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Stratification in Southeast Asia's semiconductor supply chain: Evidence from the perspective of intra-industry trade

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Abstract: Amidst the profound geo-economic restructuring of the global semiconductor supply chain, this study quantifies the Grubel-Lloyd (GL) index to measure the extent of intra-industry trade (IIT) for semiconductor products across six ASEAN economies during the 2021–2025 period. By employing the Grubel-Lloyd (GL) index on highly disaggregated trade data (6-digit HS codes) computed against the world, Research indicate that integration into the intra-regional production network is heterogeneous, forming a distinct multi-tiered differentiated structure. Quantitative results categorize the region into three distinct tiers: (1) High IIT ($GL > 0.8$) in Thailand and Vietnam, characterized by export-oriented downstream processing where high indices largely reflect processing and packaging operations conducted by foreign affiliates, albeit with positive signals of functional upgrading in supporting components; (2) Medium but mature IIT ($GL = 0.616\text{--}0.836$) in Singapore and Malaysia, where Singapore's robust trade surpluses underscore its upstream dominance as a design and net component supplier, while Malaysia solidifies its midstream integration by transitioning toward advanced Assembly, Testing, and Packaging (ATP); and (3) low and volatile IIT ($GL = 0.557$ on the period mean) in Indonesia, reflecting an asymmetric dependence on imported inputs. The Philippines is a distinct case: Its level remains high at 0.810, but it records the steepest decline in the sample, from 0.957 in 2021 to 0.686 in 2025, indicating a progressive shift toward one-way import dependence. Based on these findings, the study argues that advancing from VIIT to Horizontal Intra-Industry Trade (HIIT) is imperative. And alongside upgrading their domestic supporting industries, human capital, and infrastructure, ASEAN countries need to forge a regional production network predicated on complementary advantages. This integration is the key for the ASEAN bloc to build a self-reliant ecosystem, enhance resilience, and ascend to higher value echelons in the global technology landscape.

Keywords: Intra-industry trade; Grubel-Lloyd index; ASEAN; global value chain

1. Introduction

The global semiconductor industry is characterized by a deeply fragmented and knowledge-intensive Global Value Chain (GVC) [1–3]. Recently, severe geopolitical disruptions and the US-China technological decoupling have accelerated the “China plus one” strategy, propelling Southeast Asia (ASEAN) into a strategic destination for production relocation [4]. However, the integration of ASEAN economies into this network is not uniform but heavily stratified. To conceptualize this multi-tiered division of labor, this study grounds its framework in the theory of Intra-Industry Trade (IIT), particularly Vertical Intra-Industry Trade (VIIT). Within highly fragmented sectors like semiconductors, VIIT acts as an empirical mapping, reflecting the cross-border exchange of components at different processing stages and illuminating a country's precise positioning—from upstream design to downstream

assembly—within the global supply chain [5].

Despite the critical role of ASEAN in the global semiconductor realignment, existing empirical literature exhibits significant research gaps. First, previous studies predominantly approach GVCs from a macro-level perspective of the general electronics industry, lacking highly disaggregated analyses (e.g., at the 6-digit HS code level) that capture the distinct fragmentation of semiconductor components [6,7]. Second, while conventional macro-trade flows are well-documented, there is a scarcity of research employing specialized measurement tools — most notably the Grubel-Lloyd (GL) index — to quantitatively demonstrate the upstream-downstream stratification among ASEAN member states [7]. Finally, the rapid restructuring of the production map driven by the post-pandemic context and recent geoeconomic shifts necessitates updated empirical studies utilizing the latest data (2021–2025) to accurately capture the dynamic realities of regional supply chains [8].

To bridge these theoretical and empirical gaps, this study utilizes the Grubel-Lloyd index on highly disaggregated trade data computed against the world to measure IIT intensity across six ASEAN economies. Specifically, the research addresses the following core questions: (1) How has the intra-industry trade intensity of semiconductor products in ASEAN economies evolved during the turbulent 2021–2025 period? (2) How does the quantitative trajectory of the GL index dynamically reveal the heterogeneous, multi-tiered stratification of these countries within the global semiconductor production network? (3) Based on these empirical footprints, what strategic pathways can ASEAN nations adopt to transition from downstream processing traps to higher value-added stages? By answering these questions, the study not only enriches the academic discourse on IIT but also provides actionable evidence for policymakers navigating the new technological era.

2. Literature review

2.1. Global value chains

The development of Global Value Chains (GVCs) is closely associated with the theory of production fragmentation [9]. According to this theory, the production process of a final good is no longer concentrated within a single country; rather, it is disaggregated into distinct stages and distributed globally. Countries participate in GVCs by specializing in specific stages (such as design, prototyping, or assembly and testing) to maximize their comparative advantages in labor costs, technology, or natural resources.

It is precisely this production fragmentation within GVCs that serves as the fundamental driver generating and promoting Intra-Industry Trade [2]. In highly fragmented industries such as semiconductors, the interdependence among cross-border production facilities leads to a massive crossflow of intermediate goods, components, and parts. Cheong and Yoo emphasize that through GVCs, countries exchange products with the same core functionality (falling under the same HS code) but varying in quality, technology, or processing stage [10]. This exchange is the very embodiment of Vertical Intra-Industry Trade (VIIT). Therefore, IIT, particularly VIIT, is not merely a trade phenomenon but an empirical footprint directly reflecting a country's integration and division of labor within the structure of GVCs.

2.2. Intra-industrial trade

The concept of intra-industry trade (IIT) began to receive wide scholarly attention in the 1960s, originating from analyses of the formation of the European Economic Community (EEC) and the process of trade liberalization. Contrary to the traditional theory of inter-industry specialization, empirical studies identified a new phenomenon: The rapid expansion of trade within the same industry among EEC member countries [11–13].

Conceptually, Balassa [14,15] defines IIT as the process in which a country simultaneously exports and imports products belonging to the same industrial sector within a given period. More broadly, Grubel and Lloyd [16] argue that IIT represents the two-way exchange of identical or similar goods; such exchange may take place either at the same stage of production or across different stages of production among countries.

Based on criteria relating to product attributes, quality, and price levels, Yusefzadeh et al. [17] decompose IIT into two main forms:

Horizontal Intra-Industry Trade (HIIT): This refers to the cross-exchange of products that are similar in quality and price level but differ in design, style, or specific characteristics. The models developed by Helpman [18], Krugman [19,20] and Lancaster [21] indicate that HIIT tends to develop strongly among economies with similar levels of development and income, as a response to increasingly diversified consumer preferences.

Vertical Intra-Industry Trade (VIIT): This occurs when countries exchange products within the same industry that differ significantly in quality, price, or stages of the value chain. Drawing on the theory of comparative advantage, Flam and Helpman [22] argue that countries abundant in capital and technology tend to specialize in exporting high-quality goods, while labor-abundant countries tend to export lower-quality products. In general, VIIT is a common trade pattern among partners with different levels of economic development [23].

2.3. Measurement of intra-industry trade

Since its introduction in 1975, the Grubel–Lloyd Index, or G–L Index, has become a standard and widely used tool for measuring the degree of intra-industry trade. Applying the G–L Index to semiconductor products in Southeast Asian countries, the intensity of IIT can be expressed as follows:

$$IIT_{jt} = \frac{(X_{jt} + M_{jt}) - |X_{jt} - M_{jt}|}{X_{jt} + M_{jt}} = 1 - \frac{|X_{jt} - M_{jt}|}{X_{jt} + M_{jt}} \quad (1)$$

Where: j denotes the semiconductor sector of country j

t denotes time.

IIT_{jt} is the intra-industry trade index for semiconductor products of country j in period t .

X_{jt} is the export value of semiconductor products of country j in period t .

M_{jt} is the import value of semiconductor products of country j in period t .

Accordingly, the value of the IIT index ranges from 0 to 1.

If $IIT_{jt} = 0$ or when either exports or imports are equal to zero, the trade

relationship between countries is entirely inter-industry trade.

If $IIT_{jt} = 1$ (when $X_{jt} = M_{jt}$), the trade relationship between countries is entirely intra-industry trade.

To provide a more specific assessment of the degree of intra-industry trade, Lima and Alvarez [24] classify IIT into three levels:

- $IIT > 0.33$: Significant intra-industry trade.
- $0.1 \leq IIT \leq 0.33$: Potential for intra-industry trade.
- $IIT < 0.1$: No intra-industry trade, meaning trade is mainly inter-industry in nature.

The restructuring of GVCs - often triggered by geopolitical shocks or shifts in foreign direct investment flows - alters the distribution of production stages across countries. Although the Grubel-Lloyd index was originally designed to measure IIT intensity at a static point in time, the dynamic changes of the G-L index at a highly disaggregated product level (the 6-digit HS code) can be utilized as an effective tool to identify these structural shifts [25].

Specifically, a continuous increase in the G-L index for an intermediate component segment indicates that the country is integrating more deeply into a two-way production network (importing raw materials while exporting semi-finished products), typical ATP hubs. Conversely, a decline in the G-L index accompanied by an increasing trade surplus may signal a value chain upgrading process, as the country transitions into the role of an upstream component supplier; whereas a decreasing G-L index coupled with a substantial trade deficit reflects signs of divergence or a downgrade to downstream processing activities. Therefore, tracking the trajectory of the G-L index provides crucial empirical evidence of the repositioning of economies within GVCs.

This study utilizes aggregate country-to-world trade data (comprising export and import values) extracted from the International Trade Centre's TradeMap database, as of the 2026 update. The scope of the data is focused on the semiconductor sector, compiled at the highly disaggregated 6-digit HS code level. The research sample comprises six representative ASEAN economies (Vietnam, Thailand, Singapore, Malaysia, the Philippines, and Indonesia), covering the period from 2021 to 2025.

To ensure the reliability and objectivity of the quantitative analyses, the data processing procedure is executed as follows:

- Harmonization and standardization: All raw export and import trade value data are standardized into a uniform currency unit (USD) to guarantee consistency when comparing cross-country trade flows.
- Calculation of the G-L Index: Rather than relying on aggregated data, this study directly utilizes micro-level trade data (at the 6-digit HS level) to compute intra-industry trade (IIT) intensity using the Grubel-Lloyd formula. Computing the G-L index at the most granular subheading level allows for the precise measurement of two-way trade and eliminates aggregation bias, thereby accurately reflecting the positioning of countries within specific segments of the semiconductor supply chain.

2.4. The semiconductor supply chain

The global semiconductor supply chain is highly fragmented, specialized, and

geographically concentrated according to the comparative advantages of individual countries [26]. According to reports by the Semiconductor Industry Association (SIA) and Boston Consulting Group (BCG), this network can be divided into three major segments: Upstream activities, including research and development, design, equipment, and materials; midstream activities, including wafer fabrication and foundry production; and downstream activities, including assembly, testing, and packaging (ATP) [27,28].

However, value added is unevenly distributed across the chain. Design and intellectual property account for nearly 60 % of total value, manufacturing contributes approximately 19 %, while downstream activities, particularly ATP, generate only around 6 % of total value [29]. Studies by Prabheesh and Vidya [3] and Tung [28] show that this structure leads to clear polarization within the semiconductor value chain. The United States, the European Union, and Japan dominate the upstream stages, which generate the highest value and involve complex technological capabilities. By contrast, East Asia, represented by Taiwan, South Korea, and China, leads in chip foundry production, while developing countries mainly undertake ATP activities.

According to the analysis of S&P Global Mobility [30], however, strategic competition between the United States and China, disruptions caused by the COVID-19 pandemic, and geopolitical risks are profoundly driving the restructuring of global supply chains. To reduce risks arising from excessive concentration, multinational corporations are actively adopting “China plus one” or “Taiwan plus one” strategies, relocating production capacity to safer regions in order to strengthen supply chain resilience [29].

In the context of global restructuring, Southeast Asia, or ASEAN, has emerged as a strategic destination for diversifying production networks and attracting strong foreign direct investment (FDI) inflows [31]. According to reports by SEMI and BCG, ASEAN accounted for nearly 20 % of global assembly, testing, and packaging capacity in 2022, and this share is expected to rise to 27 % by 2032 [29].

Pau & Yong [7] indicate that the production network in ASEAN shows clear multi-tiered differentiation based on technological capabilities and the degree of integration. Specifically, the regional supply chain can be divided into the following stages of labor specialization: First, the leading group, or upstream segment, is represented by Singapore, which serves as a center of innovation and network coordination, focusing on chip design, equipment manufacturing, and advanced technologies. This country currently contributes approximately 11 % of global semiconductor output and 20 % of global semiconductor equipment production [32]. Second, the intermediate group, or complete assembly segment, is represented by Malaysia, which is one of the world’s leading assembly and testing hubs, accounting for around 13 % of global ATP capacity, with the presence of major corporations such as Intel and Infineon [32]. Within this group, Thailand is also positioning itself as a semiconductor production hub serving the automotive and power electronics sectors [29]. Third, the downstream group, or ATP segment, includes Vietnam and the Philippines, which are currently located in the downstream part of the value chain, mainly undertaking processing, assembly, and final testing activities. Nevertheless, these countries are making effective use of the FDI relocation wave. Vietnam, for

example, has attracted significant investment from Intel, Samsung, and Amkor, while setting a strategic objective to upgrade its position toward higher stages such as chip design and wafer fabrication by 2030 [33].

2.5. Positioning of this study relative to the existing empirical literature

Appendix **Table A1** situates the present study within the empirical literature on intra-industry trade and on the semiconductor global value chain. Three observations follow. First, the studies that apply the Grubel-Lloyd index to this region do so for the electrical and electronics aggregate rather than for semiconductor subheadings, so distinct processing stages are conflated; the closest methodological precedent at the 6-digit level, Czarny et al. [25], is global in scope and not sector-specific. Second, the studies that address the semiconductor value chain directly Prabheesh and Vidya [3], Liu and Kang [6], Pau and Yong [7] rely on network-analytic or participation indicators rather than on a quantitative measure of two-way trade. Third, none of them covers the post-pandemic reconfiguration of 2021–2025.

These three gaps define the contribution of this study. They also frame the comparisons made in Section 5.4, where the indices obtained here are set against the orderings reported in the studies listed below. One limitation should be stated at the outset: Prabheesh and Vidya [3] cover both HS 8541 and HS 8542, whereas the dataset used here contains HS 8541 only, so integrated circuits fall outside the measurement.

3. Data and methodology

3.1. Data source and scope

Export and import values are drawn from the International Trade Centre TradeMap database, retrieved on the 28th, April, 2026. TradeMap reports these series as ITC calculations based on ASEAN statistics from January 2022 onwards and on UN Comtrade statistics up to January 2022; the change of underlying source in the middle of the sample period is noted here because it bears on comparability across 2021 and 2022. All values are given in thousands of current United States dollars in the source and are converted to billions in **Table 1**. The scope is heading HS 8541 at the 6-digit level, comprising the fourteen subheadings listed in **Table A2**. Heading HS 8542, under which electronic integrated circuits are classified, is not contained in this dataset; the coverage of the study is therefore confined to discrete semiconductor devices, optoelectronic and photovoltaic devices, mounted piezo-electric crystals and their parts. The sample comprises Vietnam, Thailand, Singapore, Malaysia, the Philippines and Indonesia.

Two features of the raw data require explicit treatment. First, coverage of the final year is incomplete: At the time of retrieval no 2025 return had been filed for Vietnam, so Vietnam is observed over 2021–2024 and the remaining five reporters over 2021–2025. The corresponding cells are reported as n.a. rather than as zero, since a zero would be read as an absence of trade rather than an absence of data. Second, the 2022 revision of the Harmonized System restructured heading 8541 in the middle of the sample period, and the six reporters did not adopt the new nomenclature simultaneously; this is addressed in Section 3.2.

Table 1. Export and import values and aggregate Grubel–Lloyd indices for semiconductor products in ASEAN countries, 2021–2025 (trade values in USD billion).

Country	Trade flow	2021	2022	2023	2024	2025	Mean
Vietnam	Exports	4.89	7.53	8.67	6.37	n.a.	0.861
	Imports	4.52	5.12	5.65	5.06	n.a.	
	GL index	0.961	0.810	0.789	0.885	n.a.	
Thailand	Exports	2.66	3.42	5.20	3.72	2.66	0.883
	Imports	2.55	2.89	3.59	3.08	4.01	
	GL index	0.979	0.916	0.817	0.906	0.798	
Singapore	Exports	11.26	13.13	12.79	11.32	11.72	0.703
	Imports	6.12	6.42	5.91	6.13	8.11	
	GL index	0.704	0.657	0.632	0.703	0.818	
Philippines	Exports	1.68	1.71	1.32	0.97	1.07	0.810
	Imports	1.83	2.13	1.80	1.93	2.05	
	GL index	0.957	0.891	0.846	0.669	0.686	
Malaysia	Exports	8.24	9.34	10.24	8.18	6.61	0.690
	Imports	4.18	4.45	4.56	4.20	4.75	
	GL index	0.673	0.645	0.616	0.679	0.836	
Indonesia	Exports	0.19	0.36	0.40	0.79	3.31	0.557
	Imports	0.56	1.18	1.04	0.61	0.80	
	GL index	0.507	0.468	0.556	0.871	0.389	

Source: Authors' calculations based on data from TRADEMAP 2026

Note: The GL index is computed over the whole of heading HS 8541 against the world. n.a. indicates that no 2025 return had been filed by Vietnam at the time of retrieval; such cells are excluded from the period mean, which for Vietnam covers 2021–2024.

3.2. Concordance between HS2017 and HS2022

The HS2022 revision replaced subheading 854140 with the series 854141 to 854149 and split 854150 into 854151 and 854159. Adoption was not simultaneous across reporters. Vietnam, Thailand, Singapore, Malaysia and Indonesia report under the new subheadings from 2022 onwards, whereas the Philippines continued to report under 854140 and 854150 through 2023 and adopted the new subheadings only in 2024. Cells for which a subheading was not in use by the reporter in a given year are therefore marked n.a. rather than zero; they are excluded from the computation of period averages, and year-on-year changes spanning the switch are not comparable for the affected subheadings. **Table A2** sets out the concordance together with the year of adoption by each reporter.

3.3. The Grubel-Lloyd index

For country j in year t the index is computed as one minus the ratio of the absolute trade imbalance to total trade, so that it takes the value zero when trade is entirely one-way and the value one when exports equal imports. The aggregate index reported in **Table 1** is computed over the whole of heading 8541 against the world; the subheading indices reported in **Tables 2–7** apply the same formula at the 6-digit level. The index

is not computed bilaterally. Because the unadjusted index is mechanically depressed for a country running a large aggregate surplus, which is material for Singapore and Malaysia, the interpretation of the index for these two reporters is qualified in Section 5.4.

3.4. Validation of the data

Two checks were carried out and are summarized in **Table A3**. First, every index reported in this study was recomputed independently from the downloaded reporter files: All twenty-nine country-year aggregate values reproduce the figures in **Table 1** to within 0.001, and the underlying export and import totals reproduce **Table 1** to the second decimal place in billions of dollars. The complete recomputation, together with the raw reporter files, is deposited as indicated in the Data availability statement, so that any reader can repeat the exercise. Second, the indices were recomputed excluding subheading-year cells in which combined trade fell below USD 1 million; the results are unchanged to three decimal places.

3.5. Robustness

The results reported in Section 4 were re-estimated (i) excluding subheading-year cells in which combined trade fell below USD 1 million, (ii) excluding the incomplete final year. Under (i) the aggregate indices are unchanged to three decimal places, the maximum absolute difference being 0.000, because such cells account for less than 0.01 per cent of total trade in the sample. Under (ii) the mean indices become Thailand 0.905, Vietnam 0.861, the Philippines 0.841, Singapore 0.674, Malaysia 0.654 and Indonesia 0.599, so the ordering of the six economies is unchanged. The detailed figures are available in the replication file (**Figure 1**).

4. Results

4.1. Overview of intra-industry trade in semiconductor products among ASEAN countries

The 2021–2023 period witnessed a decline in the GL index in most countries, particularly in Thailand, from 0.98 to 0.82; Malaysia, from 0.67 to 0.62; and the Philippines, from 0.96 to 0.85 (**Figure 1**). This can be explained by the global semiconductor downturn in 2023 [34], when the decline in consumer electronics demand led to an imbalance in export and import flows among export-oriented producers. By contrast, the 2024–2025 period recorded a recovery of the GL index in Singapore and Malaysia, consistent with the new wave of FDI in advanced semiconductor packaging in the region amid the China+1 trend following the United States' chip export controls [29,31].

Overall, the six ASEAN economies in the sample fall into three tiers of IIT intensity, classified on the mean GL index over 2021–2025 (2021–2024 for Vietnam, for which no 2025 return was available). Within each tier the trajectory over the period differs, and the two dimensions — level and trend — are treated separately below:

Tier 1 — High IIT (mean GL > 0.80): Thailand (0.883), Vietnam (0.861) and the Philippines (0.810). All three maintain a high degree of two-way trade in heading 8541,

reflecting deep insertion into cross-border production networks. A high index at this level of disaggregation does not, however, imply participation in high value-added stages: The two-way flows arise largely from export-oriented processing, in which inputs are imported, transformed and re-exported [6]. The three economies diverge markedly in trend. Thailand and Vietnam remain broadly stable, whereas the Philippines records the steepest and most sustained decline in the sample, from 0.957 in 2021 to 0.686 in 2025 — a fall of 0.271 index points — indicating a progressive shift toward one-way import dependence.

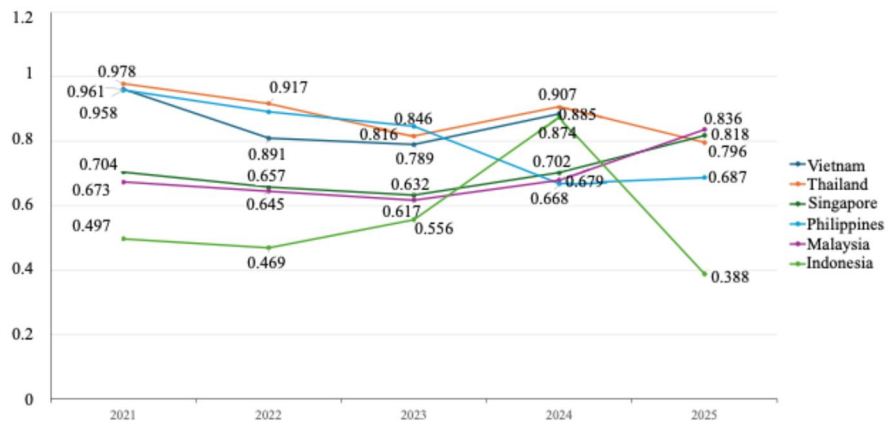


Figure 1. Intra-industry trade index among ASEAN countries in the semiconductor sector, HS 8541, 2021–2025.

Source: Authors' calculations based on data from TRADEMAP 2026. Note: The GL index is computed over the whole of heading HS 8541 against the world. n.a. indicates that no 2025 return had been filed by Vietnam at the time of retrieval; such cells are excluded from the period mean, which for Vietnam covers 2021–2024.

Tier 2 — Intermediate IIT (mean GL 0.65–0.75): Singapore (0.703) and Malaysia (0.690). These are the two economies with the highest technological capabilities in the sample, and their lower indices relative to Tier 1 are mechanical rather than substantive: Both run large and persistent trade surpluses in this heading, which depresses the unadjusted index by construction [32]. Both recover in 2025, to 0.818 and 0.836 respectively, though for different reasons (Sections 4.4 and 4.6).

Tier 3 — Low and highly volatile IIT (mean GL < 0.60): Indonesia (0.557). Indonesia records both the lowest mean and by far the largest within-country dispersion in the sample (standard deviation 0.187, against 0.127 for the Philippines, the next most variable). Its index moves from 0.507 in 2021 down to 0.468 in 2022, up to 0.871 in 2024 and back down to 0.389 in 2025. A swing of 0.482 index points in a single year points to a trade structure driven by a small number of large transactions rather than by a sustained domestic production base [2].

4.2. Vietnam

In 2021, Vietnam's trade structure reflected relatively limited export and import values, standing at USD 4.89 billion and USD 4.52 billion, respectively (**Table 错误! 未找到引用源。1**). Despite these modest trade volumes, the country recorded a very high aggregate GL index in the region at GL = 0.961 (**Table 2**), though this high value should be interpreted with caution. The balance between exports and imports at the

aggregate industry level was partly created by a trade structure in which Vietnam simultaneously imports input components and re-exports processed final products, a typical feature of an export-oriented processing economy.

During the 2022–2023 period, exports increased sharply, reaching USD 7.53 billion and USD 8.67 billion, while imports grew more slowly, reaching USD 5.12 billion and USD 5.65 billion. This widened the trade surplus and caused the GL index to fall to 0.79. In 2024, exports declined to USD 6.37 billion due to the cooling of the global chip investment cycle, leading to a slight recovery of the GL index to 0.88.

Table 2. GL index of Vietnam’s semiconductor products, 2021–2024.

HS code	2021	2022	2023	2024
854110	0.040	0.033	0.021	0.032
854121	0.063	0.055	0.029	0.034
854129	0.066	0.052	0.059	0.070
854141	n.a.	0.996	0.833	0.817
854142	n.a.	0.519	0.347	0.937
854143	n.a.	0.035	0.045	0.050
854149	n.a.	0.144	0.014	0.038
854150	0.335	n.a.	n.a.	n.a.
854151	n.a.	0.000	0.132	0.841
854190	0.307	0.327	0.353	0.604

Source: Authors’ calculations based on data from TRADEMAP 2026 Note: n.a. denotes a subheading that did not exist under the nomenclature in force in that year (see Section 3.2, HS2017-HS2022 concordance); such cells are not zero values and are excluded from period averages.

Vietnam’s downstream position is clearly reflected in the GL index. First, overwhelming import deficits in input component HS codes provide the strongest evidence of Vietnam’s downstream position. HS codes 854110, diodes, with GL = 0.021–0.040; 854121 and 854129, transistors, with GL values below 0.07, all record extremely low GL values, by a factor of roughly 28 to 94. These are simple components that Vietnam must import almost entirely from Japan, South Korea, and China for assembly purposes [6]. The absolute import dependence on this group of discrete components confirms that Vietnam has not yet developed domestic production capacity in basic component manufacturing [33].

Second, subheading 854143 — photovoltaic cells assembled in modules or made up into panels — records an overwhelming export surplus: USD 7.89 billion in 2023 and USD 5.39 billion in 2024, or 91.0 and 84.6 per cent of Vietnam’s total exports under heading 8541, with a GL index of only 0.045–0.050. Trade in this subheading is therefore almost entirely one-way. Two implications follow. Because assembled modules dominate the heading by value, the aggregate index reported for Vietnam is driven to a substantial degree by photovoltaic rather than chip-related trade. And the combination of a near-total export surplus in the assembled article with very low indices in the discrete-component subheadings indicates an assembly platform that imports inputs and re-exports finished modules, rather than a producer integrated across stages.

Third, subheading 854141 — light-emitting diodes — records consistently high indices, between 0.833 and 0.996. Unlike the assembled-module segment, trade here is close to balanced in both directions. This is consistent with the presence of LED packaging operations that import chips and substrates and export finished emitters, generating genuine two-way flows at the customs level while the domestic contribution remains concentrated in the packaging stage. The high index in this subheading should therefore be read as evidence of two-way processing trade rather than of upstream capability.

Although Vietnam remains in the downstream group, the data show several positive signals. HS code 854190, semiconductor parts and components, recorded a continuous increase in its GL index from 0.307 in 2021 to 0.604 in 2024, reflecting growing production and export capacity in the supporting components segment. This is an indication that Vietnam is gradually participating more deeply in the supporting segment of the value chain. Although it has not yet reached the stages of design or wafer fabrication, Vietnam is moving toward higher-value assembly and testing activities within ATP [6,33].

4.3. Thailand

In 2021, Thailand maintained relatively balanced export and import values at USD 2.66 billion and USD 2.55 billion, respectively (**Table 1**). Alongside these balanced trade volumes, the country recorded the highest aggregate GL index in the region with $GL = 0.979$ (**Table 3**). During the 2022–2023 period, exports surged to USD 5.20 billion, while imports increased more slowly to USD 3.59 billion, causing the GL index to decline to 0.82. This was the period when several major FDI projects in chip packaging in Thailand, including Western Digital and Hana Microelectronics, began generating export output, thereby increasing the trade surplus and reducing the aggregate GL index.

Table 3. GL index of Thailand’s semiconductor products, 2021–2025.

HS code	2021	2022	2023	2024	2025
854110	0.626	0.579	0.554	0.594	0.587
854121	0.295	0.273	0.192	0.218	0.464
854129	0.440	0.343	0.296	0.392	0.452
854141	n.a.	0.926	0.460	0.532	0.580
854142	n.a.	0.766	0.555	0.172	0.818
854149	n.a.	0.700	0.828	0.858	0.918
854150	0.640	n.a.	n.a.	n.a.	n.a.
854160	0.999	0.961	0.959	0.988	0.864
854190	0.170	0.133	0.191	0.367	0.603

Source: Authors’ calculations based on data from TRADEMAP 2026.

Note: n.a. denotes a subheading that did not exist under the nomenclature in force in that year (see Section 3.2, HS2017–HS2022 concordance); such cells are not zero values and are excluded from period averages.

HS code 854160, mounted piezo-electric crystals, is the most stable and highest-GL code for Thailand, with GL values ranging from 0.864 to 0.999. Near-perfect balance sustained over five years is unusual at the subheading level and indicates that Thailand both manufactures and imports this component at a comparable scale. The result is genuine two-way trade in a discrete component, in contrast with the one-way patterns observed in Vietnam and Indonesia for comparable items.

HS codes 854141 and 854142 show strong fluctuations in the GL index. For 854141, the GL index moved from 0.926 down to 0.460 and then up to 0.580; for 854142, it moved from 0.766 down to 0.172 and then up to 0.818. These fluctuations indicate that FDI order structures changed according to production cycles. Without a strong domestic IC production base, Thailand depends on the production schedules of multinational corporations to generate trade balance [29].

HS code 854190, parts and components, recorded an increase in its GL index from 0.170 in 2021 to 0.603 in 2025. This is an important signal that Thailand is increasing its exports of semiconductor accessories, possibly related to PCB assembly and electronic module projects under the Thailand 4.0 industrial development strategy [35].

Thailand can therefore be seen as occupying a mid-to-downstream position in the semiconductor value chain, focusing on assembly and testing, particularly in storage drives and discrete and passive components. The high GL index in HS 854160 and the relative stability in the diode segment (HS 854110, 0.554–0.626), show that Thailand has maintained more sustainable two-way production capacity than Vietnam in the basic components segment [7].

4.4. Singapore

Singapore is the largest semiconductor economy in the research sample in terms of absolute value, with exports ranging from USD 11.26 billion in 2021 to USD 13.13 billion in 2022, and imports ranging from USD 5.91 billion to USD 8.11 billion (**Table 1**). Its large and stable semiconductor trade surplus, averaging more than USD 5 billion per year, is a characteristic of an integrated production and export economy, placing Singapore in the position of a net supplier of semiconductor products to the region and the world.

Singapore's aggregate GL index remains at a medium level, between 0.632 and 0.818 (**Table 4**), considerably lower than those of Vietnam and Thailand. This does not imply that Singapore has a lower level of integration. On the contrary, the large trade surplus is the direct mathematical reason for the lower GL index. Singapore is a major net exporter because it is a genuine chip production hub.

Singapore's leading upstream position is reflected in its high and stable GL indices across most basic HS codes. HS codes 854110, diodes, with GL = 0.750–0.857; 854121, small-signal transistors, with GL = 0.747–0.954; and 854129, other transistors, with GL = 0.705–0.868, all maintain high IIT levels. This signals an economy with sufficiently strong domestic production capacity to export, while still importing products of the same type to meet diverse domestic assembly needs [32]. This reflects the characteristics of an integrated manufacturing hub [36].

Table 4. GL index of Singapore's semiconductor products, 2021–2025.

HS code	2021	2022	2023	2024	2025
854110	0.750	0.804	0.774	0.769	0.857
854121	0.747	0.915	0.958	0.936	0.954
854129	0.786	0.707	0.705	0.742	0.868
854130	0.872	0.872	0.969	0.884	0.818
854141	n.a.	0.909	0.876	0.921	0.976
854142	n.a.	0.121	0.206	0.985	0.977
854143	n.a.	0.219	0.329	0.620	0.714
854149	n.a.	0.679	0.597	0.779	0.887
854159	n.a.	0.560	0.717	0.831	0.992
854160	0.389	0.450	0.395	0.312	0.368
854190	0.567	0.484	0.394	0.340	0.195

Source: Authors' calculations based on data from TRADEMAP 2026 Note: n.a. denotes a subheading that did not exist under the nomenclature in force in that year (see Section 3.2, HS2017–HS2022 concordance); such cells are not zero values and are excluded from period averages.

In addition, HS code 854190, parts and components, is the most important code supporting the argument about Singapore's upstream position. Singapore's GL index for this code declined continuously from 0.567 in 2021 to 0.195 in 2025, while exports consistently exceeded imports. In 2021, exports reached USD 2.70 billion compared with imports of USD 1.07 billion; in 2025, exports reached USD 1.28 billion compared with imports of USD 0.138 billion. The trend of declining GL combined with a strong export surplus in HS 854190 provides clear evidence that Singapore is increasingly concentrating on the role of supplying parts and components to the rest of the chain, that is, upstream activity [32,35].

Moreover, the GL index for HS 854141 (light-emitting diodes) and 854142 (photovoltaic cells not assembled) recovers over 2024–2025, reaching 0.921–0.985. Two-way trade in these subheadings is consistent with Singapore's role as an integrated hub that both produces and sources comparable devices, rather than with a one-directional processing relationship.

4.5. Philippines

Regarding trade balances, the Philippines consistently experienced imports exceeding exports, with imports of USD 1.93 billion compared with exports of USD 0.97 billion in 2024, and imports of USD 2.05 billion compared with exports of USD 1.07 billion in 2025 (**Table 1**). Driven by these shifting trade dynamics, the Philippines stood out as the country with the clearest and most continuous decline in the GL index in the research sample: From 0.96 in 2021 to 0.85 in 2023, and further down to 0.67 in 2024, before recovering slightly to 0.686 in 2025 (**Table 5**). This shows that the Philippines is gradually shifting into a semiconductor trade deficit. It is a signal that the country is becoming increasingly dependent on imports of complex components for domestic electronics production, while its export capacity has not increased correspondingly.

HS code 854160 records extremely low GL values, ranging from 0.001 to 0.013, with imports overwhelmingly exceeding exports. Imports reached USD 129–190

million, compared with exports of only USD 0.09–1.21 million. This is the strongest evidence that the Philippines has in mounted piezo-electric crystals and relies entirely on imports of these components for assembly [32].

Table 5. GL index of the Philippines’ semiconductor products, 2021–2025.

HS code	2021	2022	2023	2024	2025
854110	0.536	0.657	0.699	0.778	0.918
854121	0.308	0.507	0.971	0.775	0.030
854129	0.765	0.768	0.837	0.881	0.880
854141	n.a.	n.a.	n.a.	0.946	0.893
854142	n.a.	n.a.	n.a.	0.508	0.347
854143	n.a.	n.a.	n.a.	0.339	0.287
854150	0.918	0.948	0.681	n.a.	n.a.
854160	0.001	0.017	0.003	0.004	0.013
854190	0.556	0.341	0.335	0.243	0.243

Source: Authors’ calculations based on data from TRADEMAP 2026. Note: n.a. denotes a subheading that did not exist under the nomenclature in force in that year (see Section 3.2, HS2017–HS2022 concordance); such cells are not zero values and are excluded from period averages.

HS code 854190, parts and components, shows a decline in the GL index from 0.556 in 2021 to 0.243 in 2024–2025, together with an increasingly large trade deficit. In 2024, imports reached USD 231 million, compared with exports of USD 31 million. This reflects the Philippines’ increasing dependence on imported supporting components without a corresponding development of domestic supply capacity.

HS codes 854129 and 854141 record relatively high GL levels, ranging from 0.765 to 0.881 and from 0.893 to 0.946, respectively. However, this does not necessarily reflect a high level of technology. Rather, it is largely due to the characteristics of the OSAT (Outsourced Semiconductor Assembly and Test) industry in the Philippines. Companies such as Texas Instruments, Amkor, and STMicroelectronics both import wafers and export packaged chips, thereby generating balanced two-way trade within their own supply chains [35].

The Philippines and Vietnam share a downstream processing position in the semiconductor value chain, but there is an important difference between them. Vietnam is showing signs of upgrading, as reflected in the rising GL index of HS 854190 and the large export surplus in HS 854143. By contrast, the Philippines is experiencing a relative deterioration in its trade position, as reflected in the continuous decline of its aggregate GL index and widening trade deficit. This difference may reflect Vietnam’s success in attracting new semiconductor FDI, including the capacity expansion of Intel and Samsung [4,33], compared with the Philippines, which is competing in a context of rising labor costs and infrastructure constraints [36].

4.6. Malaysia

Malaysia presents the most distinctive pattern in the research sample. While its trade value is very large, with exports of USD 8.24–10.24 billion and imports of USD 4.18–4.75 billion (**Table 1**), its aggregate GL index remains at a medium-low level, between 0.616 and 0.679 during the 2021–2024 period (**Table 6**). Its stable and large

trade surplus, usually exceeding USD 4 billion per year, confirms that Malaysia is one of ASEAN's leading semiconductor export hubs, with a particular focus on Assembly, Test and Packaging (ATP). In 2025 the aggregate index rose sharply to 0.836. The mechanics of this rise warrant attention, since it is not straightforwardly a sign of deepening integration: Imports rose moderately, from USD 4.20 billion to USD 4.75 billion, whereas exports fell by 19.2 per cent, from USD 8.18 billion to USD 6.61 billion. The surplus therefore narrowed principally because export values contracted, and the index rose as an arithmetic consequence. This illustrates a general property of the unadjusted Grubel–Lloyd index that is material to the interpretation of the whole sample: A contraction in the dominant flow raises the index just as an expansion in the weaker flow does, and the two carry opposite economic meanings. Whether the 2025 movement reflects a transition toward advanced packaging, a cyclical downturn in export demand, or both cannot be settled on aggregate data alone.

Table 6. GL index of Malaysia's semiconductor products, 2021–2025.

HS code	2021	2022	2023	2024	2025
854110	0.858	0.829	0.917	0.919	0.976
854121	0.452	0.160	0.233	0.211	0.400
854129	0.786	0.857	0.825	0.775	0.845
854141	n.a.	0.678	0.688	0.630	0.763
854142	n.a.	0.013	0.055	0.039	0.373
854143	n.a.	0.181	0.233	0.214	0.637
854151	n.a.	0.125	0.115	0.345	0.761
854159	n.a.	0.766	0.726	0.867	0.852
854160	0.975	0.850	0.771	0.733	0.824
854190	0.960	0.936	0.942	0.952	0.993

Source: Authors' calculations based on data from TRADEMAP 2026 Note: n.a. denotes a subheading that did not exist under the nomenclature in force in that year (see Section 3.2, HS2017–HS2022 concordance); such cells are not zero values and are excluded from period averages.

Malaysia's midstream position in Southeast Asia's semiconductor supply chain is demonstrated by HS code 854190, parts and components, where Malaysia has the highest and most stable GL index among all six countries: 0.960 in 2021, 0.936 in 2022, 0.942 in 2023, 0.952 in 2024, and peaking at 0.993 in 2025. With exports and imports almost perfectly balanced, at USD 1.18 billion in exports and USD 1.16 billion in imports in 2025, this is clear evidence that Malaysia both produces and exports, and imports, semiconductor supporting components at a comparable scale. This reflects the central position of an integrated ATP hub [31].

In addition, HS code 854110, diodes, with GL = 0.858–0.976, and HS code 854129, transistors, with GL = 0.775–0.857, both maintain high and stable two-way trade. This reflects Malaysia's genuine production capacity in discrete components, supported by numerous chip production facilities operated by Infineon, ON Semiconductor, and NXP Semiconductors, which conduct final fabrication stages there [35].

Furthermore, HS codes 854142 and 854143 show low GL values, with HS 854142 recording values of 0.013–0.055 during 2022–2024, together with large export

surpluses. This indicates that Malaysia is a net producer and exporter of photovoltaic cells and modules. The pattern is one-way rather than integrative, and should be read separately from the discrete-component evidence above, which is where Malaysia's semiconductor capability is visible, which produces power semiconductors. These stages generate higher value added than pure assembly [35].

Investment projects in advanced packaging by Intel and by OSAT operators in Penang [31] may account for part of the 2025 movement, but the subheading evidence does not isolate that effect from the general export contraction, and the aggregate index alone cannot distinguish the two. Investment projects by Intel, Nvidia through OSAT partners in Penang, and Infineon in Chip-on-Wafer (CoW) and wafer-level packaging in Malaysia are creating greater demand for imports of higher-end equipment and input components. This simultaneously increases exports of finished products and imports of inputs, thereby pushing the GL index upward [4,31,35]. Malaysia is therefore in the process of shifting from traditional ATP to a new generation of higher value-added ATP.

4.7. Indonesia

In 2025, Indonesia's export value increased abnormally to USD 3.31 billion, compared with USD 0.79 billion in 2024 (**Table 1**). Due to this sudden shift, Indonesia emerged as the country with the most volatile and unpredictable GL index in the sample: From 0.507 in 2021, dipping to 0.468 in 2022 before rising to 0.871 in 2024, and then falling sharply to 0.389 in 2025 (**Table 7**). A fluctuation range of more than 0.48 GL points within one year, from 2024 to 2025, indicates an unstable trade structure that depends heavily on several large-scale transactions by multinational corporations rather than on a sustainable domestic production base.

Table 7. GL index of Indonesia's semiconductor products, 2021–2025.

HS code	2021	2022	2023	2024	2025
854110	0.205	0.264	0.405	0.299	0.183
854121	0.027	0.070	0.079	0.079	0.071
854129	0.115	0.029	0.065	0.155	0.357
854141	n.a.	0.473	0.070	0.051	0.085
854142	n.a.	0.541	0.510	0.919	0.130
854143	n.a.	0.600	0.653	0.250	0.100
854159	n.a.	0.941	0.945	0.890	0.989
854160	0.726	0.835	0.827	0.741	0.741
854190	0.215	0.138	0.018	0.203	0.163

Source: Authors' calculations based on data from TRADEMAP 2026. Note: n.a. denotes a subheading that did not exist under the nomenclature in force in that year (see Section 3.2, HS2017–HS2022 concordance); such cells are not zero values and are excluded from period averages.

This specific trade movement was mainly explained by the export boom in two specific HS codes: HS 854142, which increased from USD 80 million to USD 1.73 billion, and HS 854143 which increased from USD 564 million to USD 1.43 billion. The sudden increase concentrated in two HS codes, while the aggregate GL index fell

to 0.39, suggests that this was most likely one-way exports from one or several new FDI projects, rather than a reflection of genuine two-way integration.

HS codes 854159 and 854160 maintain the highest and most stable GL values in Indonesia. HS 854159 recorded values of 0.941–0.989, while HS 854160 recorded values of 0.726–0.835. This indicates the presence of several sensor and optoelectronic device manufacturers in Indonesia with balanced two-way trade flows. This may be the most stable segment in Indonesia's semiconductor value chain, although its scale remains small.

HS code 854190, parts and components, declined from 0.215 in 2021 to a low of 0.018 in 2023, before recovering to 0.203 in 2024 and 0.163 in 2025. Imports consistently dominated exports, with imports of USD 142 million compared with exports of USD 12 million in 2025. Indonesia is therefore completely dependent on imports of supporting components, similar to the Philippines but on a smaller scale.

HS codes 854110 and 854129, diodes and transistors, recorded low and volatile GL values. HS 854110 ranged from 0.183 to 0.405, while HS 854129 ranged from 0.029 to 0.357, with imports overwhelmingly exceeding exports. This provides evidence that Indonesia has not yet developed sufficient discrete component production capacity to participate in two-way trade in these two basic segments [36].

Indonesia currently has the lowest and least stable level of participation in the semiconductor value chain among the six countries studied [37]. However, the surge in photovoltaic exports in 2025, although one-way and not yet stable, suggests that large-scale FDI projects are beginning to operate [38,39]. With its large population, important mineral resources such as nickel and cobalt, and geopolitical position amid United States–China competition, Indonesia has the potential to attract mid-to-downstream semiconductor investment in the long term [31,35].

5. Discussion

5.1 The Vietnam – Thailand pair

Although Vietnam and Thailand record remarkably high aggregate GL indices, a deeper analysis through the lens of Global Value Chains (GVCs) reveals that this integration harbors underlying structural fragilities. The fact that discrete-component subheadings such as 854110 exhibit very low indices under an absolute import deficit, while the assembled-module subheading 854143 records a near-total export surplus, reflects the characteristics of an FDI-led assembly network. The two-way flows observed in Vietnam arise largely from the intra-firm trade of foreign affiliates, which import inputs from related parties, perform labor-intensive assembly and testing domestically, and re-export the finished article. Note that this pattern is documented here for photovoltaic modules and discrete devices; the integrated-circuit segment in which Samsung and Intel principally operate is classified under HS 8542 and lies outside the present measurement.

Consequently, a high GL index here does not equate to an increase in Domestic Value-Added or endogenous technological capabilities. These two countries are currently situated at the bottom of the “Smile Curve” in the semiconductor industry. Nevertheless, the strategic “China + 1” FDI relocation trend is presenting opportunities for functional upgrading. The rise of the GL index in the auxiliary

component segment (854190) indicates that Vietnam and Thailand are beginning to transition from traditional assembly to Advanced Packaging processes, gradually localizing portions of the supply chain rather than functioning purely as outsourced processing hubs.

5.2. The Singapore – Malaysia pair

In stark contrast to the outsourcing group, the IIT structures of Singapore and Malaysia reflect the maturity of a highly integrated semiconductor ecosystem. Singapore's strong trade surplus and declining GL index in the parts and components code (854190) serve as clear empirical evidence that the country is proactively withdrawing from downstream assembly stages to advance toward capital- and R&D-intensive upstream positions, acting as a core component supplier and a fabless design hub for the entire region.

Meanwhile, Malaysia's high and strictly balanced level of IIT across most component segments underscores the spillover effects and robust backward and forward linkages between foreign MNEs and the domestic supporting enterprise system. The surge of the GL index in Malaysia in 2025 represents not merely a quantitative increase but a qualitative transformation: A shift from traditional Outsourced Semiconductor Assembly and Test (OSAT) services to the era of wafer-level packaging. This phenomenon corroborates the theory that once a nation accumulates sufficient human capital and technological absorptive capacity, the influx of FDI driven by geopolitical impacts will directly propel that country up the higher value-added rungs of GVCs.

5.3. The Indonesia – Philippines pair

The two economies diverge in kind rather than in degree: The Philippines declines steadily from a high level, while Indonesia fluctuates around a low one. Both cases highlight a crucial analytical dimension: The restructuring of global supply chains does not yield uniform benefits, but rather induces divergence even within the ASEAN bloc. The Philippines, despite its historical development of OSAT, is gradually losing its competitive edge and being marginalized from new FDI flows due to infrastructure bottlenecks and a shortage of high-tech engineers.

For Indonesia, an asymmetric trade structure and low IIT levels reflect integration efforts primarily predicated on resource advantages (such as nickel minerals) rather than manufacturing capabilities. The sudden boom in certain export codes (photovoltaic cells and modules) brought about by isolated FDI projects reveals an extreme dependency on the supply chain rerouting decisions of the West. This substantiates the argument that without synchronized preparation in institutional frameworks and domestic supporting industrial capabilities, developing countries will be unable to translate FDI inflows into sustainable intra-industry trade capacity, ultimately leading to the risk of value chain downgrading.

5.4. Comparison with prior findings

Two of the results reported above are consistent with the existing literature. The finding that vertical rather than horizontal intra-industry trade predominates between

partners at different levels of development corroborates the theoretical expectation of Flam and Helpman [22] and the decomposition evidence of Ekanayake, Veeramacheneni and Moslares [23], and matches the reading Turkcan [5] gives of a high index in a fragmented parts industry. The finding that regional integration in this heading is broad-based is consistent with Prabheesh and Vidya [3], who report that Vietnam, Malaysia, Thailand, the Philippines and Indonesia are all well integrated into the semiconductor trade network while the smaller ASEAN members remain peripheral. It is also consistent with Chin, Ong and Foo [2], who find that the relocation of Chinese FDI raises vertical intra-industry trade in ASEAN-4 and that the effect spills across member states.

Two results depart from the literature, and both concern the ordering of countries. First, Pau and Yong [7] place Malaysia and Singapore in the advanced group of the regional electrical and electronics network, above the intermediate and peripheral economies, and Prabheesh and Vidya [3] find Singapore to be the central ASEAN node. The unadjusted Grubel-Lloyd index obtained here places both in the middle tier, at 0.703 and 0.690. The divergence is mechanical rather than substantive: Singapore and Malaysia run large structural surpluses in this heading, which depresses the index by construction. The magnitude of the effect can be read directly from the trade balances. Over the period, the absolute trade imbalance of Singapore averages 29.7 per cent of its total trade under this heading and that of Malaysia 31.0 per cent, against 11.7 per cent for Thailand and 13.9 per cent for Vietnam. Since the unadjusted index is by construction one minus this ratio, the entire gap between the first and second tiers is accounted for by the difference in structural imbalance. The unadjusted index should therefore not be read as a measure of position in the value chain. Second, the index for Vietnam and Thailand at the 6-digit level is high relative to what the aggregate literature would lead one to expect: Czarny et al. [25] report that intra-industry trade accounts for roughly 29 per cent of world trade in 2022, whereas the indices here exceed 0.8. The difference does not arise from the level of disaggregation, since Czarny et al. also compute the index on 6-digit subheadings. It arises from scope. Their figure is an average across all merchandise and across roughly 150 reporters, in which inter-industry trade between economies at different levels of development dominates; the indices reported here are confined to a single heading in an industry organized around cross-border processing, and to six economies that sit inside the same regional production network. Heading 8541 is precisely the kind of fragmented, network-organized industry in which the index would be expected to run well above the all-merchandise average, and the comparison should be read as confirming that expectation rather than as a discrepancy.

The contribution of this study relative to the works listed in **Table A1** is therefore threefold: It supplies the first 6-digit measurement of intra-industry trade in heading HS 8541 for these six economies across the post-pandemic reconfiguration; it shows that a high index at this level of disaggregation is compatible with a low domestic value-added contribution, which qualifies the conventional reading of the index in fragmented industries; and it demonstrates that the unadjusted index and the network-based participation measures used in the prior literature can rank the same economies in opposite orders, so that the two families of indicator answer different questions.

Viewed comprehensively, the dynamic changes in the GL indices of the six ASEAN countries are not merely fluctuations in trade flows; rather, they serve as a metric reflecting the spatial restructuring process of the global semiconductor supply chain. Under the pressure of export controls and the US CHIPS Act, coupled with China's technological autonomy strategy, multinational enterprises have been reshaping the production network in Southeast Asia.

Empirical data analysis has elucidated the emergence of a new division of labor model characterized by complementary specialization within the ASEAN bloc. Instead of competing directly, these countries are filling each other's gaps: Singapore provides upstream design and R&D; Malaysia operates as a midstream integrated transit and advanced packaging hub; while Vietnam and Thailand assume the role of absorbing downstream assembly and testing stages relocating from China. This profound stratification explains why Vertical Intra-Industry Trade (VIIT) is booming within the region. However, the analysis also points out that this network currently retains a "hub-and-spoke" nature, heavily dependent on core technology and capital from the US, Japan, South Korea, and China. The paramount challenge for ASEAN lies not merely in expanding trade volumes, but in determining how to leverage IIT flows for technology transfer, mitigate the nature of "hollow manufacturing," and build genuine resilience against future geo-economic shocks.

6. Policy implications

Southeast Asia is standing at a historic crossroad to enhance its position within the global semiconductor value chain. Driven by geoeconomic restructuring and the "China plus one" strategy, ASEAN economies are absorbing unprecedented FDI inflows. However, to transform this geopolitical advantage into substantive endogenous capability and mitigate the risks of "hollow manufacturing", ASEAN nations must implement targeted strategies tailored to their specific stratifications within the production network:

First, for the downstream group (Vietnam and Thailand): Strategic FDI absorption and value chain upgrading. Although Vietnam and Thailand exhibit high Intra-Industry Trade (IIT) indices, empirical evidence reveals that this is primarily driven by the processing and assembly operations of foreign affiliates rather than by domestic technological capacity. To break out of this "processing trap," these countries must transition their strategies from merely attracting mass FDI to implementing conditionally targeted FDI. Policymakers should stipulate that tax incentives for MNEs must be strictly tied to localization commitments and technology transfer agreements. Specifically, capitalizing on the positive upgrading signals observed in the semiconductor parts and components segment (HS code 854190), governments should establish financial support funds to help domestic small and medium-sized enterprises (SMEs) meet global standards. Integrating local SMEs as Tier-2 or Tier-1 suppliers for Advanced Packaging facilities will generate genuine spillover effects, shifting the structure from Vertical Intra-Industry Trade (VIIT) to higher-value Horizontal Intra-Industry Trade (HIIT).

Second, for the mid-to-upstream group (Singapore and Malaysia): Consolidating advanced nodes. Singapore and Malaysia must continue to elevate their established

mature ecosystems. For Malaysia, the surge in the GL index in 2025 signifies a critical transition toward advanced packaging. The government should further incentivize R&D investments in Chip-on-Wafer (CoW) and wafer-level packaging technologies to retain operations by tech giants such as Intel and Infineon. Meanwhile, Singapore should solidify its apex position by focusing purely on capital-intensive upstream activities, acting as the region's premier fabless design and innovation hub.

Third, for resource-abundant and vulnerable nodes (Indonesia and the Philippines): Anchoring integration through domestic readiness. For the Philippines, reversing the trend of a declining GL index and supply chain divergence requires urgent state intervention to resolve critical infrastructure bottlenecks and stabilize energy costs for the Outsourced Semiconductor Assembly and Test (OSAT) sector. Conversely, Indonesia must strategically leverage its massive reserves of critical minerals, such as nickel and silica, as geoeconomic bargaining chips. Rather than exporting raw materials, Indonesia should compel MNEs to establish local processing and power semiconductor fabrication facilities, ensuring that intermittent export booms translate into sustainable intra-industry integration.

Fourth, deepening human capital to absorb technological spillovers. The acute shortage of specialized engineers remains the most severe bottleneck across ASEAN. Ambitious quantitative targets, such as Vietnam's objective to train 50,000 semiconductor engineers by 2030, must be accompanied by qualitative "how-to" execution to avoid educational hollow-out. Beyond the "quadruple helix" linkage model (state-university-institute-enterprise), countries must implement highly flexible visa policies to attract diasporic experts and high-tech engineers from Taiwan, South Korea, and the United States. These foreign experts should be incentivized to participate in direct technology transfer programs at shared public-private R&D laboratories, thereby rapidly elevating the practical capabilities of the domestic workforce.

Finally, institutionalizing a synchronized regional production network. No single ASEAN country possesses the comprehensive market size, capital, and technological capability to independently build an entire semiconductor ecosystem and compete against major powers. Therefore, policymakers must champion regionally supply chain cooperation frameworks to harmonize technical standards, customs procedures, and Rules of Origin (ROO). By linking Singapore's R&D prowess, Malaysia's advanced ATP capabilities, Indonesia's strategic resources, and the dynamic manufacturing capacity of Vietnam and Thailand, ASEAN can forge a self-reliant, complementary production network. This unified ecosystem is the ultimate key to enhancing the bloc's resilience against the unpredictable geoeconomic shocks of the new technological era.

7. Conclusion

This study employed the Grubel–Lloyd index to clarify the structure of intra-industry trade and the deep stratification within the semiconductor production network across six ASEAN countries during the 2021–2025 period. The empirical results confirm that a clearly multi-tiered supply chain is taking shape in the region. Singapore has consolidated its leading upstream position, serving as a hub for component supply

and design. Malaysia has strengthened its solid midstream position as a leading integrated ATP hub and is moving toward advanced packaging segments. At lower stages, Thailand and Vietnam are positioned in the lower-to-midstream segment, mainly engaging in export-oriented processing and assembly, while showing positive signs of capability upgrading within the value chain. By contrast, the Philippines and Indonesia remain at the downstream level, with substantial volatility, heavy dependence on imported components, and an unstable trade structure.

Under the impact of geoeconomic restructuring and global supply chain diversification strategies, ASEAN is facing a historic opportunity to make a breakthrough. However, in order to fully seize this window of opportunity, countries cannot develop in isolation. The policy implications indicate that, in addition to their own efforts to upgrade domestic supporting industries, develop high-quality human resources, and improve specialized infrastructure, the key lies in creating a regional production network. Leveraging the complementary comparative advantages among intra-regional economies will help shape a more self-reliant and integrated semiconductor ecosystem, strengthen resilience, and enhance ASEAN's strategic position on the global technology map.

8. Limitations and future research

Although providing important empirical evidence on the structure of the ASEAN semiconductor production network, this study still presents certain methodological and data limitations.

First, the scope of heading HS 8541 does not coincide with the semiconductor industry as ordinarily understood. The heading covers discrete devices, optoelectronic and photovoltaic devices, mounted piezo-electric crystals and their parts, but excludes the electronic integrated circuits classified under HS 8542. Two consequences follow. Logic, memory and processor devices — the segments in which the technological hierarchy of the industry is most sharply expressed — fall entirely outside the measurement. Conversely, subheadings 854142 and 854143, which cover photovoltaic cells and assembled solar modules, are included, and in several reporters, they account for a substantial share of the heading: Assembled modules under 854143 represent approximately 91 per cent of Vietnam's total 8541 exports in 2023, and the 2025 surge in Indonesian exports is concentrated in the same two subheadings. The indices reported here should therefore be read as measuring intra-industry trade in heading 8541 rather than in semiconductors in the narrow sense, and the photovoltaic component should be borne in mind wherever a country-level index is interpreted.

Second, the measurement of the Grubel-Lloyd (GL) index based on gross trade data fails to disentangle Domestic Value-Added. Consequently, this may lead to an overestimate of the actual degree of integration driven by the intra-firm trade of multinational corporations. Third, the assessment is currently confined to a descriptive statistical analysis of the GL index's dynamic trends; it has not yet established econometric models to rigorously test the causal relationships between Intra-Industry Trade (IIT) and macroeconomic factors such as market size, FDI shifts, or geopolitical shocks.

The most immediate extension is to HS 8542, so that the integrated-circuit segment enters the measurement and the photovoltaic and chip components of regional trade can be reported separately. To overcome the aforementioned limitations and further deepen this topic, future studies are recommended to adopt approaches applying Trade in Value-Added (TiVA) data or Network Analysis to resolve the double-counting problem of gross data, thereby more accurately measuring the true position and the shift in technological surplus of ASEAN countries within the global value network. Furthermore, integrating advanced econometric models such as Dynamic Panel Data or Spatial Panel Models will help precisely quantify the impact of industrial policies (such as the CHIPS Act) and FDI flows on the variance of intra-industry trade. Additionally, expanding the analysis to the micro-level (Firm-level data) by utilizing enterprise-level data will clarify the role of domestic firms relative to multinational FDI corporations, thereby providing a micro-perspective on technological absorptive capacity and functional upgrading strategies within the supply chain.

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References

1. Goodman S, VerWey J, Kim D. The South Korea-Japan trade dispute in context: Semiconductor manufacturing, chemicals, and concentrated supply chains. *Chemicals, and Concentrated Supply Chains* (October 1, 2019). 2019. doi: 10.2139/ssrn.3470271
2. Chin MY, Ong SL, Foo LP. ASEAN-4 -China FDI and vertical intra-industry trade links amid the us-China trade war—A spatial panel analysis. *Sage Open*. 2026; 16(1): 21582440251410197. doi: 10.1177/21582440251410197
3. Prabheesh KP, Vidya CT. Interconnected Horizons: ASEAN's journey in the global semiconductor trade network amidst the COVID-19 pandemic. *Economic Research Institute for ASEAN and East Asia*; 2024.

4. Singh J, Thornton M, Casanova R, Isaacs D. Emerging resilience in the semiconductor supply chain. 2024. Available online: <https://web-assets.bcg.com/25/6e/7a123efd40199020ed1b4114be84/emerging-resilience-in-the-semiconductor-supply-chain-r.pdf> (accessed on 28th April 2026)
5. Türkcan K. Vertical Intra-Industry Trade and Product Fragmentation in the Auto-Parts Industry. *Journal of Industry, Competition and Trade*. 2011; 11(2): 149–186. doi: 10.1007/s10842-010-0067-0
6. Liua J, Kangb S J. Vietnam’s position in semiconductor global value chains: A network analysis The Institute of Comparative Economic Studies Hosei University. 2026; (40): 23–54.
7. Pau EJN, Yong CC. Strengthening ASEAN’s electrical and electronics sector: Enhancing regional production networks and economic resilience. *Transnational Corporations Review*. 2025; 17(4): 200158. doi: 10.1016/j.tncr.2025.200158
8. Xiong W, Wu DD, Yeung JHY. Semiconductor supply chain resilience and disruption: Insights, mitigation, and future directions. *International Journal of Production Research*. 2025; 63(9): 3442–3465. doi: 10.1080/00207543.2024.2387074
9. Jones R W, Kierzkowski H. The role of services in production and international trade: A theoretical framework. *World Scientific Book Chapters*. 2018. pp. 233–253.
10. Cheong I, Yoo J. A study on the characteristics of intra-industry trade for korea’s e-commerce trade. *Journal of International Logistics and Trade*. 2020; 18(1): 1–11. doi: 10.24006/jilt.2020.18.1.001
11. Balassa BA. *Economic Development and Integration*. Centro de Estudios Monetarios Latinamericanos; 1965.
12. Drèze J. Les exportations intra-C.E.E. en 1958 et la position belge. *Rech Économiques Louvain*. 1961; 27(8): 717–738. doi: 10.1017/S0770451800002566
13. Verdoorn PJ. The Intra-Bloc Trade of Benelux. *Economic Consequences of the Size of Nations: Proceedings of a Conference Held by the International Economic Association*. Palgrave Macmillan UK; 1960. pp. 291–329. doi: 10.1007/978-1-349-15210-0_19
14. Balassa B. Intra-Industry specialization: A cross-country analysis. *European Economic Review*. 1986; 30(1): 27–42. doi: 10.1016/0014-2921(86)90030-9
15. Balassa B. Tariff reductions and trade in manufacturers among the industrial countries. *The American Economic Review*. 1966; 56(3): 466–473.
16. Grubel HG, Lloyd PJ. *Intra-Industry trade: The theory and measurement of international trade in differentiated products*. Macmillan; 1975.
17. Yusefzadeh H, Rezapour A, Lotfi F, et al. A Study of Comparative Advantage and Intra-Industry Trade in the Pharmaceutical Industry of Iran. *Global Journal of Health Science*. 2015; 7(6): p295. doi: 10.5539/gjhs.v7n6p295
18. Helpman E. International trade in the presence of product differentiation, economies of scale and monopolistic competition: A Chamberlin-Heckscher-Ohlin approach. *Journal of International Economics*. 1981; 11(3): 305–340. doi: 10.1016/0022-1996(81)90001-5
19. Krugman PR. Increasing returns, monopolistic competition, and international trade. *Journal of International Economics*. 1979; 9(4): 469–479. doi: 10.1016/0022-1996(79)90017-5
20. Krugman P. Scale Economies, Product Differentiation, and the Pattern of Trade. *The American Economic Review*. 1980; 70(5): 950–959.
21. Lancaster K. Intra-industry trade under perfect monopolistic competition. *Journal of International Economics*. 1980; 10(2): 151–175. doi: 10.1016/0022-1996(80)90052-5
22. Flam H, Helpman E. Vertical Product Differentiation and North-South Trade. *The American Economic Review*. 1987; 77(5): 810–822.
23. Ekanayake EM, Veeramacheneni B, Moslares C. Vertical and horizontal intra-industry trade between the U.S. and NAFTA Partners. *Revista de Análisis Económico-Economic Analysis Review*. 2009; 24(1): 21–42.
24. Lima JED, Alvarez M. *Indicadores de comercio exterior y política comercial: Mediciones de posición y dinamismo comercial*. 2008.
25. Czarny E, Folfas P, Szarek-Piaskowska A. Intra-industry trade: A portrait of global patterns during 2000–2022. *International Entrepreneurship Review*. 2026; 12(1): 41–58. doi: 10.15678/IER.2026.1201.03
26. Li L, Wang H, Li Z, Hu S. Analysis of the structure and robustness of the global semiconductor trade network. *PLOS ONE*. 2025; 20(1): e0313162. doi: 10.1371/journal.pone.0313162
27. OECD. *Review of the Dominican republic’s enabling environment for the semiconductor and microelectronics industries*. OECD Publishing; 2026. doi: 10.1787/0b35b5a6-en

28. Tung CY. Taiwan and the global semiconductor supply chain: 2023 in review. Representative Taipei Representative Office in Singapore. 2024.
29. Yang TSW. Can southeast Asia challenge China's dominance in mature chips? ThinkChina - Big Reads, Opinions & Columns on China. 2025. Available online: <https://www.thinkchina.sg/technology/big-read-can-southeast-asia-challenge-chinas-dominance-mature-chips> (accessed on 6 May 2026).
30. S&P Global Mobility. Semiconductor supply chain disruption: Unpacking the US-China Trade Conflict. S&P Automotive Insights; 2024. Available online: <https://www.spglobal.com/automotive-insights/en/blogs/2024/9/semiconductor-supply-chain-disruption-us-china-trade-conflict> (accessed on 6 May 2026).
31. AMRO. ASEAN+3 Regional Economic Outlook 2026. 2026. Available online: <https://amro-asia.org/wp-content/uploads/2026/04/high-res-AMRO-AREO-2026-Updated-6Apr2.pdf> (accessed on 28 April 2026).
32. PRF. Navigating Geopolitics & Supply Chains: An Analysis of Southeast Asia's Semiconductor Frontier - Politeia Research Foundation. 2025. Available online: <https://prfworld.org/navigating-geopolitics-supply-chains-an-analysis-of-southeast-asias-semiconductor-frontier/> (accessed on 6 May 2026).
33. Trung tâm thông tin Công nghiệp và Thương mại. Restructuring in Industry and Trade. Specialized in Semiconductor Industry. 2024. <https://thongtinconghuong.vn/upload/vtic/Truyen.thong.2021/Nam.2024/n2199.pdf> (accessed on 28 April 2026).
34. Genc TS. A sustainable semiconductor supply chain under regulation. *International Journal of Production Economics*. 2024; 278: 109426. doi: 10.1016/j.ijpe.2024.109426
35. The ASEAN Secretariat and the UN. ASEAN Investment Report 2025 - Foreign Direct Investment and Supply Chain Development. Available online: https://asean.org/wp-content/uploads/2025/10/AIR2025_rev17-Okt.pdf (accessed on 28 April 2026).
36. Wang CN, Nhieu NL, Chiang CT, Wang YH. Assessing Southeast Asia countries' potential in the semiconductor supply chain: an objectively weighting multi-criteria decision-making approach. *Humanities and Social Sciences Communications*. 2024; 11(1): 1260. doi: 10.1057/s41599-024-03768-x
37. Banerjee A. Critical industries, critical risks in ASEAN supply chains. *Asia Times*; 2025. Available online: <https://asiatimes.com/2025/11/critical-industries-critical-risks-in-asean-supply-chains/> (accessed on 19 May 2026).
38. Kurniawan H. US–Germany–Indonesia Consortium Pledges \$26.7 Billion for Semiconductor Hub in Batam. *Jakarta Globe*; 2025. Available online: <https://jakartaglobe.id/business/usgermanyindonesia-consortium-pledges-267-billion-for-semiconductor-hub-in-batam> (accessed on 19 May 2026).
39. Business Indonesia. US–Germany–Indonesia Consortium to Build IDR 444 Trillion Semiconductor, Silica and Glass Facilities in Batam. *Business Indonesia*. 2025. Available online: <https://business-indonesia.org/news/us-germany-indonesia-consortium-to-build-idr-444-trillion-semiconductor-silica-and-glass-facilities-in-batam> (accessed on 19 May 2026).

Appendix

Table A1. Comparison of this study with selected prior empirical studies.

Study	Coverage	Sector / HS level	Period	Method	Reported findings
Grubel and Lloyd [16]	Ten OECD economies	Manufacturing, aggregate and by industry	1959–1967	GL index: Original and imbalance-adjusted formulations	Establishes the measure and shows that a large and rising share of trade among industrial economies is two-way within the same industry. Also introduces the adjustment for aggregate trade imbalance that this study applies as a robustness check in Section 3.5.
Balassa [14,15]	Industrial countries (1966); cross-country panel (1986)	Manufacturing	1960s; panel to the mid-1980s	Share of IIT in total trade; cross-country determinants	Tariff reductions among industrial countries produced specialization within rather than between industries. The 1986 cross-country analysis finds IIT intensity rising with income per head and market size and falling with distance and trade barriers. [Authors: Insert the specific magnitudes cited.]
Cheong and Yoo [10]	Korea and its trading partners	E-commerce trade	to 2020	GL index and IIT decomposition	[Authors: Complete from the article. Note that the coverage is Korean e-commerce trade, not GVC-linked manufacturing, so this reference supports the measurement approach rather than the sectoral comparison.]
Chin et al. [2]	ASEAN-4, China and the United States	Manufacturing	Trade-war period	VIIT measure with spatial panel estimation	Chinese FDI significantly raises the VIIT of ASEAN-4 with the United States, so relocation of FDI cushions the effect of the trade war. Spatial VIIT is positive and significant, meaning trade expansion in one ASEAN-4 member spills over to the others; the negative spatial FDI and GDP terms indicate competition within ASEAN-4.
Turkcan [5]	Austria and 29 trading partners	Auto-parts (parts and components)	1996–2006	Decomposition into inter-industry, HIIT and VIIT; panel estimation	Vertical IIT dominates auto-parts trade throughout. Its extent rises with average market size, differences in per-capita GDP and outward FDI, and falls with distance. This is the fragmentation reading of a high index that Section 5.4 applies to heading HS 8541.
Ekanayake et al. [23]	United States and its NAFTA partners	Manufacturing	to 2009	HIIT / VIIT decomposition	Vertical IIT accounts for the greater part of United States intra-industry trade with Canada and Mexico, consistent with trade between partners at different levels of development. [Authors: Insert the reported VIIT shares.]
Czarny et al. [25]	About 150 countries	All merchandise, HS 6-digit	2000–2022	GL index computed on WITS-Comtrade	World trade remains predominantly inter-industry: IIT accounts for roughly 32 per cent of world trade in 2000 and about 29 per cent in 2022, and developed economies trade far more intensively within industries than the rest of the world. This is the closest methodological benchmark for the present study, since it also computes GL indices at the 6-digit level.
Liu and Kang [6]	Vietnam	Semiconductors	recent	Network analysis of position in the GVC	[Authors: Complete from the article, and state the position it assigns to Vietnam so that the downstream reading in Section 4.2 can be compared with it.]
Pau and Yong [7]	ASEAN	Electrical and electronics	to 2025	Production-network and GVC participation indicators	Identifies a hierarchical three-group structure. The advanced group, led by Malaysia and Singapore, shows high network embeddedness and strong backward and forward linkages and acts as the coordination and innovation hub, above intermediate and peripheral economies. This ordering differs from the one obtained here on the unadjusted GL index, which places Singapore and Malaysia in the middle tier; the divergence is discussed in Section 5.4.
Prabheesh and Vidya [3]	ASEAN within the global trade network	HS 8541 and HS 8542, plus manufacturing inputs and testing, packaging and distribution	COVID-19 period	Network analysis: Degree, eigenvector and closeness centrality	Singapore occupies the central ASEAN position in the semiconductor trade network, with Vietnam, Malaysia, Thailand, the Philippines and Indonesia well integrated and Myanmar, Cambodia, Brunei and Lao PDR still peripheral; the pandemic reduced flows and connectivity. Note that this study covers HS 8541 and HS 8542, whereas the present study covers HS 8541 only.
This study	Six ASEAN economies	HS 8541 at 6-digit (discrete, optoelectronic and photovoltaic devices)	2021–2025	GL index, disaggregated, with robustness checks and full replication	Three-tier stratification on recomputed means: Thailand 0.883 and Vietnam 0.861 high and stable; Singapore 0.703 and Malaysia 0.690 intermediate; the Philippines high in level at 0.810 but falling steadily from 0.958 to 0.687, and Indonesia lowest at 0.557 and the most volatile (standard deviation 0.187). Every index is reproducible from the deposited files.

Note: Findings are summarized from the abstracts and reported results of each source.

Table A2. Concordance between HS2017 and HS2022 for heading 8541.

HS2017 subheading	HS2022 subheading	Product label as given in the source	Adoption within the sample
854110	854110	Diodes, excluding photosensitive diodes and LED	Reported by all six reporters, 2021–2025
854121	854121	Transistors with a dissipation rate below 1 W	Reported by all six reporters, 2021–2025
854129	854129	Transistors with a dissipation rate of 1 W or more	Reported by all six reporters, 2021–2025
854130	854130	Thyristors, diacs and triacs	Reported by all six reporters, 2021–2025
854140	854141 / 854142 / 854143 / 854149	854140: Photosensitive semiconductor devices incl. photovoltaic cells. 854141: Light-emitting diodes. 854142: Photovoltaic cells not assembled. 854143: Photovoltaic cells assembled in modules or panels. 854149: Other photosensitive semiconductor devices	854140 used through 2021 by five reporters and through 2023 by the Philippines; new subheadings from 2022, and from 2024 for the Philippines
854150	854151 / 854159	854150: Semiconductor devices n.e.s. 854151: Semiconductor-based transducers. 854159: Other semiconductor devices n.e.s.	Same adoption pattern as the row above
854160	854160	Mounted piezo-electric crystals	Reported by all six reporters, 2021–2025
854190	854190	Parts of the devices classified in this heading	Reported by all six reporters, 2021–2025

Note: Product labels are reproduced from the source files. TradeMap does not back-cast the new subheadings, which is why the 2021 column of **Tables 2–7** shows n.a. for them.

Table A3. Validation of the trade data

Check	Benchmark source	Coverage	Result
Recomputation of the indices reported here	Independent recomputation from the downloaded reporter files	29 country-year cells (Vietnam 2025 unavailable)	All 29 values reproduce Table 1 to within 0.001; export and import totals reproduce to the second decimal in USD billion
Sensitivity to very small flows	Recomputation excluding cells below USD 1 million of combined trade	All subheadings and years	Indices unchanged (maximum absolute difference 0.000); such cells carry under 0.01 per cent of total trade