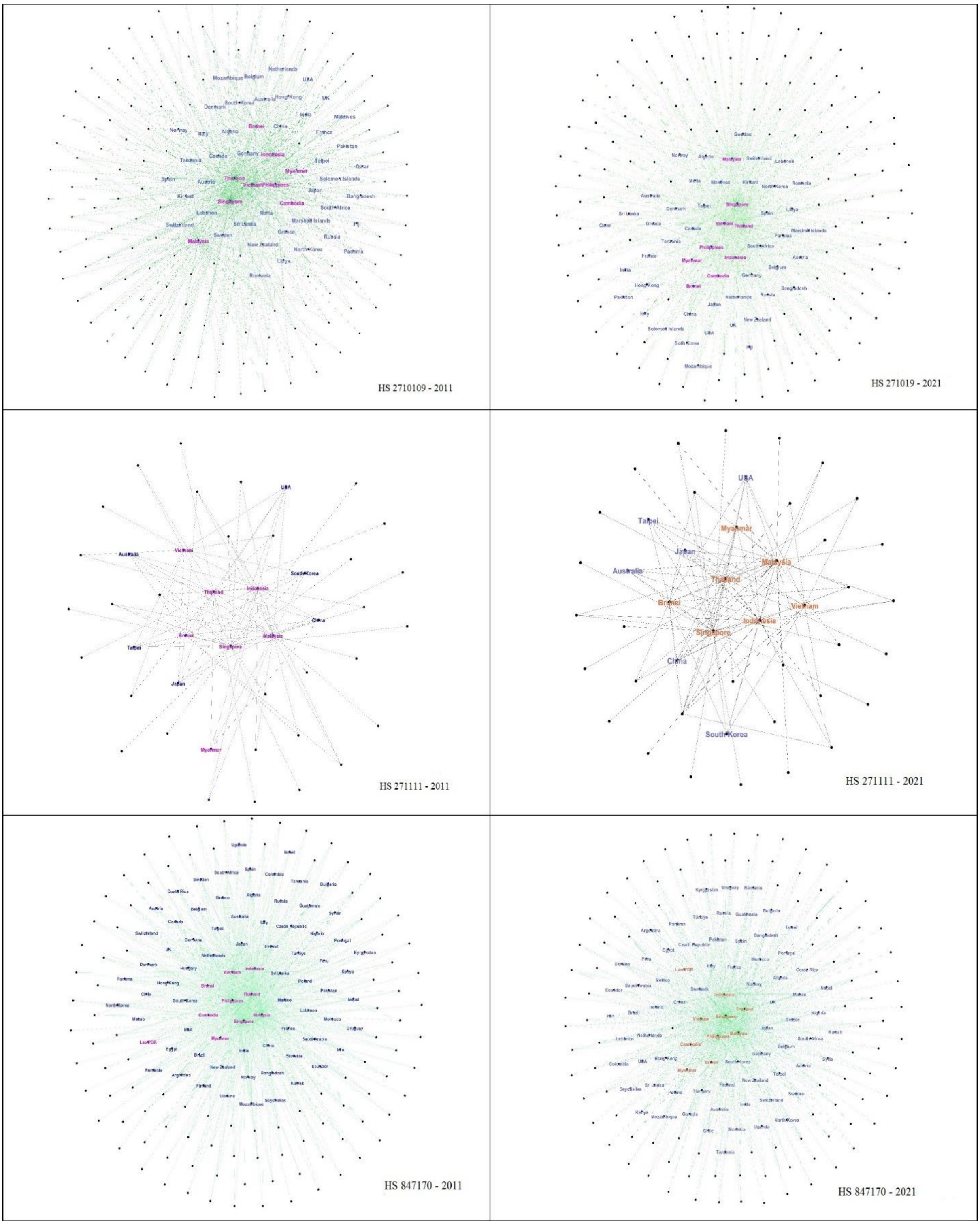
For electronics, including integrated circuits (HS 854231), memories (HS 854232), and microprocessors (HS 854239), Singapore has traded with various countries, including Australia, Cambodia, China, Germany, Hong Kong, Poland, Taiwan, and the United States. The increasing trade complementarity index between Singapore and Cambodia suggests growing complementarity in their trade in electronics-integrated circuits.

In summary, the analysis shows that the TCI can provide a useful insight into the evolving trade patterns between ASEAN and their trading partners. It highlights the importance of identifying the complementary trading partners and the product categories that show the highest degree of complementarity to enhance trade and promote economic growth

**c) Spatial distribution (Networks) of Trade Competitiveness Index**

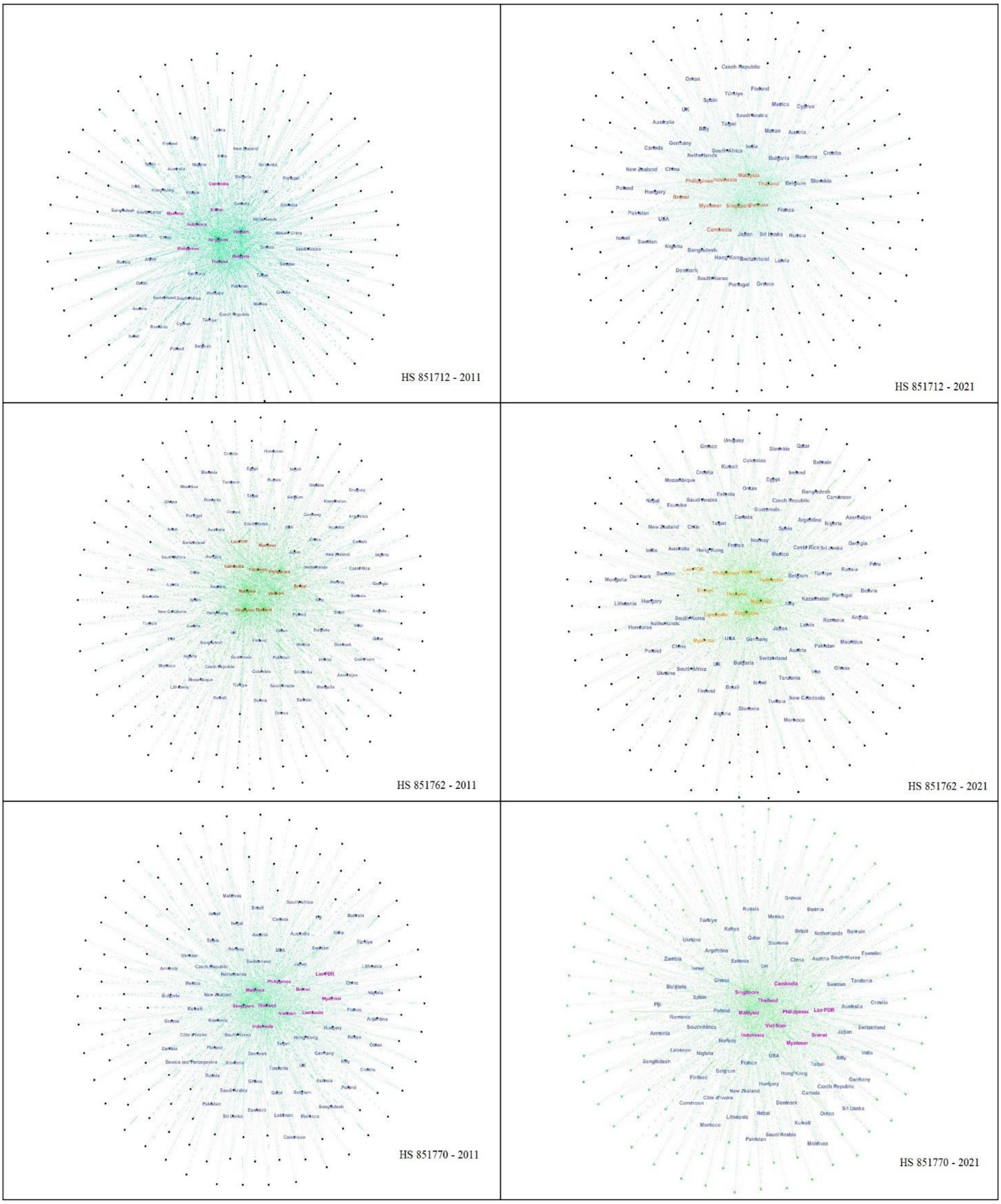
This section examines the trade networks of different goods, which helps to understand the spatial distribution of trade complementarity patterns. We compared the trade complementarity network graphs for each product in 2011 and 2021 and presented the TCI network graph density for each product in Figure 1 and its network parameters in Table 4.

**Figure 1A: Product-Wise Network Trade Complementarity, 2011 and 2021**



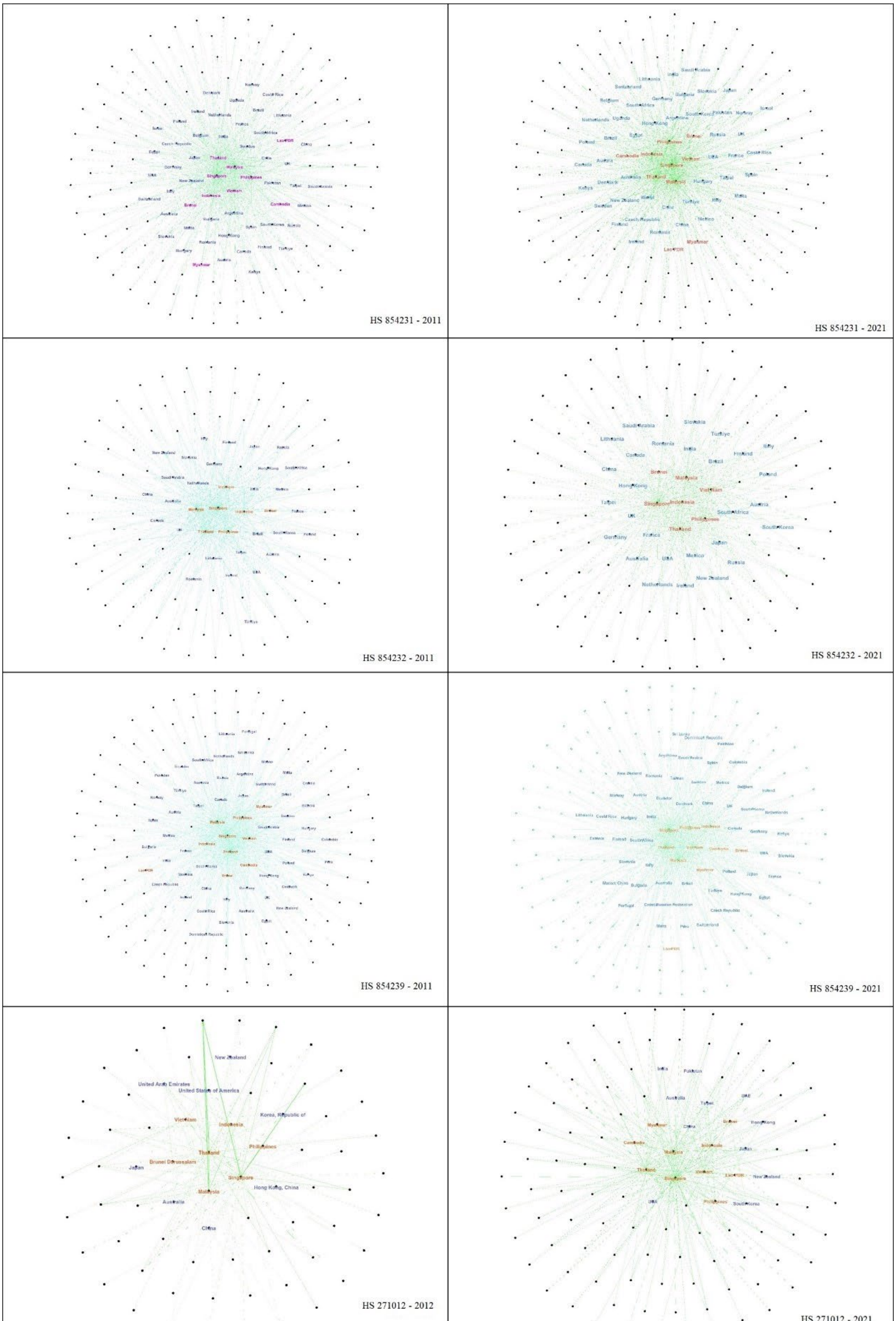

Source: Author's representation based on analysis.

**Figure 1B: Product-Wise Network Trade Complementarity, 2011 and 2021**




Source: Author's representation based on analysis.

**Figure 1C: Product-Wise Network Trade Complementarity, 2011 and 2021**




Source: Author's representation based on analysis.

Table 4: Trade Complementarity Network Parameter Results

| Product Name | Nodes | | Edges | | Average Degree | | Average Eigen centrality | | Average Closeness Centrality | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2021 | 2011 | 2021 | 2011 | 2021 | 2011 | 2021 | 2011 | 2021 |
| Bituminous minerals (HS 271012) | NA | 119 | NA | 303 | NA | 2.54 | NA | NA | NA | NA |
| Bituminous minerals without biodiesel (HS 271019) | 218 | 218 | 684 | 684 | 3.13 | 3.13 | 0.462 | 0.462 | 0.444 | 0.444 |
| Natural gas, liquefied (HS 271111) | 54 | 54 | 108 | 108 | 2.00 | 2.00 | 0.325 | 0.325 | 0.771 | 0.771 |
| Storage units for data processing (HS 847170) | 212 | 212 | 780 | 780 | 3.67 | 3.67 | 0.417 | 0.417 | 0.660 | 0.660 |
| Telephones for cellular networks (HS 851712) | 202 | 202 | 639 | 639 | 3.16 | 3.16 | 0.395 | 0.395 | 0.643 | 0.643 |
| Electrical communication apparatus (HS 851762) | 221 | 221 | 828 | 828 | 3.74 | 3.74 | 0.432 | 0.432 | 0.671 | 0.671 |
| Electrical parts of telephone (HS 851770) | 214 | 214 | 793 | 793 | 3.70 | 3.706 | 0.414 | 0.414 | 0.660 | 0.660 |
| Electronics – integrated circuit – processors (HS 854231) | 200 | 200 | 612 | 612 | 3.06 | 3.060 | 0.384 | 0.384 | 0.637 | 0.637 |
| Electronics – memories (HS 854232) | 150 | 150 | 405 | 405 | 2.70 | 2.700 | 0.419 | 0.419 | 0.461 | 0.461 |
| Electronics – integrated circuits (HS 854239) | 202 | 202 | 633 | 633 | 3.13 | 3.134 | 0.361 | 0.361 | 0.630 | 0.565 |

NA = not applicable.
Source: Author’s calculations based on analysis.

Table 4 displays the competition network patterns in trade complementarity cases for ASEAN economies. The nodes represent the number of countries involved in trade networks for various products in 2011 and 2021. In contrast, edges represent the number of connections or relationships between these ASEAN and their partners. Electrical products, electronics, and bituminous minerals exhibit high nodes and edges, implying a dense network with numerous connections. On the other hand, natural gas demonstrates a low number of nodes and edges, suggesting sparse networks with fewer connections.

**Table 5: TCI Trade Network Graph Density, 2011 and 2021**

| Product Name | 2011 | 2021 | Difference |
|---|---|---|---|
| Bituminous minerals (HS 271012) | NA | 0.022 | NA |
| Bituminous minerals without biodiesel (HS 271019) | 0.014 | 0.016 | 0.002 |
| Natural gas, liquefied (HS 271111) | 0.042 | 0.041 | –0.001 |
| Storage units for data processing (HS 847170) | 0.018 | 0.018 | 0.000 |
| Telephones for cellular networks (HS 851712) | 0.016 | 0.017 | 0.001 |
| Electrical communication apparatus (HS 851762) | 0.017 | 0.018 | 0.001 |
| Electrical parts of telephone (HS 851770) | 0.017 | 0.019 | 0.002 |
| Electronics – integrated circuit – processors (HS 854231) | 0.016 | 0.016 | 0.000 |
| Electronics – memories (HS 854232) | 0.018 | 0.019 | 0.001 |
| Electronics – integrated circuits (HS 854239) | 0.016 | 0.016 | 0.000 |

NA = not applicable, TCI = trade complementarity index.
Source: Author's calculations based on analysis.

Likewise, the average degree offers insight into the connectivity and complexity levels of trade networks. The average degree for most products remained fairly stable in 2021. The trade network for electrical and communication apparatus (HS 851762) had the highest average degree of 3.74 in both years, indicating a relatively dense network with many connections between the entities involved in trading this product. In comparison, the trade networks for other products, such as liquefied natural gas and electronics–memories, had lower average degrees of 2 signifying less connectivity and potentially less complexity in the trade networks for these products.

The eigenvector centrality measures each node's connectivity or influence in the network model. Amongst the products, the highest eigenvector centrality score was for bituminous minerals with biodiesel (0.462) in both years, indicating central and influential nodes within the networks. Closeness centrality scores amongst the products reveal how well connected the products of ASEAN are to the central players or their closeness. According to the table, the trade network for liquefied natural gas had the highest closeness centrality score of 0.771, indicating well-connected nodes for this product. The trade networks for electrical–communication apparatus and storage units for data processing also had relatively high closeness centrality scores of 0.671 and 0.66, respectively. In contrast, the trade network for electronics–memories (0.461) and bituminous minerals (without biodiesel) (0.44) had the lowest closeness centrality, suggesting that this product's nodes were less well connected and more isolated within the network.

Table 5 reveals that the trade complementarity graph density remained stable for storage units for data processing, electronics–integrated circuits, and electronic–microprocessors when comparing 2011 and 2021. However, there was a minimal increase in trade density for the remaining products, except for liquefied natural gas. These data indicate that the trade complementarity patterns for these products remained mostly consistent over the years, except for natural gas, which experienced a significant increase in trade density.

**Table 6: Central Countries in the Network (TCI Index)**

| Product Name | 2011 | 2021 |
|---|---|---|
| Bituminous minerals (HS 271012) | NA | NA |
| Bituminous minerals without biodiesel (HS 271019) | Malaysia, China, Japan, South Africa, Canada | Malaysia, China, Japan, South Africa, Canada |
| Natural gas, liquefied (HS 271111) | China, Japan, US, Australia, Rep. of Korea, Taiwan | China, Japan, US, Australia, Rep. of Korea, Taiwan |
| Storage units for data processing (HS 847170) | Thailand, Hong Kong, China, Japan, Netherlands | Thailand, Hong Kong, China, Japan, Netherlands |
| Telephones for cellular networks (HS 851712) | Hong Kong, China, Japan, Hungary, Thailand | Hong Kong, China, Japan, Hungary, Thailand |
| Electrical communication apparatus (HS 851762) | Rep. of Korea, Australia, Hong Kong, China, Netherlands | Rep. of Korea, Australia, Hong Kong, China, Netherlands |
| Electrical parts of telephone (HS 851770) | China, Japan, Australia, Hong Kong, Sweden | China, Japan, Australia, Hong Kong, Sweden |

| Product Name | 2011 | 2021 |
|---|---|---|
| Electronics – integrated circuit – processors (HS 854231) | Hong Kong, China, Australia, Singapore, Argentina | Hong Kong, China, Australia, Singapore, Argentina |
| Electronics – memories (HS 854232) | Hong Kong, Taiwan, US, India, Rep. of Korea | Hong Kong, Taiwan, US, India, Rep. of Korea |
| Electronics – integrated circuits (HS 854239) | China, Germany, UK, US, Canada | China, Germany, UK, US, Canada |

NA = not applicable, TCI = trade complementarity index, UK = United Kingdom, US = United States.
Source: Author's calculations based on analysis.

Table 6 delineates the central countries in the trade complementarity network based on the TCI Index for specific products in 2011 and 2021. A consistent pattern emerges for several products over the decade: the central countries for bituminous minerals without biodiesel (HS 271019), natural gas, liquefied (HS 271111), and telephones for cellular networks (HS 851712) remained unchanged between 2011 and 2021. Countries such as China, Japan, and Hong Kong repeatedly appear as pivotal players in multiple product categories, emphasising their prominent role in the trade complementarity landscape. Moreover, diverse products such as storage units for data processing (HS 847170) and electrical parts of telephone (HS 851770) exhibit steady central countries over the decade, hinting at entrenched trade relationships and stable product-specific complementarities amongst these nations.

### 4.3. Fragility of the Trade Networks

In this section, we analyse and measure the fragility of individual goods' trade networks in two ways. First, we follow the International Monetary Fund (IMF) work by Korniyenko, Pinat, and Dew (2017) on developing product-wise fragility. This involves calculating fragility based on two key factors: (i) identifying the central players of each product and assessing risks using out-degree, which pertains to the risks arising from specific nodes; and (ii) evaluating the clustering tendency, indicating the spillover of shocks through the weighted average of local clustering and network diameters.

#### 4.3.1. Fragility Assessment 1: Central Players and Product Riskiness amongst ASEAN

The previous section highlighted the importance of trade networks and the interdependence amongst countries in the ASEAN region. However, recent evidence suggests that global shocks can significantly disrupt these trade networks and have cascading effects on the local and global scale. The COVID-19 pandemic is a recent example of how a global shock can disrupt trade interconnections. The pandemic led to border closures, travel restrictions, and disruptions in supply chains, which caused significant disruptions in the global trade network. Similarly, wars, recessions, and other global shocks can disrupt trade networks and cause significant economic impacts. Recent studies by Viña and Liu (2023); Barbero, de Lucio, and Rodríguez-Crespo (2021); and Dudek and Śpiewak (2022) have provided evidence on how global shocks can disrupt trade networks and have highlighted the need for policymakers to be prepared to mitigate these impacts. Therefore, policymakers should consider the risks associated with global shocks and work towards building resilient trade networks to minimise the economic impacts of these shocks.

To assess product fragility, two main approaches are employed: *out-degree centrality* and the *clustering tendency* of goods in network models. The out-degree centrality method measures the influence of nodes in the network graph, and we used the standard deviation of out-degree centrality to identify high-risk products.

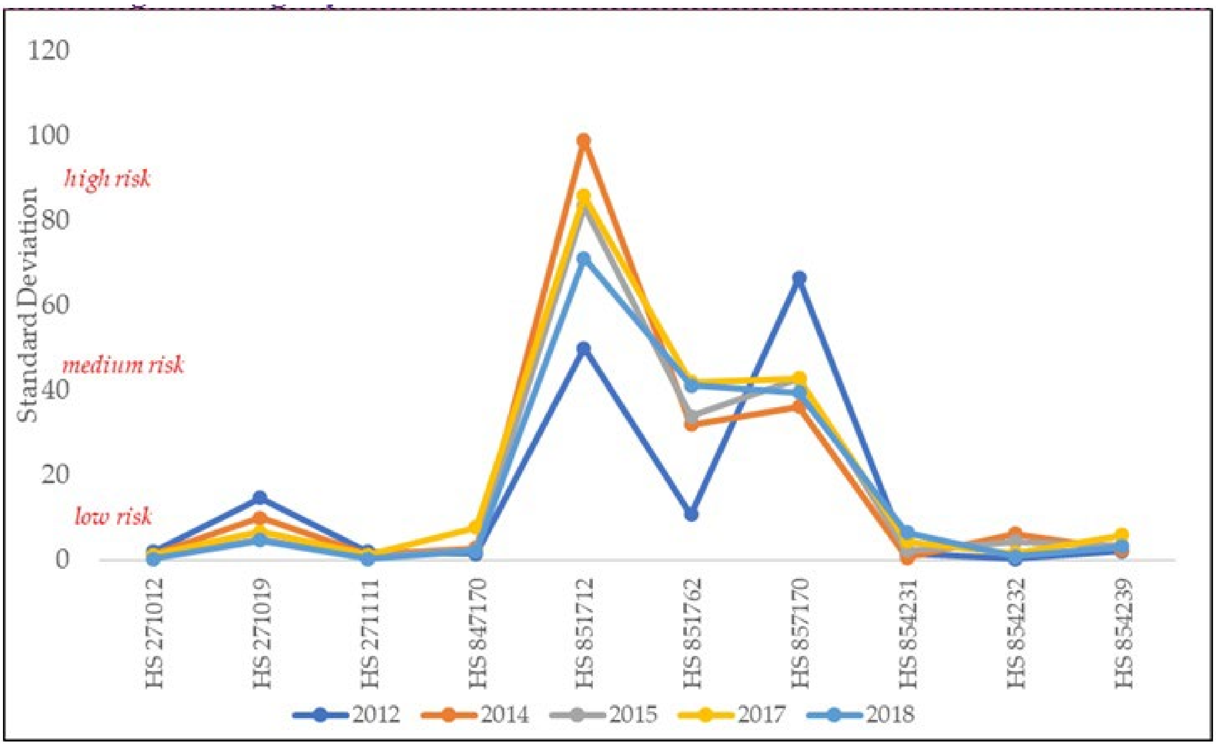
**Table 7: Fragility Assessment 1 – Out-Degree Centrality**

| Year | HS 271012 | HS 271019 | HS 271111 | HS 847170 | HS 851712 | HS 851762 | HS 851770 | HS 854231 | HS 854232 | HS 854239 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | 2.075 | 14.870 | 2.075 | 1.648 | **50.063** | 10.904 | **66.585** | 1.569 | 0.419 | 2.179 |
| 2013 | 0.458 | 11.374 | 0.458 | 3.267 | **79.676** | 20.908 | **30.250** | 2.103 | 2.274 | 1.920 |
| 2014 | 1.296 | 10.069 | 1.296 | 2.961 | **99.217** | 32.029 | **36.377** | 0.696 | 6.383 | 2.594 |
| 2015 | 0.939 | 5.046 | 0.939 | 2.542 | **83.601** | 34.058 | **42.762** | 2.353 | 4.460 | 3.675 |
| 2016 | 0.684 | 4.944 | 0.684 | 6.263 | **91.355** | 33.087 | **45.176** | 5.165 | 3.117 | 3.988 |
| 2017 | 1.365 | 6.807 | 1.365 | 7.769 | **85.942** | 42.102 | **42.943** | 4.494 | 1.712 | 6.002 |
| 2018 | 0.370 | 4.842 | 0.370 | 2.233 | **71.289** | 41.348 | **39.649** | 6.590 | 1.093 | 3.238 |
| 2019 | 0.251 | 3.782 | 0.251 | 3.288 | **73.763** | 48.057 | **45.248** | 7.125 | 1.303 | 6.796 |
| 2020 | 0.263 | 2.695 | 0.263 | 1.957 | **76.677** | 52.648 | **46.911** | 8.106 | 2.947 | 7.627 |
| 2021 | 4.836 | 19.023 | 4.836 | 51.078 | **12.579** | 18.323 | **31.485** | 7.693 | 5.277 | 19.534 |

Source: Author's calculations based on analysis.

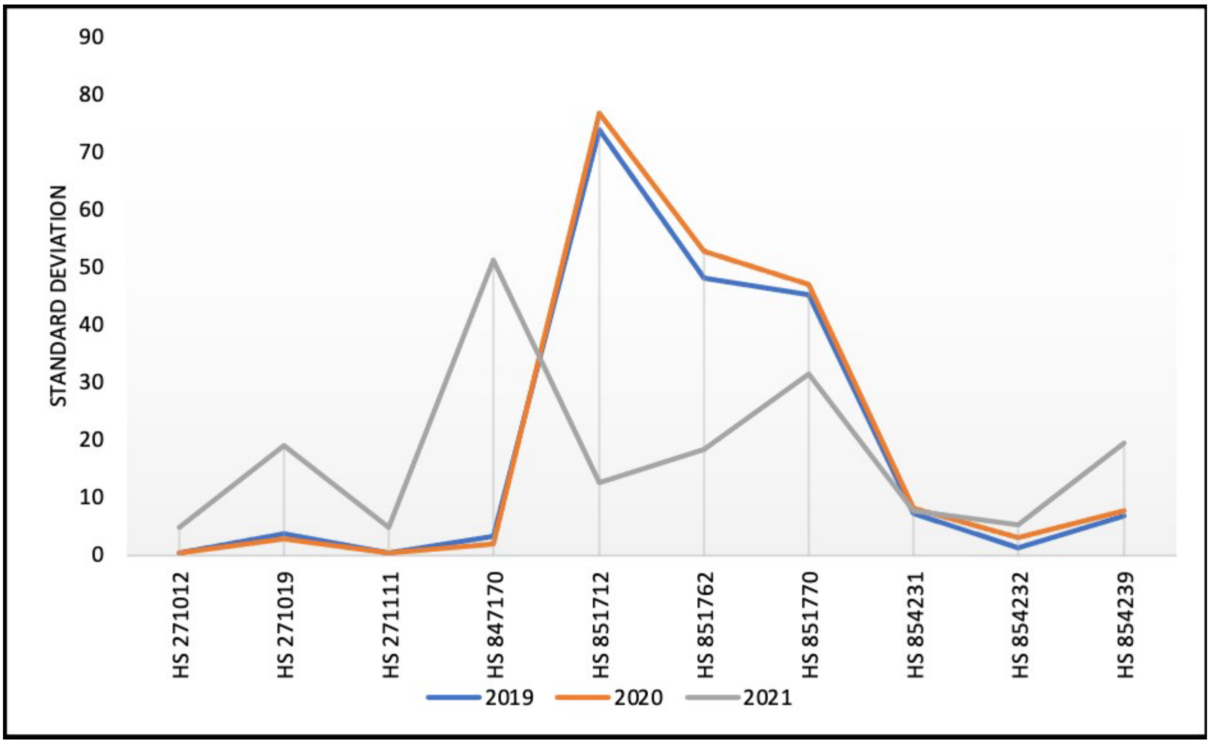
Amongst the 10 commodity groups studied, electrical products such as telephones for cellular networks (871512) and electrical parts of telephone has the highest out-degree centrality and, therefore, the highest standard deviation. These findings suggest that these products are highly sensitive.

**Figure 2: Fragility Assessment – Standard Deviation – Before the Pandemic**




Source: Author's representation based on analysis.

**Figure 3: Fragility Assessment – Standard Deviation – After the Pandemic**




Source: Author's representation based on analysis.

Figures 2 and 3 show the product riskiness based on standard deviation in two phases: before and after the pandemic. Figure 2 reveals that products HS 847170 (storage units for data processing machines), HS 851712 (electrical machinery products), HS 851762 (electrical–communication apparatus), and HS 851770 (electrical–telephone related) were identified as high-risk products before the COVID-19 pandemic year. However, after the COVID-19 pandemic, from 2020 to 2021, the spread of riskiness increased towards products such as electronic products (e.g. HS 854231, HS 854232, and HS 854239) (Figure 3). Most of these products are essential components of modern electronic devices and are used in parts and components of wide variety of applications. Henceforth, high demand could cause more vulnerable supply chains and further disruptions. Other reasons for the high riskiness is that they are specialised components that are not readily available.

#### 4.3.2. Fragility Assessment 2: Clustering Tendency within the ASEAN

The study also investigates another characteristic of product networks that increases potential spillover risks when countries cluster with active trade partners, in line with the findings of Korniyenko, Pinat, and Dew (2017). The two-way clustering tendency was analysed using (i) the weighted average local clustering coefficient, and (ii) the network diameter.

**Table 8: Fragility Assessment 2 – Clustering Coefficient**

| **Year** | **HS 271012** | **HS 271019** | **HS 271111** | **HS 847170** | **HS 851712** | **HS 851762** | **HS 851770** | **HS 854231** | **HS 854232** | **HS 854239** |
|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | 0.027 | 0.014 | 0.027 | 0.043 | 0.031 | 0.021 | 0.023 | 0.027 | 0.035 | 0.024 |
| 2013 | 0.065 | 0.023 | **0.065** | 0.040 | 0.027 | 0.011 | 0.025 | 0.027 | 0.035 | 0.042 |
| 2014 | **0.084** | 0.022 | **0.084** | 0.040 | 0.027 | 0.018 | 0.010 | 0.019 | 0.032 | 0.023 |
| 2015 | **0.058** | 0.019 | **0.058** | 0.034 | 0.025 | 0.014 | 0.014 | 0.016 | 0.032 | 0.038 |
| 2016 | **0.048** | 0.028 | **0.048** | 0.037 | 0.014 | 0.028 | 0.011 | 0.015 | 0.039 | 0.027 |
| 2017 | **0.056** | 0.027 | **0.056** | **0.061** | 0.025 | 0.030 | 0.015 | 0.024 | 0.037 | 0.026 |
| 2018 | **0.071** | 0.022 | **0.071** | **0.067** | 0.036 | 0.020 | 0.024 | 0.017 | 0.030 | 0.033 |
| 2019 | **0.086** | 0.019 | **0.086** | **0.091** | 0.039 | 0.033 | 0.051 | 0.022 | 0.037 | **0.051** |
| 2020 | 0.115 | 0.017 | 0.115 | **0.064** | **0.056** | 0.034 | 0.045 | 0.036 | 0.046 | 0.036 |
| 2021 | 0.058 | 0.017 | 0.058 | **0.053** | **0.058** | 0.023 | 0.027 | 0.013 | 0.024 | 0.025 |

Source: Author's calculations based on analysis.

The clustering coefficient measures the tendency of countries to cluster. The higher the clustering coefficient, the more likely countries will cluster. Meanwhile, the network diameter measures the maximum number of paths that separate two distant countries. The results show that bituminous minerals (HS 271012), (HS 71019), natural gas liquefied (HS 271111), storage units for data processing (HS 847170), and telephones for cellular networks (HS 851712) had high clustering coefficients in the product networks. These findings suggest that these products have higher spillover risks as they cluster amongst active trade partners. This may be due to identical production processes or complementary inputs, which can lead to interdependence amongst countries. The high clustering coefficients for certain products indicate a reasonably high concentration level amongst certain countries in the region and their partners.

Some of these products, such as storage units for data processing and telephones for cellular, are complementary inputs. This means that they are used together in the production of other products. For example, storage units for data processing are used in the production of computers, and telephones for cellular in the production of smartphones. This means that countries producing these products are likely trading partners, as they need to import the other products to make their own. The high clustering coefficients for certain products indicate a high level of interdependence amongst countries in the region. This means that countries rely on each other to supply these products. If there is a disruption in the supply of one of these products, it has a knock-on effect on the supply of other products.

Moreover, it can make it difficult for countries to meet the demand for these products and lead to higher prices. The increased clustering coefficients for these products also suggest a relatively high concentration of production in a few countries. This can pose challenges to export suppliers, as they may rely on a few buyers. If one of these buyers experiences a disruption, it can significantly impact the export supplier.

In conclusion, the high clustering coefficients for certain products suggest that these products may be subject to higher spillover risks. This is due to factors like similar production processes, complementary inputs, and interdependence. The high clustering coefficients also suggest a relatively high concentration of production in a few countries, which can pose challenges to export suppliers and increase vulnerability to supply chain disruptions.

### 4.3.3. Fragility Assessment 3: Network Diameter within the ASEAN

The network diameter results provide valuable insights into the potential spillover effects within the trade landscape. A high network diameter indicates more intermediary countries, which act as conduits for these effects. Therefore, in networks with larger diameters, shocks or disturbances in one country can rapidly permeate through these intermediaries, leading to swift and widespread repercussions across the network. Conversely, a shorter diameter suggests that the impact of shocks is more likely to be contained and localised, as there are fewer countries in the transmission path for the spillover to propagate.

**Table 9: Fragility Assessment 3 – Diameter**

| Year | HS 271012 | HS 271019 | HS 271111 | HS 847170 | HS 851712 | HS 851762 | HS 851770 | HS 854231 | HS 854232 | HS 854239 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 3 |
| 2013 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 3 |
| 2014 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| 2015 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 3 |
| 2016 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 4 | 3 |
| 2017 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 3 |
| 2018 | 4 | 3 | 4 | 4 | 3 | 4 | 3 | 3 | 3 | 4 |
| 2019 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 2020 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 2021 | 3 | 4 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 |

Source: Author's calculations based on analysis.

Within the framework of fragility analysis, the network diameter stands out as a crucial metric indicating susceptibility to systemic shocks. When the network diameter is high, it signifies a dense web of interconnections, wherein a disruption at one node can cascade across numerous other nodes, magnifying its impact. Drawing from the realm of electronics, consider the potential ripple effects stemming from a disturbance in the production of storage units for data processing (HS 847170). Such a perturbation doesn't just stay localised; it reverberates across the spectrum of electronics, potentially throttling the production pipelines of related products, such as computers, smartphones, integrated circuit processors (HS 854231), and electronic memories (HS 854232).

These products, in particular, boast high network diameters chiefly because of their ubiquity across various electronic items. Their widespread use means a diverse set of countries manufactures them, each interwoven in a labyrinthine supply chain network. Thus, a production or supply chain bottleneck in any of these products isn't merely a localised crisis—it's a potential global snag. This multifaceted interdependency underscores the inherent vulnerabilities and risks. When one node faces disruption, the repercussions are not linear; they are exponential, affecting many countries, industries, and, by extension, global markets. Recognising and understanding such nuances is vital for policymakers and industry leaders as they strategise to bolster the resilience of these interconnected trade networks.

## 5. Conclusions

In today's globalised world, international trade has become increasingly interconnected, and the ASEAN region is no exception. To better understand the competitiveness and complementarity of trade in goods amongst ASEAN and their trade partners, we have conducted a comprehensive analysis of trade indexes and trade network analysis. The study was based on the HS 6-digit goods classification from 2010 to 2021. Apart from competitiveness and complementarity, the study also examined the fragility of trade in goods in terms of risky products in the import baskets of ASEAN. It identified the role of central players in spreading riskiness and vulnerability. The study considered a sample of 10 ASEAN economies and 110 trade partners.

The trade characteristics of the ASEAN region demonstrate that trade complementarity holds more dominance than trade similarities. An analysis of the ESI suggests that there is less similarity in export patterns amongst AMS, with only a few exceptions such as natural gas and electronic integrated circuits. The analysis of trade competitiveness indicates a decline in trade similarity for some products, while others, such as liquefied natural gas, remain stable. The TCI analysis reveals that certain products, including bituminous minerals, natural gas, and electrical items, exhibit high complementarity, leading to increased competitiveness and efficiency. The trade complementarity network graphs demonstrate consistency over time, indicating strong trade relationships within the region and the potential for expansion and cooperation. In the inter-regional TCI, it was found that Singapore has traded with a variety of countries, including Korea, Australia, and Mozambique, indicating growing complementarity in their trade of bituminous minerals, liquefied natural gas, and storage units for data processing. In the intra-regional TCI, it was found that there has been a consistent increase in the TCI between Singapore, Viet Nam, and Thailand in their trade in bituminous minerals. The competition network pattern, analysed using trade network analysis, provides valuable insights into the evolving trade patterns amongst ASEAN and their trading partners. The study finds that the trade networks are dense and intense in trade in goods. The density and complexity of the trade networks vary across different product categories, with electrical products, electronics, and bituminous minerals showing dense networks with numerous connections.

Global shocks such as the COVID-19 pandemic can have a significant impact on trade networks and cause economic disruptions. To evaluate the fragility of products, this study employed out-degree centrality, clustering tendency measures, and network diameters, revealing that electrical products related to telecommunications are particularly vulnerable and sensitive. Moreover, since the pandemic, the risk level of products increased towards electronics, underscoring the importance of effective risk management strategies to ensure supply chain resilience. The study also analysed the clustering tendency and network diameter of product networks to identify potential spillover risks amongst active trade partners. The results for the clustering tendency show that bituminous minerals (HS 271012), bituminous minerals with biodiesel (HS 271019), natural gas liquefied (HS 271111), storage units for data processing (HS 847170), and telephones for cellular (HS 851712) had high clustering coefficients in the product networks. This may be due to identical production processes or complementary inputs, which can lead to interdependence amongst countries. This stems from factors such as similar production processes, complementary inputs, and interdependence. The high clustering coefficients also suggest a relatively high concentration of production in a few countries, which can pose challenges to export suppliers and increase vulnerability to supply chain disruptions. Similarly, the study found that fragility amongst storage units for data processing (HS 847170), electronics – integrated circuit processors (HS 854231), and electronics – memories (HS 854232) have high network diameters because they are essential components in many different products. This means that they are produced by a wide range of countries and are traded through a complex network of supply chains. As a result, a disruption to the production or supply of any of these products could have a significant impact on many other countries and industries.

These findings hold significant policy implications, emphasising the need for policymakers to prioritise understanding trade linkages and potential spillover effects when designing policies aimed at mitigating the impact of shocks. The study underscores the importance of coordinated policy responses and collaboration amongst ASEAN to minimise the negative effects of shocks on their economies. Overall, the study highlights the need for proactive and collaborative approaches towards managing and reducing the impact of shocks on the region's economies.

As policy interventions, it is necessary to devise policies that are relevant to ASEAN:

(i) Promoting regional integration and competitiveness

ASEAN could promote regional economic integration and competitiveness by extending trade relations with more countries and investing in highly competitive sectors. This would help to increase the number of potential trading partners for ASEAN businesses, which would boost trade and economic growth in the region. Investing in highly competitive sectors would help to attract foreign investment and create jobs, which would also contribute to economic growth.

(ii) Managing supply chain disruptions

ASEAN could manage supply chain disruptions by diversifying suppliers, investing in technology and infrastructure, and promoting collaboration and information sharing amongst supply chain stakeholders. Diversifying suppliers would reduce the risk of disruptions caused by a single supplier. Investing in technology and infrastructure would help to make supply chains more resilient to shocks. Promoting collaboration and information sharing would help to improve coordination and communication amongst supply chain stakeholders, which would help to mitigate the impact of disruptions.

(iii) Understanding trade linkages and potential spillover effects

Shocks can have a ripple effect through trade linkages, affecting not only the country that is directly affected by the shock, but also other countries that are linked to it through trade. By understanding these trade linkages and potential spillover effects, policymakers could design policies that are more effective in mitigating the impact of shocks. This could be done by gathering information on trade linkages and potential spillover effects through a variety of sources, including trade data, economic models, and expert opinion. This information could then be used to design policies that are targeted at the specific risks that are identified.

(iv) Coordinating policy responses and collaboration

AMS should coordinate their policy responses and collaborate to minimise the negative effects of shocks on their economies. This is because shocks can have a significant impact on economies, and they can be even more damaging if they are not managed effectively. By coordinating their policy responses and collaborating, AMS could ensure that they are better prepared to respond to shocks and minimise their negative impact. This could be done through a variety of channels, including the ASEAN Economic Community and the

ASEAN+3 Finance Ministers' Meetings. They could also collaborate on a range of initiatives, such as the development of early warning systems and the sharing of information.

(v) Relevance of the policy implications to ASEAN

The policy implications are relevant to ASEAN because they address the specific challenges that the region faces in terms of trade and economic integration. They also take into account the lessons that have been learnt from previous shocks, such as the COVID-19 pandemic. For example, the COVID-19 pandemic has shown that ASEAN economies are vulnerable to shocks that originate outside the region. By implementing the policy implications, ASEAN could become more resilient to future shocks and contribute to the region's economic growth and development.

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**Appendix I: Top 3 ASEAN Country Pairs – Intra-Regional (TCI)**

| Product Name | 2010 | 2015 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Bituminous minerals (HS 271012) | NA | Singapore–Thailand Singapore–Viet Nam Brunei–Singapore | Singapore–Thailand Singapore–Viet Nam Brunei–Singapore | Singapore–Thailand Singapore–Viet Nam Brunei–Singapore | Singapore–Thailand Singapore–Viet Nam Brunei–Singapore |
| Bituminous minerals without biodiesel (HS 271019) | Brunei–Singapore Cambodia–Singapore Indonesia–Singapore | Brunei–Singapore Cambodia–Singapore Indonesia–Singapore | Brunei–Singapore Cambodia–Singapore Indonesia–Singapore | Brunei–Singapore Cambodia–Singapore Indonesia–Singapore | Brunei–Singapore Cambodia–Singapore Indonesia–Singapore |
| Natural gas, liquefied (HS 271111) | Singapore–Indonesia Malaysia–Indonesia Brunei–Malaysia | Indonesia–Myanmar Malaysia–Myanmar Thailand–Myanmar | Indonesia–Myanmar Malaysia–Myanmar Thailand–Myanmar | Brunei–Malaysia Indonesia–Malaysia Singapore–Malaysia | Brunei–Malaysia Indonesia–Malaysia Singapore–Malaysia |
| Storage units for data processing (HS 847170) | Brunei–Thailand Cambodia–Thailand Indonesia–Thailand | Brunei–Thailand Cambodia–Thailand Indonesia–Thailand | Thailand–Philippines Cambodia–Philippines Singapore–Philippines | Thailand–Philippines Cambodia–Philippines Singapore–Philippines | Thailand–Philippines Cambodia–Philippines Singapore–Philippines |
| Telephones for cellular networks (HS 851712) | Myanmar–Viet Nam Malaysia–Viet | Myanmar–Viet Nam Malaysia–Viet | Myanmar–Viet Nam Malaysia–Viet | Myanmar–Viet Nam Malaysia–Viet | Myanmar–Viet Nam Malaysia–Viet |

| Product Name | 2010 | 2015 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| | Nam<br>Philippines–Viet Nam | Nam<br>Philippines–Viet Nam | Nam<br>Philippines–Viet Nam | Nam<br>Philippines–Viet Nam | Nam<br>Philippines–Viet Nam |
| Electrical communication apparatus (HS 851762) | Brunei–Singapore<br>Cambodia–Singapore<br>Indonesia–Singapore | Singapore–Malaysia<br>Brunei- Malaysia<br>Cambodia–Malaysia | Singapore–Viet Nam<br>Brunei–Viet Nam<br>Lao PDR–Viet Nam | Singapore–Viet Nam<br>Brunei–Viet Nam<br>Lao PDR–Viet Nam | Singapore–Viet Nam<br>Brunei–Viet Nam<br>Lao PDR–Viet Nam |
| Electrical parts of telephone (HS 851770) | Brunei–Thailand<br>Cambodia–Thailand<br>Indonesia–Thailand | Thailand–Viet Nam<br>Malaysia–Viet Nam<br>Brunei–Viet Nam | Thailand–Viet Nam<br>Malaysia–Viet Nam<br>Brunei–Viet Nam | Thailand–Viet Nam<br>Malaysia–Viet Nam<br>Brunei–Viet Nam | Thailand–Viet Nam<br>Malaysia–Viet Nam<br>Brunei–Viet Nam |
| Electronics – integrated circuit – processors (HS 854231) | Brunei–Malaysia<br>Indonesia–Malaysia<br>Philippines–Malaysia | Thailand–Singapore<br>Brunei–Singapore<br>Cambodia–Singapore | Indonesia–Philippines<br>Malaysia–Philippines<br>Singapore–Philippines | Indonesia–Philippines<br>Malaysia–Philippines<br>Singapore–Philippines | Indonesia–Philippines<br>Malaysia–Philippines<br>Singapore–Philippines |
| Electronics – memories (HS 854232) | Brunei–Singapore<br>Indonesia–Singapore<br>Philippines–Singapore | Brunei–Singapore<br>Indonesia–Singapore<br>Philippines–Singapore | Brunei–Singapore<br>Indonesia–Singapore<br>Philippines–Singapore | Brunei–Singapore<br>Indonesia–Singapore<br>Philippines–Singapore | Brunei–Singapore<br>Indonesia–Singapore<br>Philippines–Singapore |
| Electronics – integrated circuits (HS 854239) | Brunei–Singapore<br>Indonesia– | Brunei–Singapore<br>Indonesia– | Brunei–Singapore<br>Indonesia– | Brunei–Singapore<br>Indonesia– | Brunei–Singapore<br>Indonesia– |

| Product Name | 2010 | 2015 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| | Singapore<br>Malaysia–<br>Singapore | Singapore<br>Malaysia–<br>Singapore | Singapore<br>Malaysia–<br>Singapore | Singapore<br>Malaysia–<br>Singapore | Singapore<br>Malaysia–<br>Singapore |

Source: Author's representation based on analysis. ASEAN = Association of Southeast Asian Nations, NA = not applicable, TCI = trade complementarity index.

**Appendix II: Top 3 ASEAN Country Pairs – Inter-Regional (TCI)**

| Product Name | 2010 | 2015 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Bituminous minerals (HS 271012) | NA | Indonesia–Timor-Leste<br>Indonesia–Japan<br>Indonesia–India | Singapore–Rep. of Korea<br>Singapore–Australia<br>Singapore–Pakistan | Singapore–Australia<br>Singapore–Pakistan | Singapore–Taiwan<br>Singapore–Rep. of Korea<br>Singapore–Australia |
| Bituminous minerals without biodiesel (HS 271019) | Singapore–Australia<br>Singapore–China<br>Singapore–Hong Kong | Singapore–Italy<br>Singapore–Japan<br>Singapore–Taiwan | Singapore–Japan<br>Singapore–Taiwan<br>Singapore–Mozambique | Singapore–Canada<br>Singapore–Denmark<br>Singapore–France | Singapore–Canada<br>Singapore–Denmark<br>Singapore–France |
| Natural gas, liquefied (HS 271111) | Indonesia–Indonesia<br>Malaysia–Indonesia<br>Singapore–Malaysia | Indonesia–Myanmar<br>Malaysia–Myanmar<br>Thailand–Myanmar | Indonesia–Myanmar<br>Malaysia–Myanmar<br>Thailand–Myanmar | Singapore–Malaysia<br>Indonesia–Malaysia<br>Singapore–Malaysia | Singapore–Malaysia<br>Indonesia–Malaysia<br>Singapore–Malaysia |
| Storage units for data processing (HS 847170) | Malaysia–Hong Kong<br>Singapore–UK<br>Thailand–North Korea | Malaysia–Hong Kong<br>Singapore–UK<br>Singapore–North Korea | Malaysia–Hong Kong<br>Singapore–UK<br>Singapore–North Korea | Malaysia–Hong Kong<br>Singapore–UK<br>Singapore–North Korea | Malaysia–Hong Kong<br>Singapore–UK<br>Singapore–North Korea |
| Telephones for cellular networks (HS 851712) | Indonesia–Hungary<br>Malaysia–Hungary<br>Myanmar–Hungary | Singapore–Mauritius<br>Indonesia–Mauritius<br>Viet Nam–Mauritius | Viet Nam–Macao<br>Malaysia–Macao<br>Philippines–Macao | Viet Nam–Macao<br>Malaysia–Macao<br>Philippines–Macao | Viet Nam–Macao<br>Malaysia–Macao<br>Philippines–Macao |

| Product Name | 2010 | 2015 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Electrical communication apparatus (HS 851762) | Singapore–China<br>Singapore–Denmark<br>Singapore–France | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia | Thailand–Hong Kong<br>Thailand–Rep. of Korea<br>Thailand–Australia | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia |
| Electrical parts of telephone (HS 851770) | Singapore–Australia<br>Thailand–Austria<br>Singapore–Canada | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia | Singapore–Hong Kong<br>Singapore–Rep. of Korea<br>Singapore–Australia |
| Electronics – integrated circuit – processors (HS 854231) | Singapore–Australia<br>Singapore– Hong Kong<br>Cambodia–Hong Kong | Singapore–Australia<br>Singapore–Hong Kong<br>Cambodia–Hong Kong | Singapore–Australia<br>Singapore–Hong Kong<br>Cambodia–Hong Kong | Singapore–Australia<br>Singapore–Hong Kong<br>Cambodia–Hong Kong | Singapore–Australia<br>Singapore–Hong Kong<br>Cambodia–Hong Kong |
| Electronics – memories (HS 854232) | Singapore–Hong Kong<br>Singapore–Taiwan<br>Singapore–US | Singapore–Hong Kong<br>Singapore–Taiwan<br>Singapore–US | Singapore–Hong Kong<br>Singapore–Taiwan<br>Singapore–US | Singapore–Hong Kong<br>Singapore–Taiwan<br>Singapore–US | Singapore–Hong Kong<br>Singapore–Taiwan<br>Singapore–US |
| Electronics – | Singapore–China | Singapore–China | Singapore–China | Singapore–China | Singapore–China |

| Product Name | 2010 | 2015 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| integrated circuits (HS 854239) | Singapore–Germany<br>Singapore–Poland | Singapore–Germany<br>Singapore–Poland | Singapore–Germany<br>Singapore–Poland | Singapore–Germany<br>Singapore–Poland | Singapore–Germany<br>Singapore– Poland |

Source: Author's representation based on analysis.

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