Heliyon 9 (2023) e18070

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Speed of convergence in global value chains: Forward or backward linkage

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ARTICLE INFO

Keywords:
Speed
Convergence
Global value chains
Forward linkage
Backward linkage
Dynamic panel data model
System GMM
Pandemic

ABSTRACT

The COVID-19 pandemic is creating uncertainty that potentially causes a decline in global trade. It hampers the catching-up processes of developing countries because they are already connected through global value chains (GVCs). This study investigates the speed of convergence in GVC participation. Furthermore, we propose a forward and backward GVC participation approach to trace domestic and foreign value-added contributions and to overcome overvaluation in gross exports. We compare forward and backward linkages and determine countries' convergence speeds. We scrutinize stochastic, σ, and β-convergence using the system generalized method of moments; additionally, we use this method to address potential endogeneity issues. Using a dynamic panel approach, we investigate global convergence countries in GVCs and possible foreign direct investment (FDI) factors that may influence convergence. In addition, we analyze the early effect of the COVID-19 pandemic on the convergence rate using the recent Asian Development Bank multi-regional input-output database that covers the period 2010–2019. The results illustrate convergence in both forward and backward GVC participation; however, the convergence speed varies among group countries. A group comprising countries in the Association of Southeast Asian Nations and other countries experiences faster convergence than advanced countries in forward GVC participation. In contrast, advanced countries experience faster convergence in backward GVC participation. Furthermore, the results reveal that FDI plays a significant role in GVC participation. Overall, The COVID-19 pandemic has decreased GVC participation on average.

1. Introduction

The global economy is experiencing fluctuations due to the COVID-19 pandemic, while new coronavirus variants continue to emerge. Lockdown policies to restrain the spread of the coronavirus disrupt the supply chain of manufactured goods and reduce global value chain (GVC) participation. Consequently, global demand has also declined, reducing the trade intensity to major export markets [1]. A consequence is a negative trade balance and a decline in economic growth [2].

Countries need to be more involved in international trade to stimulate the economy, especially international production sharing. According to the new international trade theory, GVCs capture countries' linkages, specializations, and trade growth. GVC activities

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https://doi.org/10.1016/j.heliyon.2023.e18070
Received 17 September 2021; Received in revised form 27 June 2023; Accepted 5 July 2023
Available online 15 July 2023

began to develop in conjunction with globalization and regional economic integration in various regions. Compared with trade in final goods, trade in intermediate goods is most likely an essential component of globalization [3]. In fragmented trade, each country is no longer involved in all stages of production. Instead, each country specializes in a specific stage to increase participation in GVCs and to catch up with advanced countries [4–6].

Based on the literature, the concept of convergence, initially proposed by Solow [7], describes how developing countries or regions might catch up economically to their more developed counterparts. Akamatsu [8,9] developed a convergence analysis model following the "flying geese" paradigm, which explains the process of catching up with industrialization in the latecomer economy. Consequently, developing countries' competitive advantage can finally match that of advanced countries [10,11]. Some widely discussed and studied convergence features include convergences in income and comparative advantage, whereas studies of convergence in GVCs remain rare [12]. The current work expands the publication base by analyzing convergence in GVC participation in the Association of Southeast Asian Nations (ASEAN) countries, with large markets and other economic integration as a strategy for recovering economic conditions.

The involvement of countries in GVCs is closely related to foreign direct investment (FDI). FDI is dominant in the absorption or transfer of technology from more developed countries to their less-developed counterparts [13]. Furthermore, firms in developed countries can easily combine their high-tech knowledge with lower-wage labor in developing countries to yield lower costs. Thus, technology transfer can increase economic activity redistribution to developing countries, including Asian countries [5,14,15].

Moreover, institutional quality and physical infrastructure assets, such as electrical grids and telecommunication networks, are central to the functioning of modern economies and critical for sustainable development [16–20]. Furthermore, the effect of a free trade area (FTA) on FDI is potentially significant. FTAs may stimulate FDI through market expansion and vertical fragmentation [21].

Research has rarely addressed convergence in GVC participation because developing countries have not been fully involved in GVCs. Trade remains largely domestic and bilateral [3,22]. Therefore, GVC participation needs to be measured appropriately. Following Wang, Wei, Zhu [23], the measurement of GVC participation refers to the decomposition of gross exports, which is based on value-added, to trace value-added domestic and foreign contributions. The level of GVC participation is measured through a backward and forward linkage approach, which allows the tracing of the value-added in each phase of production. The forward-looking perspective demonstrates that an economy can generate domestic added value (DVA) by exporting intermediary goods to other countries. On the other hand, the backward-linked view asserts that final goods and services utilize foreign intermediate inputs [24]. Here, we propose a pair of GVC participation indices that we show to have more desirable properties than existing measures in the literature. Few studies have relied on these two approaches, resulting in narrow policymaking. However, both are appropriate for determining the leading sectors that developing countries can target in attempting to catch up with advanced countries. Furthermore, it is necessary to know whether the forward or backward linkage of GVC participation is more appropriate for countries in the catching-up process. Thus, an analysis of the speed of convergence in GVCs is fundamental.

In addition, the measurement of participation in GVCs has not been adequately explored because it requires input-output data, while an updated input-output database is difficult to obtain [25–28]. Compared with existing studies, our current work covers value-added trade employing the currently released Asian Development Bank (ADB) multi-regional input-output (MRIO) database, allowing us to track the value-added in producing particular products.

The COVID-19 pandemic is increasingly causing a trade downturn because some countries are already connected through GVCs [24,27,29]. Furthermore, the pandemic threatens developing countries' catching-up process. Hence, an analysis of the speed of convergence is important for determining the recovery of economic conditions.

The remainder of this article is structured as follows: A brief literature review and the stylized facts employed in this study are introduced in Sections 2 and 3. The data and methodology are explained in detail in Section 4, while the empirical results are presented in Section 5. The discussion is assessed in Section 6. The final section concludes with significant findings and policy recommendations.

2. Brief literature review

2.1. Global value chains participation

Participation in GVCs is inevitable, since the current condition of world trade has been captured in them. GVCs are a network of production stages of intermediate goods, from product design to the distribution of goods to final consumers, produced and assembled in various countries or across international borders [29–31]. Given these chains, a country no longer requires every phase of goods manufacturing. As a result, countries can specialize in a specific production stage with high value-added, to eventually catch up with advanced countries [4,5]. Based on the literature, developing countries' participation in GVCs remains low because these countries' sector positions remain in the lowest area of the smile curve [5,6]. Some academics, however, take the opposite view, so that the catching-up process for developing countries remains under debate regarding whether a country can converge faster by forward or backward linkage.

2.2. Convergence in GVCs

Convergence in GVC is important because it examines how developing countries catch up to developed countries. After all, they are already connected through global value chains (GVCs). Each country participating in GVC has the potential to increase value-added not just in one location, but in several locations, allowing countries to catch up and achieve greater convergence [5,15,32,33].

In addition, as noted, convergence analysis in GVCs follows the flying geese paradigm introduced by Akamatsu [8,9]. In this

framework, industry is transmitted from lead-geese countries. The transmission process occurs through outsourcing lead countries to follower countries [8–11,34]. Flying geese is marked by economic dynamism in Japan, as the lead country, to newly industrialized economies, and then to ASEAN countries and China. Consequently, ASEAN's comparative advantage pattern has finally matched that of Japan, China, and Korea. However, there are differences in the catching-up process and the stage of economic development in ASEAN+3. In this structural change in the East Asian industry, China is arguably the new dominant player in the new industrial pattern. Gaulier et al. [35] noted that multinational corporations used China as an export base for the final assembly to export final goods to the United States (US) and the EU. International production fragmentation has become an exciting phenomenon in East Asia, with vertically integrated production processes [25].

Convergence in GVCs has not been widely studied, in contrast to convergence of income, output, and productivity [12,32,36,37]. Filip [12] analyzed the relationship between income convergence and GVCs in European Union (EU) countries, and shows that the Central Eastern European-3 (CEEC-3) (Romania, Bulgaria, and Croatia) have grown faster than the EU-25. High FDI inflows underlie the convergence that does occur.

Research on convergence in GVCs remains relatively scant due to limited data and the unavailability of a standard decomposition method for trade flows [25,32,38,39]. Nevertheless, GVCs open up new opportunities for developing countries to catch up with advanced countries. Furthermore, with increasing GVC activity, research on participation in GVCs is growing. For example, Jangam and Rath research [32], using the club panel convergence technique in 61 Organisation for Economic Co-operation and Development countries, found that GVCs converged, although the processes were heterogeneous.

2.3. Foreign direct investment

In fragmentation production, FDI plays a significant role concerning GVC activities that allow each country to produce goods using intermediate inputs from other countries. FDI through multinational companies is a crucial driver of global production networks, influencing the distribution of value-added across countries. Multinational companies can produce better quality goods more efficiently than local producers [13,40]. Participation in GVCs requires local companies to have capabilities that fulfill international market requirements [14].

FDI is an investment that involves long-term relationships. It reflects the interest of and continuous supervision by a parent firm, which is a company domiciled in a country (affiliation firm). Usually, the highest FDI involvement is found in the manufacturing sector, which includes basic metals, machinery and equipment, and electrical and optical equipment [15]. In addition, FDI can encourage GVC participation through forward linkages, as in greenfield FDI, which aims to develop natural resource potential in capital-starved countries, or through backward linkages when directed to building export processing facilities [5,41].

2.4. Institution

Domestic institutions positively and significantly impact GVCs [20,42]. Good governance minimizes uncertainty and transaction costs to encourage trade flows between countries. In addition, stronger institutional laws promote the involvement of local sources in GVC activities [14]. On the other hand, low institutional quality, such as rampant corruption, political instability, weak accountability, and ineffective governance systems, becomes unattractive to investors and slows economic growth [20].

2.5. Infrastructure

Another factor that is thought to influence a state's participation in GVCs is infrastructure facilities. A robust telecommunications infrastructure in a country is expected to encourage its trade activities with other countries. Internet access needs are met by increasing information and communications technology infrastructure capabilities [43]. Several studies have shown the potential positive co-influence of infrastructure and institutions on economic growth [16–18,20].

2.6. The COVID-19 pandemic

The COVID-19 pandemic has caused uncertainty. Moreover, the coronavirus has mutated repeatedly, while several variants have changed the virus's transmissibility, risk profile, and symptoms. Measures to control contagion have demonstrated the more significant traders' vulnerability to shocks suffered by global value chain trading partners (GVCs). Further, this condition driven by supply chain restrictions affects business sustainability, employment opportunities, and income [29,31,44]. Moreover, the epidemic has also contributed to a decline in aggregate demand [45]. The pandemic has exacerbated the gap between developed and developing nations. Therefore, this study also analyzes the effects of the pandemic on convergence in GVCs.

Concerning structural convergence across countries and in parallel with economic integration, a crucial question arises about the dynamics of countries' specialization: How far have the convergence and speed of convergence in GVCs gone? To answer this question, we use dynamic panels to overcome bias in the static panel approach. We use an input-output database to measure forward and backward linkage participation and explore the interrelationship between country sectors [24]. A comprehensive approach is required for a thorough measurement of GVC participation, while it is crucial to examine whether convergence has occurred and at what level of speed [12]. Furthermore, it is necessary to know which countries have a faster convergence rate in GVCs, and the direction of the linkage (forward or backward).

3. Stylized facts

3.1. GVC participation

Fig. 1a shows the forward linkage GVC participation of several ASEAN countries based on broad sectors in 2019. Most ASEAN countries are still developing. DVA embedded in the primary sector appears to dominate in Indonesia, Malaysia, and Thailand, amounting to 0.79, 0.74, and 0.58, respectively.

Nonetheless, the DVA embedded in the manufacturing sector recorded a higher value in Indonesia, Malaysia, and Thailand than in Singapore and the Philippines. Singapore has the highest forward linkage GVC participation in the personal and public services sector, at 0.57, whereas the Philippines is dominant in the business service sector, also at 0.57.

Advanced countries have a high average forward linkage GVC participation value in almost all the sectors. The US dominates the primary sector, although other sectors also have a high value (Fig. 1b). Thus, developing countries' trading patterns are similar to those of advanced countries.

In addition, ASEAN may be catching up with advanced countries in terms of backward linkage in the low-, medium-, and high-technology manufacturing sectors (Fig. 1c and d). ASEAN's trade in value-added resembles that of advanced countries, with the value of backward GVC participation in the manufacturing sector, on average, exceeding that of advanced countries. Participation on the backward side shows involvement in GVCs more precisely, because of the greater use of foreign value-added (FVA) in production fragmentation [46]. The higher the use of FVA, the greater the involvement of a country in GVCs.

ADB research [22] shows that ASEAN countries' forward linkage dominates backward linkages. Consequently, most of the trade-in value-added remains low, especially in the upstream phase. As stated in the literature, the upstream position in the supply chain is

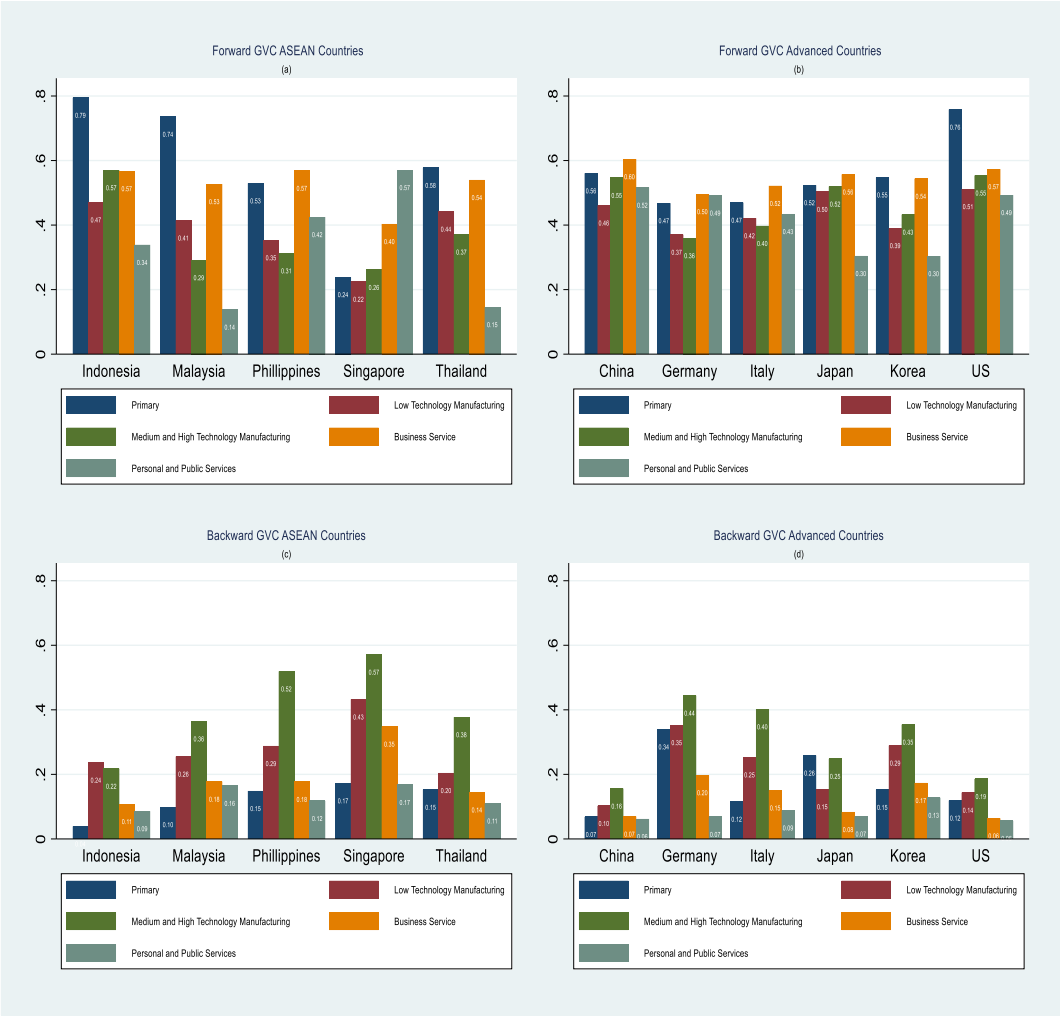

Fig. 1. (a) Forward GVC participation ASEAN countries; (b) Forward GVC participation advanced countries; (c) Backward GVC participation ASEAN countries; (d) Backward GVC participation advanced countries. Source: ADB MRIO, Author's computations.

Table 1
Manufacturing sector multiregional input-output, 2019 (million USD).

	Exporter											
Source of Value-Added	US	UK	Germany	Italy	China	Japan	Korea	Indonesia	Malaysia	Philippines	Singapore	Thailand
US	·	8.6	187.7	29.1	36.3	20.6	49.4	0.3	3.1	13.4	120.0	7.8
UK	27.7	·	48.6	52.0	1.6	0.9	2.2	0.0	0.2	0.1	1.8	0.2
Germany	91.3	15.8	·	222.8	31.3	7.7	31.1	0.2	1.2	2.8	0.9	1.0
Italy	45.0	20.6	248.4	·	20.2	2.1	21.2	0.1	0.5	0.6	5.0	1.9
China	528.1	17.5	357.4	199.5	·	36.1	227.4	6.4	8.9	20.9	37.5	8.6
Japan	26.0	0.6	30.7	8.5	29.8	·	37.3	1.1	2.0	3.8	18.6	3.9
Korea	1.2	0.1	0.8	0.3	49.3	0.3	·	0.1	0.6	1.1	0.4	0.1
Indonesia	21.5	0.2	17.2	4.9	7.2	3.3	12.5	·	2.0	1.3	14.5	0.5
Malaysia	6.8	0.4	1.8	0.1	0.0	0.0	0.0	0.0	·	0.0	45.3	0.3
Philippines	3.4	0.1	3.9	0.1	0.1	5.7	0.8	0.0	0.1	·	0.5	0.6
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	·	0.3
Thailand	27.2	1.4	6.7	0.8	1.0	8.1	2.8	0.1	1.5	1.7	1.1	·

Source: ADB MRIO database.

often associated with the context of less-developed countries. Where the level of innovation tends to be low, the production of raw materials and primary inputs is unlikely to develop [5,15,47]. This position shows that less-developed countries are not fully integrated into the international production network.

3.2. Value-added export interrelation in the manufacturing sector

As explained in the previous section, in fragmentation production, FDI plays a major role concerning GVC activities that allow each country to produce goods using intermediate inputs from other countries. Thus, the connection between a country's manufacturing sector and other countries can be seen from the multi-regional input-output table (Table 1). This table shows the interrelationships between countries' intermediate goods production. For example, the figure of USD 357.4 million in the China row and Germany column shows that Germany is dependent on USD 357.4 million worth of exports of intermediate products from China's manufacturing sector.

Table 1 also shows some facts pertaining to Chinese dominance in imported intermediate products. First, China has become the center of all trade and global production networks. Manufacturing inputs from China produce more than 3.6% of each major country's manufacturing output; thus, global manufacturers rely on Chinese input. Lockdown or production restrictions due to COVID-19 in China will significantly affect the global manufacturing sector. Production restrictions result in supply chain contagion [29]. The limited availability of intermediate inputs from different countries reduces aggregate demand and supply [45]. This pattern points to the harmful impacts of the COVID-19 pandemic on international trade [1,48].

Second, German manufacturing input is essential for Europe, the US, China, and Korea. Germany relies on manufacturing inputs from various countries, including the US and Italy, besides China. In addition, input from the US is critical in many countries, such as Malaysia, Brunei, and China [1,15]. Furthermore, in the ASEAN region, US manufacturing input is crucial for Singapore.

Finally, Table 1 also illustrates the regionalization of trade supply chains. ASEAN intraregional GVC participation in the trade chain remains low. The low intraregional trade is inseparable from East Asian regionalism, which remains fragile because the industrial

Fig. 2. (a) GVC participation and FDI involvement in ASEAN; (b) GVC participation and FDI involvement in East Asia; (c) GVC participation and FDI involvement in European Union; (d) GVC participation and FDI involvement in North America. Source: ADB MRIO, Author's computations.

competitiveness of each country depends on the smooth functioning of Asian factories, and because of a lack of cooperation and communication between regions [49]. Meanwhile, the interregional ASEAN data show the dependence of manufacturing input products in the ASEAN countries on East Asia, Europe, and the US. The real implications of this pattern are that supply disruptions in the US, Germany, China, Korea, and Japan will significantly impact consumers and companies in all major economies [1].

3.3. GVC participation and FDI involvement

Fig. 2a shows the involvement of FDI and GVC participation in ASEAN during the period 2010–2019. Although it fluctuates, FDI plays a significant role in driving the forward and backward linkages of GVC participation in ASEAN. On average, FDI involvement is 6.6%; however, the early COVID-19 pandemic resulted in an average decrease from 7.2% in 2018 to 6.9% in 2019. Similarly, backward GVC participation decreased during the pandemic, from 0.29 in 2018 to 0.28 in 2019. Meanwhile, forward GVC participation was relatively stable, at 0.48.

The involvement of FDI in the East Asia region, which comprises China, Japan, and Korea, tended to decrease during the observation period (Fig. 2b). The role of FDI in this region is insignificant, at an average of 1.16%, indicating an increase in domestic resources. Especially during the COVID-19 pandemic, the role of FDI, on average, declined, dropping from 0.98% in 2018 to 0.82% in 2019. The average backward GVC participation value for East Asian countries was 0.22, which decreased to 0.21 during the early stages of the pandemic. In contrast, forward GVC participation in East Asian countries was slightly higher during the observation period. The high forward GVC participation in East Asia is reasonable, considering that China has become the world's manufacturing center [1]. In addition, East Asia uses most of its domestic resources to produce intermediate export products.

FDI involvement in EU countries fluctuated and decreased during the period 2010–2019, although it remained relatively deep compared to other regions. FDI involvement was approximately 14.2% in 2010, falling to 6.4% in 2019 (Fig. 2c). Backward linkage GVC participation, which shows the contribution of FVA, decreased from 0.40 in 2018 to 0.39 in 2019. Furthermore, forward linkage GVC participation was driven mainly by DVA, while the average forward GVC participation value was 0.39%.

Compared to the EU, FDI involvement in North America (NA) tends to be smaller, at approximately 2.2%, over the observation period (Fig. 2d). The low FDI involvement shows that the US and Canada use DVA in their production processes. The forward GVC participation value was approximately 0.56 during the period 2010–2019, whereas the average backward GVC participation was 0.18. In the NA region, DVA dominated FVA during the observation period.

Table 2
Variable description and sources.

Variables	Description	Source
Domestic Value Added (DVA)	Domestic value added comprises VAX_G + RDV_G (million USD)	MRIO
VAX_G	Domestic value added (DVA) is embedded in exports and ultimately absorbed abroad. VAX_G comprises DVA_FIN + DVA_INT + DVA_INTrex (million USD)	MRIO
DVA_FIN	Domestic value added (DVA) embedded in final use commodity exports to country r (million USD)	MRIO
DVA_INT	DVA in intermediate export is used by direct importers (r) to produce their domestic final use commodities and consumed in the country (million USD)	MRIO
DVA_INTrex	DVA embedded in intermediate exports used by direct importers to produce exports to third economies (million USD)	MRIO
Return Domestic Value Added (RDV_G)	DVA embedded in economies' intermediate exports, but returned to the economies and finally consumed at home (million USD)	MRIO
Vertical Specialization (VS)	Vertical Specialization comprises FVA + PDC (million USD)	MRIO
Foreign Value Added (FVA)	Foreign value added (FVA) comprises FVA_FIN + FVA_INT + PDC (million USD)	MRIO
FVA_FIN	Foreign value-added embedded in final exports (million USD)	MRIO
FVA_INT	Foreign value-added embedded in intermediate exports (million USD)	MRIO
Domestic Double Counting (DDC)	DVA embedded in intermediate exports to countries (r) but returned home as their intermediate imports used to produce export goods (million USD)	MRIO
Foreign Double Counting (FDC)	FVA embedded in intermediate exports to countries (r) but returned home as their intermediate imports used to produce their intermediate and final use commodity exports (million USD)	MRIO
Pure Double Counting (PDC)	Pure Double Counting (PDC) comprises DDC + FDC (million USD)	MRIO
Backward GVC Participation (GVCB)	The ratio between FVA and gross exports	MRIO, Computed by Authors
Forward GVC Participation (GVCF)	The ratio between DVA and gross exports	MRIO, Computed by Authors
Gross Export (EXP)	Gross Export comprises DVA and VS	MRIO
Foreign Direct Investment (FDI)	Inflow FDI (% Gross Domestic Product)	WDI-World Bank
COVID-19 Pandemic	Dummy COVID-19 pandemic (1 = 2019, 0 = otherwise)	–
Institutional Index (Ins)	The average of six institutional indices from the World Bank, covering voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, and control of corruption (index lies between −2.5 and 2.5)	WGI-World Bank, Computed by Authors
Infrastructure (Infra)	The average of three infrastructure measures covering (1) fixed broadband subscriptions, (2) access to electricity, and (3) fixed telephone subscriptions (%)	WDI-World Bank, Computed by Authors

Source: Authors' compilations.

4. Data and methodology

4.1. Data

Using the recently available ADB MRIO database, covering 62 countries and another 132 countries aggregated as the rest of the world, with a disaggregation level of 35 industries, we examine convergence in GVCs [22], Appendix B). Using annual data, we address the research issue based on the ASEAN members and advanced countries, considering 41 countries over the period 2010–2019 (Appendix A). Furthermore, we employ data regarding FDI and institutional and infrastructure data for each country [50]. These data were derived from several sources: the ADB MRIO, the Worldwide Governance Indicators (WGI), and the World Development Indicators (WDI) published by the World Bank. The details are presented in Table 2.

This study is based on the sectoral interdependence analysis introduced by Leontief [51]. A multi-regional input-output model builds on the input-output framework of a single economy to track linkages between countries and sectors. In a global economic environment that is increasingly characterized by fragmented production processes and internationally distributed by intermediary trade, fairly complex quantitative information is required. The input-output economic analysis framework provides an ideal system for describing and analyzing integrated production and trade activities in a globalized world. Studying one in isolation from others would be suboptimal.

4.2. Methodology

4.2.1. Measuring GVC participation

Gross exports are decomposed into value-added terms to measure GVC participation, as illustrated in Equations (1)–(3). The gross export decomposition follows Leontief's [51] insight. Gross outputs X can be divided into intermediate (A) and final products (Y): X = AX + Y. Without loss of generality, let us consider a world economy with G countries and N sectors. All gross outputs produced by countries should be used as intermediate or final products in the countries of origin or abroad [22,52]:

$$X = AX + Y = A^D X + Y^D + A^F X + Y^F = A^D X + Y^D + E \tag{1}$$

where X denotes gross output production; A^D is the GN × GN diagonal block matrix, as units of domestic intermediate goods are used, as stated by the concept of the input-output coefficients ($A^F = A - A^D$). $Y = [\sum_r^G Y^{1r} \sum_r^G Y^{2r} \ldots \sum_r^G Y^{gr}]'$ is a GN × 1 matrix of the final goods and services production. $Y^D = [Y^{11} Y^{22} \ldots Y^{gg}]'$ is a GN × 1 matrix of the domestic final goods and services production, while $Y^F = Y - Y^D$ is a GN × 1 matrix of the final product exports. $E = [\sum_{r\neq 1}^G E^{1r} \sum_{r\neq 2}^G E^{1r} \ldots \sum_{r\neq g}^G E^{gr}]'$ *is* a GN × 1 matrix of the gross exports. Rearranging Formula 1, we obtain [22,52]:

$$X = \left(1 - A^D\right)^{-1} Y^D + \left(1 - A^D\right)^{-1} E = LY^D + LE$$

$$= L\,Y^D + LY^F + LA^F X \tag{2}$$

where $(1 - A^D)^{-1}$ is the GN × GN diagonal block matrix of the local Leontief inverse. By pre-multiplying the GN × GN diagonal matrix, $\widehat{V}$, of the direct value-added coefficient, replacing X with BY, and further converting the three final goods and service production vectors (Y^D, Y^F, and Y) into the GN × GN diagonal matrix $\widehat{Y}$, $\widehat{Y}^D$, and $\widehat{Y}^F$, we can obtain a decomposition of the value-added of the countries' sectors, and the standard Leontief decomposition can be applied directly to determine the final production level as follows [22,52]:

$$\widehat{V}B\widehat{Y} = \widehat{V}L\widehat{Y}^D + \widehat{V}L\widehat{Y}^F + \widehat{V}LA^F B\widehat{Y}$$

$$= \widehat{V}L\widehat{Y}^D + \widehat{V}L\widehat{Y}^F + \widehat{V}LA^F L\widehat{Y}^D + \widehat{V}LA^F\left(B\widehat{Y} - L\widehat{Y}^D\right) \tag{3}$$

Each element in the matrix represents the value-added from a source country sector that is directly or indirectly used to produce the final goods and services in the particular country sector. The element of Row (s,i) and Column (r,j) in the matrix, $v_i^s b_{ij}^{sr} y_j^r$, is the total value added for Sector i in Country s embodied in the final products produced by Sector j of Country r [52].

The sum of the $\widehat{V}B\widehat{Y}$ matrix along a row accounts for how each country's DVA originating in a particular sector is used by the sector itself and all countries' sectors. The sum traces forward industrial linkages across all countries. The sum of the $\widehat{V}B\widehat{Y}$ matrix down a column accounts for al country sectors' value-added contributions (FVA) to a specific country sector final product. The sum traces backward industrial linkages across countries.

The GVC participation ratio determines a country's participation in GVCs. As previously stated, this study uses a forward and backward industrial linkage approach. The forward linkage perspective shows the share of DVA in intermediate exports relative to gross exports globally, as shown in Equations (4) and (5). Following Wang et al. [23], DVA comprises DVA_INT, DVA_INTrex, and RDV_G. The forward GVC participation ratio of the economy, s ($GVCF_s$), is as follows [23,24,53]:

$$GVCF_s = \left(\sum_k \sum_r DVA\_INT_{sr}^k + DVA\_INTrex_{sr}^k + RDV\_G_{sr}^k\right) \Big/ \left(\sum_k \sum_r EXP_{sr}^k\right) \tag{4}$$

whereas for Sector k in Economy s, the forward GVC participation ratio ($GVCF_s^k$, hereafter GVCF) is:

$$GVCF = \left(\sum_r DVA\_INT_{sr}^k + DVA\_INTrex_{sr}^k + RDV\_G_{sr}^k\right) \Big/ \left(\sum_r EXP_{sr}^k\right) \tag{5}$$

The export decomposition formula is based on forward linkage as follows [23]:

$$DVA\_INT = (V^s L^{ss})^T \# (A^{sr} B^{rr} Y^{rr}) \tag{6}$$

$$DVA\_INTrex = (V^s L^{ss})^T \# \left(A^{sr} \sum_{t \neq s,r}^{G} B^{rt} Y^{tt}\right) + (V^s L^{ss})^T \# \left(A^{sr} B^{rr} \sum_{t \neq s,r}^{G} Y^{rt}\right) + (V^s L^{ss})^T \# \left(A^{sr} \sum_{t \neq s,r}^{G} \sum_{u \neq s,t}^{G} B^{rt} Y^{tu}\right) \tag{7}$$

$$RDV\_G = (V^s L^{ss})^T \# (A^{sr} B^{rr} Y^{rs}) + (V^s L^{ss})^T \# \left(A^{sr} \sum_{t \neq s,r}^{G} B^{rt} Y^{ts}\right) + (V^s L^{ss})^T \# (A^{sr} B^{rr} Y^{ss}) \tag{8}$$

Equation (6) shows the DVA in the intermediate exports utilized by the direct importer (r) to manufacture domestic final goods. Equation (7) illustrates the DVA included in the intermediate exports used by the direct importer, r, for generating exports eventually absorbed by nations other than the source country, s. Equation (8) explains the DVA initially exported and then returned home from the direct importer, r, and third country, t. V^s represents the DVA in Country s, while B^{ss} denotes the inverse Leontief GN × GN matrix as the total requirement matrix representing the number of gross outputs needed by Country s to produce a unit of final demand increase in Country s. Y^{sr} is the GN × 1 matrix of the final demand of Country r for the final products produced in Country s, while L^{ss} denotes the local Leontief inverse, and A^{sr} is the GN × GN input-output matrix coefficient. Additionally, X^s is the GN × 1 matrix of Country s's gross output.

The backward-linked perspective shows the share of FVA embedded in intermediate exports relative to gross exports globally, as revealed in Equations (9) and (10). The backward GVC participation ratio (GVCB_s) for each economy, s, with Sector k exporting to all other countries, r, is as follows [23,24,53]:

$$GVCB_s = \left(\sum_k \sum_r DDC_{sr}^k + FVA\_FIN_{sr}^k + FVA\_INT_{sr}^k + FDC_{sr}^k\right) \Big/ \left(\sum_k \sum_r EXP_{sr}^k\right) \tag{9}$$

whereas for Sector k in Economy s, the backward participation ratio ($GVCB_s^k$, hereafter GVCB) is as follows:

$$GVCB = \left(\sum_r DDC_{sr}^k + FVA\_FIN_{sr}^k + FVA\_INT_{sr}^k + FDC_{sr}^k\right) \Big/ \left(\sum_r EXP_{sr}^k\right) \tag{10}$$

The export decomposition formula is based on backward linkage as follows [23]:

$$DDC = (V^s L^{ss})^T \# \left(A^{sr} \sum_{t \neq s}^{G} B^{rs} Y^{st}\right) + (V^s B^{ss} - V^s L^{ss})^T \# (A^{sr} X^r) \tag{11}$$

$$FVA\_FIN = (V^r B^{rs})^T \# Y^{sr} + \left(\sum_{t \neq s,r}^{G} V^t B^{ts}\right) \# Y^{sr} \tag{12}$$

$$FVA\_INT = (V^r B^{rs})^T \# (A^{sr} L^{rr} Y^{rr}) + \left(\sum_{t \neq s,r}^{G} V^t B^{ts}\right) \# (A^{sr} L^{rr} Y^{rr}) \tag{13}$$

$$FDC = (V^r B^{rs})^T \# (A^{sr} L^{rr} E^{r*}) + \left(\sum_{t \neq s,r}^{G} V^t B^{ts}\right) \# (A^{sr} L^{rr} E^{r*}) \tag{14}$$

Equation (11) represents the double-counted DVA that was utilized to produce the exports of both final-use and intermediate commodities. Equation (12) denotes the FVA embodied in final exports from an importer, r, and a third country, t. By comparison, Equation (13) indicates The FVA embedded in intermediate exports from an importer, r, and a third country, t, which is subsequently used by r to generate its consumption. Equation (14) shows the double-counted FVA in domestic export manufacturing. Furthermore, DVA_FIN is defined as $(V^s B^{ss})^T \# Y^{sr}$.

4.2.2. Estimation techniques

As noted, there are three major types of convergence analysis (stochastic, σ, and β). Similar convergence analysis methods have

been commonly used in the economic convergence literature in recent years to analyze the income convergence of various samples covering different periods. However, convergence in GVCs has not been fully implemented for countries worldwide [12,32]. Therefore, for this study, we develop a stochastic, σ, and β-convergence analysis of GVCs in the ASEAN region, other than East Asia, the EU, and NA.

4.2.2.1. Stochastic convergence. Previous research has widely discussed stochastic convergence analysis (e.g., Refs. [21,54,55]. If stochastic convergence is confirmed, the temporary shock in GVC participation, relative to its average level, disappears over time. Therefore, unit root tests (to avoid potentially biased results) for time series or panel data with structural breaks are currently gaining attention in stochastic convergence analysis, including the Im-Pesaran-Shin panel unit root test, the Augmented Dickey-Fuller (ADF) test, and the Levin-Lin-Chu (LLC) test. The stochastic convergence analysis in this study includes structural breaks due to the shock of the COVID-19 pandemic.

4.2.2.2. σ-convergence. σ-convergence denotes a decrease in the degree of dispersion of GVC participation across different economies over time. Otherwise, σ-divergence is recommended. The coefficient of variation and standard deviation (SD) are two methods that can be used in the existing literature to measure the degree of dispersion [12,21,56–58]. Specifically, the standard deviation that measures the dispersion degree of σ-convergence in GVC participation is as follows [21,58]:

$$\sigma_{i,t} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(gvc_{i,t} - \overline{gvc_{i,t}}\right)^2} \tag{15}$$

where the subscripts, i and t, denote country and year, respectively. n denotes the total number of countries, gvc represents GVC participation, $\overline{gvc_{i,t}}$ is the mean of GVC participation in Country i in Year t, while $\sigma_{i,t}$ defines the standard deviation of GVC participation (Equation (15)).

4.2.2.3. β-convergence. The most elementary convergence test is the so-called β-convergence test. The empirical convergence literature has relied heavily on dynamic panel data generalized method of moment (GMM) estimation. Dynamic panel data estimations can analyze dynamic adjustment observations, which help measure the catching-up process in GVC participation. In addition, these estimations can control unobserved individual heterogeneity and provide more information and data variations, minimizing the occurrence of multicollinearity. The characteristics of a dynamic panel are contained in lag-dependent variables in the model, as follows [12,36,59–61]:

$$y_{it} = \delta y_{i,t-1} + x_{it}^{'}\beta + u_{it};\ i = 1, .., N\ ;\ t = 1, 2, ..., N \tag{16}$$

where δ is a scalar, $x^{'}$ is a matrix of size $1 \times k$ (row vector containing a set of control variables), and β is a matrix of size $k \times 1$ (β denotes a column vector of the corresponding coefficients of the control variables). The subscripts, i and t, represent the country and year, respectively. N refers the total number of countries. y_{it} represents the GVC participation. It is assumed that u_{it} follows a one-way error component model, such that [59,60]:

$$u_{it} = \mu_i + v_{it} \tag{17}$$

where u_{it} is the error term decomposed into μ_i individual effects (unobserved individual heterogeneity), and v_{it} is the idiosyncratic error term (an error that varies over time). μ_i and v_{it} are assumed $\sim$ $IID\ (0, \sigma_v^2)$, where μ_i and v_{it} are independent and identically distributed (IID), with a mean value of zero and a variance of σ_μ^2, or μ_i and v_{it} are independent of each other (Equation (17)). The problems with the model include time-invariant unobserved individual heterogeneity; for instance, a state leader's managerial ability, hard-work culture, or unwritten trade policy [62].

In Equation (16) above, if $y_{i,t-1}$ is correlated with u_{it}, despite no autocorrelation on v_{it}, then the ordinary least squares estimator will be biased and inconsistent. Therefore, the GMM approach is used to produce a consistent and unbiased estimator.

The conditional convergence characteristic of GVC participation can be confirmed when $\beta \neq 0$ and δ is statistically significant and lies between 0 and 1. This implies that there is an equilibrium level for GVC participation that depends on existing economic development conditions, such as FDI. An unconditional convergence characteristic for GVC participation is implied when $\beta = 0$ (i.e., the control variables are absent) and the estimated coefficient for the lag variable is significant, with a value between 0 and 1. Hence, all the countries eventually converge to the same steady state, with no conditionality.

Econometric analysis employs two estimation procedures within the GMM framework: first-difference GMM (FD-GMM) and system GMM (SYS-GMM). This study employs SYS-GMM analysis, due to limitations associated with the FD-GMM estimator, specifically the weak instrument [60]. The SYS-GMM estimator was created to eliminate bias and address this limitation [59,60,63].

SYS-GMM emerges from a correlation between unobserved individual heterogeneity and the lagged dependent variable. To overcome the endogeneity problem, an instrumental variable approach can be used. However, it is often difficult to find reliable instruments, which should be associated with explanatory variables but not with error terms. In the empirical literature, a GMM-based dynamic panel data estimator addresses unobserved individual heterogeneity, omitted variable bias, and potential endogeneity.

Blundell and Bond [60] introduced the SYS-GMM estimator to reduce the bias in the FD-GMM by estimating a system of equations that includes a lag of the regressor as the instrument. However, if the errors are serially correlated, an estimator that employs a lagged

variable as an instrument assumes white noise errors will no longer be consistent. Therefore, it is necessary to explicitly test the validity of instrument variables, along with their parameter estimates, using the Hansen and the Arellano and Bond tests (AB test).

The Hansen test is used to isolate overidentifying restrictions, i.e., testing whether an exogenous instrument is valid. For this test, the null hypothesis is that the instrument is valid because it is unrelated to the error term. If the Hansen test rejects the null hypothesis, it is possible that the estimator is biased and inconsistent due to a correlation between the instrument and the error term.

The AB test determines whether a residual serial correlation exists (Equations (18)–(20)). If ε_{it} is serially independent, then [59,60,63]:

$$E\left[\left(\Delta\varepsilon_{i,t}\Delta\varepsilon_{i,t-1}\right)\right] = E[(\varepsilon_{it} - \Delta\varepsilon_{it-1})(\Delta\varepsilon_{it-1} - \Delta\varepsilon_{it-2})] = -E\left[\varepsilon_{it-1}^2\right] = -\sigma_\varepsilon^2 \tag{18}$$

Thus, a first-, and not a second-order serial correlation is expected, as follows:

$$E\left[\left(\Delta\varepsilon_{i,t}\Delta\varepsilon_{i,t-2}\right)\right] = E[(\varepsilon_{it} - \Delta\varepsilon_{it-1})(\Delta\varepsilon_{it-2} - \Delta\varepsilon_{it-3})] = 0 \tag{19}$$

Detection of a second-order serial correlation indicates a specification error. The null hypothesis is expected to be accepted, implying no second-order serial correlation or autocorrection in idiosyncratic errors, as follows [59,60,63]:

$$E\left[\left(\Delta\varepsilon_{it}\Delta\varepsilon_{i,t-2}\right)\right] = 0 \tag{20}$$

This study uses the GMM system estimator to estimate the speed of convergence in GVCs. Thus, our base model is the SYS-GMM model [59,60,63]:

$$y_{it} = \alpha + \sum_{j=1}^{p} \beta_j y_{i,t-j} + \delta X_{it} + \mu_i + v_{it} \tag{21}$$

The SYS-GMM model eliminates individual effects because it does not vary over time; thus, the estimated value is valid and unbiased. Parameter β is crucial for the direction of convergence.

This approach to testing the convergence hypothesis has been widely applied as a panel test for a group of countries over time. For example, if the coefficient, β, lies in the interval, $0 < \beta < 1$, convergence occurs (accept H_o convergent). This represents a reduction of the gap between countries. This coefficient is also related to the speed of convergence, which provides information about the speed of adjustment in the GVCs in response to a shock in the economy. The speed of convergence is calculated as follows [12,64,65]:

$$\gamma = -ln\,(\beta) \tag{22}$$

In this study, we analyze unconditional and conditional convergence [12]. The empirical model for unconditional GVC convergence is as follows:

$$GVC_{it} = \alpha + \sum_{j=1}^{p} \beta_j GVC_{i,t-j} + u_{it};\ i = 1, .., N\ ;\ t = 1, 2, ..., N \tag{23}$$

where the subscript, i (i = 1,2,3, …N), indicates countries, while the subscript, t (t = 1,2,3, …T), denotes years. GVC indicates participation in both backward and forward linkages. The above equation does not include variables that affect GVC participation, which represents unconditional convergence. Finally, α is held constant, while β is the estimated regression parameter. Thus, the β parameter is significant for the direction of convergence.

Furthermore, conditional convergence aims to detect the trend in GVC convergence by considering the factors that are the main drivers of country participation in GVCs during the analyzed period. The empirical strategy involves estimating a GVC participation model in which FDI is an explanatory variable by considering institutions and infrastructure as control variables. In addition, potential endogeneity concerns are addressed by employing GMM estimators that use internal instruments. Some studies have shown that FDI has a major impact on convergence in GVCs [5,14,15,42,47]. Based on Equation (21), the empirical model for conditional convergence is presented in equation (24), as follows:

$$GVC_{it} = \alpha + \sum_{j=1}^{p} \beta_j GVC_{i,t-j} + \delta_1\ FDI_{i,t} + ... + \delta_p\ FDI_{i,t-p} + \omega\ COVID19_{it} + \tau X_{it} + \mu_i + v_{it} \tag{24}$$

where the subscript, i = 1, …, N indicates countries, t = 1, …, T, denotes years, μ_i is *unobserved individual heterogeneity,* while v_{it} represents *idiosyncratic error*. *IID* $(0, \sigma_v^2)$ is assumed for μ_i and v_{it}. Moreover, GVC_{it} is the backward and forward GVC participation of Country i during period t. Variables affecting GVC, such as FDI (FDI_{it}), are used in the conditional convergence equation to influence the level of GVC convergence. X_{it} is a row vector that consists a set of control variables, while τ denotes a column vector that contains the coefficients of these control variables. The conditional convergence model includes institutional (INS_{it}) and infrastructure ($INFRA_{it}$) variables as control variables. Furthermore, α is constant, while $\beta, \delta, \omega,$ and τ are the estimated regression parameters. The observed period spans from 2010 to 2019. We analyze the impact of the early COVID-19 pandemic shock by incorporating a COVID-19 dummy variable into the GVC convergence model, considering the COVID-19 pandemic is expected to have caused an economic shock.

We employ a dynamic panel model based on panel data from 41 countries (N) over ten years (T) to achieve the research objectives. These methods serve as robustness tests to assess the consistency of the relationships between the variables of interest. The dynamic model is an SYS-GMM method designed for dynamic panel analysis, and relies on specific assumptions about the data generation

process, including that the process may be dynamic, with the current realization of the dependent variable being influenced by past realizations. The regressors are not completely exogenous, and are possibly correlated with past and potentially recent realizations of the error term [66].

5. Empirical result

5.1. Summary statistics

The summary statistics for the variables of interest, based on the groups of countries, are shown in Table 3. Appendix A lists the members of the country groups. The average ASEAN GVCF is 0.46, with Laos reporting the lowest GVCF, at 0.21, in 2011. Brunei has the highest GVCF in 2015, at 0.85. The SD of 0.16 indicates a minimal dispersion of the sample means. Similarly, the sample average ASEAN GVCB is 0.29, with Brunei having the lowest, at 0.08, in 2010, while Singapore has the highest, at 0.56, in 2012. The SD of 0.13 reveals a minimal dispersion of the sample means.

The sample mean for FDI for the ASEAN countries is 6.64%, with Brunei having the lowest, at −1.32%, in 2016, while Singapore has the highest mean, at 28.60%, in 2017. The SD of 6.77 demonstrates a wide dispersion among nations compared to the sample average of 6.64%. Moreover, the sample averages for institutional and infrastructure variables in the ASEAN countries are −0.04 and 10.83, respectively.

Comparatively, NA has the highest average of forward GVC participation of 0.56, while the EU has the highest average GVCB of 0.39 [46]. Inflow FDI to Europe drove the high backward GVC participation in the EU, which had the highest average of 10.19%, supported by high FDI in Cyprus, at 280.13%, in 2012.

5.2. Sectoral analysis

The sectoral-level analysis results indicate forward GVC participation in the big five ASEAN countries and big five advanced countries. Fig. 3 shows the relatively similar leading sectors between the ASEAN countries and advanced countries during the pandemic. The sectors that tend to be more forward integrated include renting of machinery and equipment (M&Eq), mining and quarrying; wood and products of wood and cork; pulp, paper, paper products, printing, and publishing; and post and telecommunications. In contrast, machinery, not elsewhere classified (NEC), electrical and optical equipment; basic metals and fabricated metals; leather, leather products, and footwear; and electricity are included in the manufacturing sectors with a higher share of backward GVC participation (see Fig. 4). These sectors contain large FVA in intermediate exports [14,15]. The significant role of FDI shows that developing countries' trade patterns, including ASEAN, resemble those of advanced countries, consistent with the flying geese paradigm [10,11,34].

Businesses sectors appear to be forward-linkage leading sectors. Renting of M&Eq has a high forward GVC participation share in

Table 3
Summary statistics.

Group	Statistics	GVCF	GVCB	FDI	INS	INFRA
ASEAN	Mean	0.46	0.29	6.64	−0.04	10.83
	SD	0.16	0.13	6.77	0.73	1.34
	Maximum	0.85	0.56	28.60	1.64	12.31
	Minimum	0.21	0.08	−1.32	−1.00	8.16
East Asia	Mean	0.43	0.24	1.16	0.55	13.53
	SD	0.04	0.09	1.09	0.77	0.66
	Maximum	0.50	0.40	4.00	1.38	14.53
	Minimum	0.35	0.13	−0.01	−0.58	12.81
EU	Mean	0.40	0.39	10.19	1.03	11.27
	SD	0.08	0.11	30.59	0.49	0.94
	Maximum	0.72	0.73	280.13	1.87	13.18
	Minimum	0.16	0.16	−40.41	0.07	9.58
NA	Mean	0.56	0.18	2.25	1.43	13.21
	SD	0.04	0.06	0.76	0.20	0.71
	Maximum	0.70	0.26	3.85	1.68	13.90
	Minimum	0.52	0.11	1.27	1.13	12.51
ASEAN and other countries	Mean	0.42	0.35	8.37	0.78	11.43
	SD	0.11	0.13	25.18	0.73	1.26
	Maximum	0.85	0.73	280.13	1.87	14.53
	Minimum	0.16	0.08	−40.41	−1.00	8.16
Advanced countries	Mean	0.41	0.36	8.85	1.01	11.60
	SD	0.09	0.12	28.27	0.54	1.19
	Maximum	0.72	0.73	280.13	1.87	14.53
	Minimum	0.16	0.11	−40.41	−0.58	9.58

Note: ASEAN=Association South East Asian Nations; EU=European Union; NA=North America; GVCF = forward GVC participation; GVCB = ard GVC participation; DI = foreign direct investment; INS = institution;GINFRA = infrastructure; ISD = standard deviation.
Source: ADB MRIO, Authors' computations.

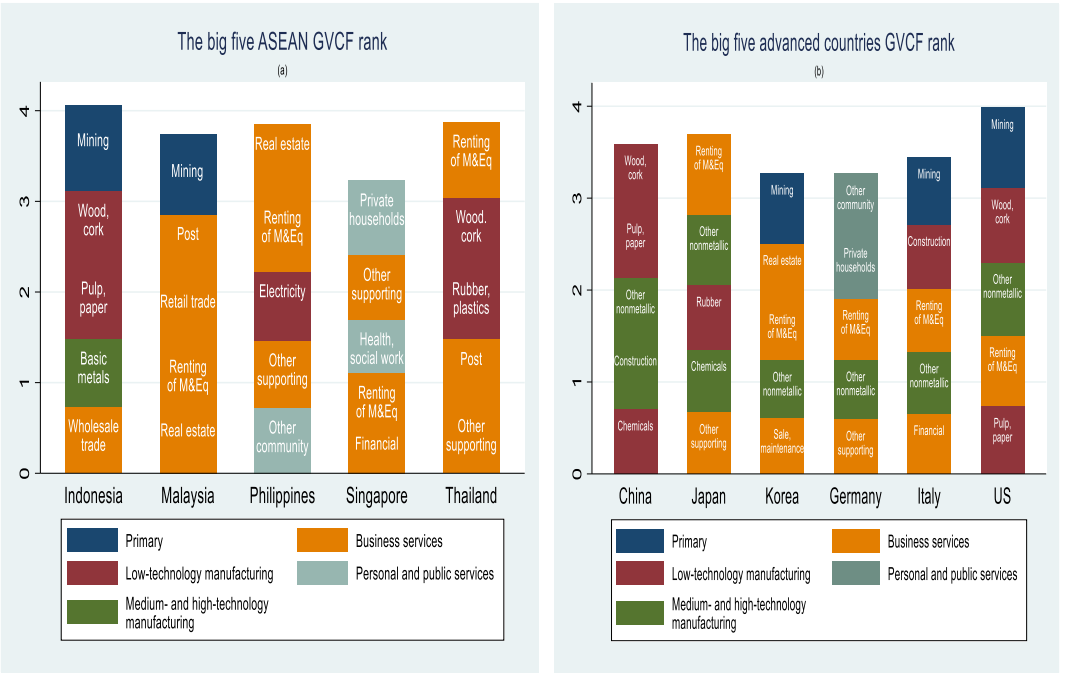

Fig. 3. (a) The big five GVCF rank for ASEAN countries, 2019; (b) The big five GVCF rank for advanced countries, 2019. Source: ADB MRIO, Author's computations.

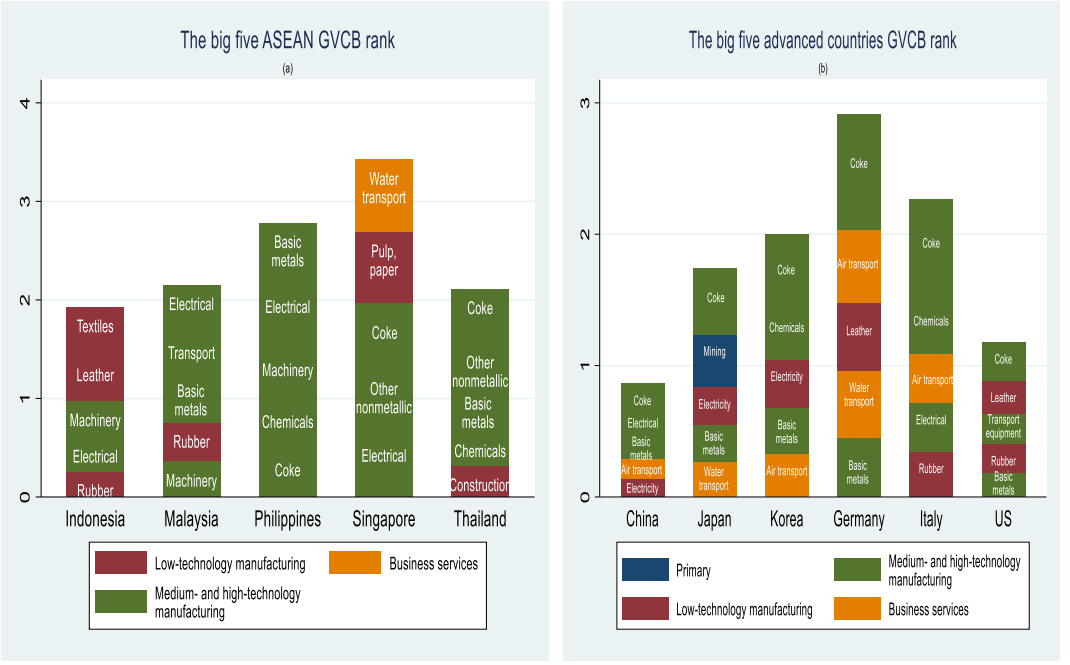

Fig. 4. (a) The big five GVCB rank for ASEAN countries, 2019; (b) The big five GVCB rank for advanced countries, 2019. Source: ADB MRIO, Author's computations.

most countries worldwide, although this share decreased during the pandemic. The highest forward GVC participation from sector renting of M&Eq in 2019 was Japan, at 0.876, followed by Thailand and the Philippines, at 0.832 and 0.812, respectively. Post and telecommunications appear to have a high share of forward GVC participation in the ASEAN region. These sectors experienced a steep increase of 1.2% in the period 2018–2019, because of significant improvement in facilities during the pandemic. This is consistent with

the literature finding that increased digitalization is the immediate urgency in GVCs as a tool to continue transactions and operations during lockdown periods [48].

In low-technology manufacturing, the electricity, gas, and water supply sectors also experienced a significant increase in the GVCF value. The need for electricity increased dramatically during the pandemic, when many people worked mostly from home [67]. In addition, the health and social work sector experienced considerable growth of 3.2%. Quak [48] found positive effects in industries that provided medical products. The production of intermediate goods containing DVA in this sector has increased dramatically during the COVID-19 pandemic.

On the other hand, from the backward linkages perspective, the leading sectors, such as electrical and optical equipment, transportation equipment, basic metals and fabricated metals, machinery, and NEC support the development of the semiconductor industry in the ASEAN region [15]. Regrettably, the pandemic has hampered the development of the semiconductor industry, which requires foreign intermediate input from these sectors.

Foreign suppliers are focused on parts that require higher manufacturing and design capabilities to produce, such as engines, electrical transmission, and suspension parts [15]. Meester and Ooijens [68] found that the automotive industry was severely affected by the initial COVID-19 outbreak in Wuhan, as several manufacturers sourced critical components from the affected area.

The business sectors highly support the forward GVC participation of the ASEAN countries, whereas the low-, medium-, and high-technology manufacturing sectors dominate the backward linkage. Moreover, the manufacturing sector's negative growth will exacerbate the countries' participation rate in GVCs during the COVID-19 pandemic.

5.3. Econometric analysis

5.3.1. Stochastic convergence

The method most often used for testing stochastic convergence is the unit root test. The ADF test, as proposed by Hao et al. [54], assumes a standard unit root process for the whole sample, whereas the LLC test assumes a unit root process for each individual. Both of these tests are widely used in panel data unit root testing; therefore, we applied both tests for the ASEAN countries that are members of ASEAN as well as of other country groups.

The ADF test value for GVCF is between −7.65 and −8.14 in the presence of individual intercepts and trends (Table 4), while the test value for LLC ranges from −27.69 to −36.92. The ADF test value for GVCB is between −6.71 and −7.52 in the presence of individual intercepts and trends, while the test value for LLC ranges from −42.46 to −42.44. The corresponding p-values for both tests are <0.05; thus, GVCF and GVCB are I (0), while there is significant evidence of stochastic convergence in GVCF and GVCB from 2010 to 2019. The presence of stochastic convergence in GVC participation indicates that a shock to GVC participation in a specific country, on the average level for the whole country, is only temporary.

5.3.2. σ convergence

The general trends of forward GVC participation and σ-convergence between 2010 and 2019 are shown in Fig. 5. Notably, the GVCF of the ASEAN and other countries fluctuated slightly during this period, ranging between 0.41 and 0.45; from 2010 to 2017, it tended to fluctuate. Beginning in 2018, the intensity of GVCF decreased, while at the beginning of the 2019 pandemic, the GVCF seemed to increase. Compared to the GVCF trend, the SD trend seems to fluctuate slightly around 0.10 and 0.11.

The general trend of forward GVC participation for advanced countries fluctuated slightly during this period, ranging between 0.48 and 0.39. From 2010 to 2017, the GVCF tended to fluctuate, although it showed a distinct decline. Beginning in 2018, the GVCF intensity declined, and then rose in 2019. Compared with the GVCF trend, the SD trend followed the same pattern, although it declined substantially from 2017. This significant decline in SD represents a remarkable decrease in the absolute disparity of the GVCF or convergence in GVCs from 2010 to 2019.

The general trends of backward GVC participation and σ-convergence between 2010 and 2019 are shown in Fig. 6. From the figure, the GVCB for the ASEAN and other countries fluctuated during this period, ranging between 0.32 and 0.35, while it tended to fluctuate between 2010 and 2017. Beginning in 2018, the GVCB intensity continued to decline until 2019. Compared to the GVCF trend, the SD trend appears to fluctuate more. Clearly, the GVCB has decreased significantly since 2017, to approximately 0.13 and 0.12 until the early pandemic period.

In the advanced countries, the GVCB fluctuated between 0.33 and 0.37 during this period. From 2010 to 2017, it fluctuated, and then declined to approximately 0.13 and 0.12 from 2017 until the late 2019 initial COVID-19 outbreaks. Thus, compared to the GVCB trend, the SD trend appears to be more volatile.

Table 4
ADF and LLC test.

Group	GVCF		GVCB	
	ADF test	LLC test	ADF test	LLC test
ASEAN and other countries*	−8.1350	−36.9226	−7.5210	−42.4384
Advanced countries*	−7.6494	−27.6867	−6.7066	−42.4567

Note: ADF = augmented Dicky Fuller; LLC = Levin-Lin-Cu; Advanced countries = East Asia, EU, NA; ASEAN and other countries = ASEAN, East Asia, EU, NA; GVCF = forward GVC participation; GVCB = backward GVC participation; All p values 0.0000.
Source: Calculated by the authors using Stata 17.

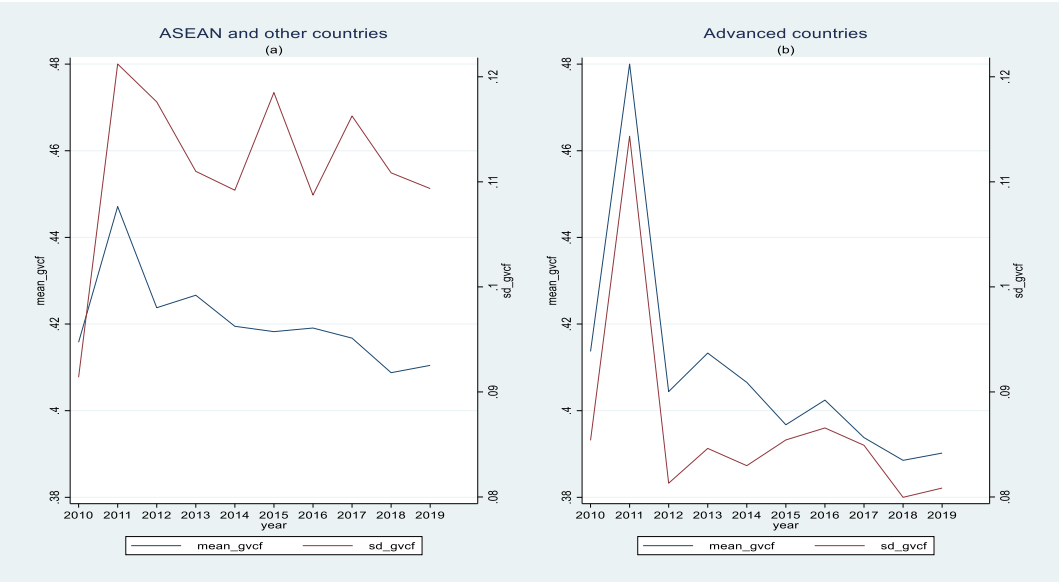

Fig. 5. (a) σ-convergence in forward GVC participation for ASEAN and other countries; (b) σ-convergence in forward GVC participation for advanced countries. Source: ADB MRIO, Author's computations.

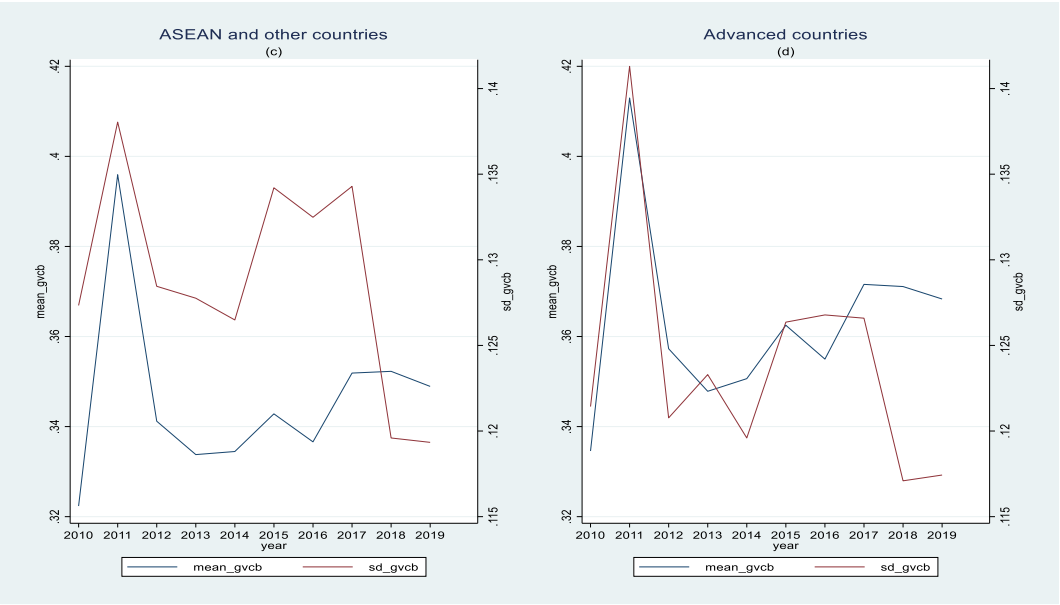

Fig. 6. (a) σ-convergence in backward GVC participation for ASEAN and other countries; (b) σ-convergence in backward GVC participation for advanced countries. Source: ADB MRIO, Author's computations.

5.3.3. β convergence

As discussed earlier, β-convergence includes unconditional and conditional convergence. The unconditional convergence analysis test can be performed without any control variables, other than the first-order lag of the dependent variable, as shown in Equation (23). In Table 5, the results of the SYS-GMM are reported. As shown in the table, when the unconditional convergence model is run, the first lag coefficient in all unconditional convergence models is significantly positive. The significant coefficient provides strong evidence of unconditional convergence with backward and forward linkages of GVC participation from 2010 to 2019 for ASEAN and other country groups, including East Asia, EU, and NA countries. In the SYS-GMM, the dependent variable is GVCF, while the corresponding speed of convergence is carried through -ln (β), where β is the coefficient of GVCF (Table 5).

In this model, the first and higher lags of the predetermined variable and the second and higher lags of the endogenous variable were used for the GMM-type instruments. The analysis was performed using Stata 17. AR (1) and AR (2) are Arellano and Bond's [69]

Table 5
The results for forward GVC participation convergence, 2010–2019.

SYS-GMM	Forward linkage			
	Conditional		Unconditional	
	ASEAN and other countries	Advanced countries	ASEAN and other countries	Advanced countries
	(1)	(2)	(3)	(4)
GVCF (−1)	0.642***	0.662***	0.180***	0.693***
FDI	0.00006**	0.0002***		
INS	0.067***	0.061***		
INFRA, log	0.210***	0.129**		
COVID-19	−0.003**	−0.011***		
Constant	0.064**	−0.047	0.288***	0.082***
Time dummies 2019	YES	YES	YES	YES
Year fixed effect (FE)	YES	YES	YES	YES
No. of observations	287	224	328	224
No. of countries	41	32	41	32
Hansen test, p-value	28.18; 0.993	14.16; 0.999	36.28; 0.893	28.95; 0.993
AB - AR (1); p-value	−1.71; 0.088	−2.66; 0.008	−1.33; 0.183	−2,70; 0.007
AB - AR (2); p-value	1.20; 0.230	0.98; 0.329	−0.87; 0.383	0.68; 0.496
Speed of convergence	0.45	0.42	1.71	0.37

Note: ***p < 0.01, **p < 0.05, and *p < 0.1.
ASEAN and other countries = ASEAN, East Asia, EU, NA; Advanced countries = East Asia, EU, NA; SYS-GMM = system GMM estimator.
Source: Calculated by the authors using Stata 17.

tests for autocorrelation in differences. As noted, Hansen is a test for over-identification restrictions.

The unconditional convergence and speed of convergence of the ASEAN countries that are members of the ASEAN and other country groups are higher, at 1.71, than the 0.37 speed of convergence in the advanced countries for forward GVC participation, irrespective of the level of FDI-specific countries. This finding shows that the gap in forward GVC participation between countries continues to narrow. Consequently, the ASEAN countries can catch up with the advanced countries from the forward linkage.

When the unconditional convergence model is performed on backward GVC participation (Table 6), there is strong evidence of unconditional convergence of the backward linkage of GVC participation from 2010 to 2019 for the group of ASEAN and other countries (0.363) and the advanced countries (0.274). However, in terms of convergence speed, those countries cannot catch up with the advanced countries. As shown in Table 6, the convergence of ASEAN and other countries is lower, at 1.02, than that of the advanced countries, at 1.31.

As the predetermined variable for the conditional convergence estimator, the first lag-dependent variable, GVCF or GVCB, is selected, providing evidence of conditional convergence. The conditional convergence model can add variables that affect GVC participation. In this study, FDI is treated as an endogenous variable that affects GVC participation [14,15]. In addition, the model includes institutional and infrastructure variables as control variables [17,20,42,48]. The pre-estimated assessment suggested that FDI inflows were not completely exogenous and required robustness checks with a two-step GMM system to address endogeneity issues in the model [60,63,66,69].

Table 6
The results for backward GVC participation convergence, 2010–2019.

SYS-GMM	Backward linkage			
	Conditional		Unconditional	
	ASEAN and other countries	Advanced countries	ASEAN and other countries	Advanced countries
	(5)	(6)	(7)	(8)
GVCB (−1)	0.801***	0.209***	0.363***	0.274***
FDI	0.00007**	−0.0002***		
INS	0.046***	0.085**		
INFRA, log	0.092***	0.562**		
COVID-19	−0.008***	−0.010**		
Constant	0.052	1.288***	0.161***	0.237***
Time dummies 2019	YES	YES	YES	YES
Year fixed effect (FE)	YES	YES	YES	YES
No. of observations	287	192	328	256
No. of countries	41	32	41	32
Hansen test, p-value	21.90; 0.991	15.31; 1.000	33.02; 0.951	27.52; 0.981
AB - AR (1); p-value	−3.30; 0.001	−2.70; 0.007	−1.51; 0.131	−1.46; 0.146
AB - AR (2); p-value	1.02; 0.310	0.11; 0.916	−1.33; 0.185	−0.10; 0.922
Speed of convergence	0.22	1.56	1.02	1.31

Note: ***p < 0.01, **p < 0.05, and *p < 0.1.
Advanced countries = East Asia, EU, NA; ASEAN and other countries = ASEAN, East Asia, EU, NA; SYS-GMM = system GMM estimator.
Source: Calculated by the authors using Stata 17.

The conditional convergence specification test results show that the first lag coefficients of GVCF and GVCB are significantly positive. The significant coefficients suggest strong evidence of convergence of GVC participation from 2010 to 2019 for ASEAN, East Asia, EU, and NA. The conditional convergence and speed of convergence of the ASEAN countries, at 0.45, is higher than the 0.42 convergence speed in the advanced countries for GVCF (Table 5). This finding shows that the gap in GVCF participation between countries continues to narrow. Consequently, the ASEAN countries can catch up with the advanced countries from the forward linkage.

When the conditional convergence model is estimated on backward linkage GVC participation, there is strong evidence of conditional convergence of GVC participation from 2010 to 2019 for ASEAN and other countries (Model 5) as well as for the advanced countries (Model 6). Nonetheless, the speed of convergence for the GVCB value of ASEAN and other countries, at 0.22, is lower than in the advanced countries, at 1.56. Consequently, the ASEAN countries require more time to catch up with the advanced countries.

The SYS-GMM conditional convergence regression results show that FDI inflows have a positive and significant effect on GVC participation in all the models. However, the COVID-19 pandemic has reduced FDI inflows in the advanced countries. These results suggest that FDI inflows affect the forward- and backward-linkage GVC participation in ASEAN and other countries, at 0.00006 and 0.00007, respectively, consistent with similar studies [14,15,33]. Furthermore, these findings support the argument that FDI affects GVC participation.

In terms of the coefficients of the control variables, there are some interesting findings. We use institutional and infrastructure variables as control variables. Our data include indices produced by the World Bank on institutional and infrastructure data. The institutional variable (INS) uses the average of six World Bank institutional indices, while the infrastructure variable (INFRA) uses the average of three World Bank infrastructure measures.

The institutional index data derive from the WGI [50]. This index is based on several sub-indices designed to measure levels of (1) voice and accountability, (2) political stability and absence of violence/terrorism, (3) government effectiveness, (4) regulatory quality, (5) the rule of law, and (6) control of corruption. Each index ranges from −2.5 to 2.5, which reflects the distribution of the underlying data. Nationally, a low value is bad, while a higher value is good.

The estimation results show consistency throughout the institutional coefficient analysis with SYS-GMM, with a positive sign and statistical significance at a rate of 1% for ASEAN and other countries (0.067) and for the advanced countries (0.061). The positive institutional coefficient suggests that a high-quality institution increases forward-linkage GVC participation [70]. Similarly, institutions appear to have a positive and significant impact on backward-linkage GVC participation.

Expectedly, the positive infrastructure coefficient is consistent with the backward and forward GVC participation models. Infrastructure data are derived from the WGI from the Information and Communications Technology Indicators Database, which includes (1) fixed broadband subscriptions, (2) access to electricity (% of the population), and (3) fixed telephone subscriptions. High-quality infrastructure was required to meet the needs of the internet, telephone, and electricity networks during the pandemic, and to deal with the era of digital technology, Industry 4.0. The level of infrastructure (INFRA) in the advanced countries (0.129) and in ASEAN and other countries (0.210) is at 5% and 1%, respectively (Table 5, Models 1 and 2). This evidence illustrates that increasing infrastructure activity encourages forward linkage GVC participation. This condition also occurs in backward-linkage GVC participation. The INFRA coefficient looks positive and significant in the advanced countries (0.562) and in the ASEAN and other countries group (0.092), at the significance level of 5% and 1%, respectively (Table 6, Models 5 and 6). The infrastructure is advanced and sophisticated in the advanced countries, influencing GVC participation in both forward and backward linkage, significantly more so than in the ASEAN countries. We have found that exports depend on the institutional quality and access of exporters and importers to well-developed communications infrastructure, both at home and in partner countries [19].

The COVID-19 pandemic has had a negative and significant influence on GVCF. The use of domestic resources has decreased, despite the involvement of FDI. The decline in the use of domestic value-added resulted from a deterioration in economic conditions. Nevertheless, the involvement of FDI remains significant. The speed of convergence of forward-linkage GVC participation in ASEAN, East Asia, EU, and NA was 0.45, which is more powerful than the speed of 0.42 in the advanced countries. The COVID-19 pandemic also has a negative and significant effect on backward-linkage GVC participation [1]. However, it is different from the case in the forward GVC participation. The speed of convergence in the advanced countries is faster than in the ASEAN countries. In other words, the ASEAN countries cannot catch up with the advanced countries. All the models satisfy the Hansen and AR tests. The results of the Hansen test show that the coefficient passed the overidentification test, while the results of the AR (2) test show that it passed the serial correlation test of the residuals in the differenced equation.

5.4. Robustness tests

We tested whether our baseline result regarding the speed of convergence in both forward and backward GVC participation was robust using different indicators for the COVID-19 variable [20,66]. We also examined the robustness of the convergence rates for both the unconditional and the conditional convergences. In the conditional convergence, we analyzed the convergence speed by considering the effect of FDI on GVC participation with variable control for the quality of institutions and infrastructure. The data were derived from WDI and WGI [50].

Following Zergawu et al. [20], the robustness test was performed using different indicators for the COVID-19 variable. We replaced the COVID-19 dummy measure with COVID shocks, representing economic fluctuations. COVID shocks are determined using the gross export gap (hereafter, export gap), which is the difference between actual and potential exports [71]. The export variable was chosen because it directly affects whether there is a trade fluctuation. To achieve convergence, it is crucial to determine whether, globally, countries' performances are above or below their potential [15]. When the potential value is greater than the actual value, a recession will occur, which causes an economic downturn, and vice versa. Consequently, the convergence process will take longer. Potential

exports cannot be observed in reality; therefore, they are often proxied by the expected value. In this study, the expected export value was calculated based on the HP filter [71,72]. Thus, COVID shocks show fluctuations in exports during the estimation period. This approach was used to investigate whether other aspects of the COVID-19 variable influenced the speed of convergence in GVCs.

The corresponding results are reported in Table 7. Again, the results illustrate the same convergence conclusion in all the models, for both backward and forward GVC participation. Thus, the impact of the COVID shock is negative and significant, indicating that the COVID-19 pandemic has reduced value-added trading activity [24].

Acknowledging the potential limitations of our baseline estimate, we consider the alternative. The preliminary results remain the same when using this alternative measure. Moreover, all the models achieve convergence, albeit at different speed levels. Consequently, the ASEAN countries can catch up with the advanced countries on forward-linkage GVC participation, but not on backward linkage.

6. Discussion

Convergence occurs in both backward and forward GVC participation. However, the convergence speed is different between the two linkage directions. The convergence speed of backward GVC participation in the ASEAN countries is slower than in the advanced countries. Consequently, the ASEAN countries have not been able to catch up with the advanced countries, especially in terms of backward linkage. This situation could have arisen because most developing countries still restrict their production to the assembly stage, providing low value-added, thus limiting their participation in international production sharing [22]. In addition, there was a decrease in trading activity because of policies in the form of border closures and quarantinerelated restrictions due to the COVID-19 pandemic. In the forward-linkage GVC participation, however, the ASEAN countries have a faster convergence speed than the advanced countries, indicating that the ASEAN countries may be catching up with the advanced countries.

Convergence refers to the flying geese paradigm, a dynamic theory of comparative advantage. This paradigm explains the catching-up process with the industrialization of a latecomer economy. Although there is convergence, there are differences in the catching-up process and the stage of economic development in the region. Differences in the catching-up process can be caused by investment characteristics, differences in endowment factors, production functions (technology), and consumption functions (tastes and preferences) between countries. Trade liberalization between countries is also believed to be a differentiating factor in the catching-up process. Baldwin [49] observed that East Asia was a protected area, compared to the North American Free Trade Agreement (NAFTA) and the EU, and thus should lower tariffs imposed on intraregional trades to a level at least the same as that in the EU and NAFTA. Therefore, the East Asian countries show despecialization along with converging trade patterns.

The convergence process in ASEAN, as measured by value-added exports, is almost the same as in the advanced countries. However, the ASEAN countries are known to be rich in natural resources. The extensive use of domestic resources increases the forward GVC participation; thus, the convergence speed can exceed that of the advanced countries [15,22]. Therefore, instead of the limited use of foreign value-added in the production process, the speed of convergence in the ASEAN countries is lower than in the advanced countries.

In cross-border trade, where production is fragmented internationally, FDI plays a major role [15,33]. FDI through multinational companies (MNEs) is the primary driver of global production networks, influencing the distribution of value-added across countries. FDI will bring technological advances to affiliated countries for them to produce goods more efficiently. It will promote high value-added products that will raise participation in GVCs. Participation in the GVCs requires that local companies have a capacity that is equivalent to international market requirements [14]. The dominant role of FDI can encourage the convergence process.

Japan, China, Korea, the US, and the EU are the dominant trading partners in interregional trade, accounting for more than 30% of ASEAN's total exports, and becoming important geographical destinations for exports from ASEAN countries. Trading activities and FDI, mainly from Japan and China, have increased significantly during the period 1976–1995. This increase in ASEAN inter and intraregional trade also occurred in the period 2000–2005, following the establishment of the ASEAN FTA (AFTA). The increasing role of East Asia as a production base requires imports of intermediate goods and capital goods, which are supplied mainly by Japan [25, 73].

Globalization and regional economic integration pose challenges and opportunities for governments to adopt new industrial policies focused on industrial transformation and upgrading, deepening industry participation in higher segments of the GVC, and creating a conducive environment for increased investment. The establishment of various trade agreements can generate more investment and liberalize trade. For example, the ASEAN-China FTA (ACFTA) integrates China's immense market with an integrated market in ASEAN's small economy. South FTA covers an area rich in low-cost labor, with a rapidly growing demand, distinguishing ACFTA from the EU, NAFTA, and other FTAs. Another distinctive feature of the ACFTA is its members' participation in advanced production networks in East Asia. China is a network hub and imports intermediate goods from its neighbors in Asia and globally [1].

A country's involvement in GVCs cannot be separated from institutions and infrastructure, included in the model as control variables. The results show that for exporters, both institutional and infrastructure quality are crucial. In all the models, the estimated coefficients are positive and statistically significant when infrastructure and institutions are controlled for, indicating that institutions and infrastructure in exporting countries significantly influence GVC participation. Recent studies on trade support the view that better institutions can encourage trade [17,42,70]. Some researchers consider certain aspects of institutions, such as contract enforcement, tariff regulations, FTAs, and openness to FDI to foster export performance [14,15]. However, developing countries' low quality of institutions and infrastructure limits export markets [18].

Furthermore, Acemoglu et al. [16] believe that differences in institutional quality can contribute to comparative advantage. Helble et al. [74] found that higher transparency of the trading environment and simplified regulations significantly impacted trading costs.

Table 7
Empirical results for robustness tests, GVC participation convergence with COVID shocks, 2010–2019.

SYS-GMM	Forward linkage				Backward linkage			
	Conditional		Unconditional		Conditional		Unconditional	
	ASEAN and other countries	Advanced countries	ASEAN and other countries	Advanced countries	ASEAN and other countries	Advanced countries	ASEAN and other countries	Advanced countries
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dependent variable (−1)	0.627***	0.631***	0.181***	0.693***	0.840***	0.259**	0.363***	0.107***
FDI	0.00006*	0.00002*			0.00008***	−0.0001**		
INS	0.046**	0.063***			0.023***	0.070***		
INFRA, log	0.214***	0.010***			0.056**	0.320***		
COVID_shocks	−0.020*	−0.140***			−0.026***	0.050***		
Constant	0.071*	−0.047	0.288***	0.082***	0.021	0.806***	0.161***	0.305***
Time dummies 2019	YES		YES	YES	YES	YES	YES	YES
Year fixed effect (FE)	YES	YES	YES	YES	NO	NO	YES	YES
No. of observations	287	224	328	224	287	192	328	288
No. of countries	41	32	41	32	41	32	41	32
Hansen test; p-value	23.76; 0.999	19.92; 0.981	36.28; 0.893	28.95; 0.993	36.31; 0.911	23.43; 0.995	33.02; 0.951	27.93; 0.963
AB - AR (1); p-value	−1.68; 0.093	−2.98; 0.003	−1.33; 0.183	−2.70; 0.007	−3.74; 0.000	−2.55; 0.011	−1.64; 0.100	−3.11; 0.002
AB - AR (2); p-value	1.22; 0.222	0.62; 0.538	−0.87; 0.383	0.68; 0.496	1.42; 0.154	−0.21; 0.834	−1.73; 0.083	−0.36; 0.718
Speed of convergence	0.47	0.46	1.71	0.37	0.17	1.35	1.08	2.23

Note: ***,**,* represent statistical significance at the 1%, 5%, and 10% levels, respectively.
SYS-GMM = system GMM estimator; in the forward linkage, the dependent variable is GVCF, and in the backward linkage, the dependent variable is GVCB.
ASEAN and other countries = ASEAN, East Asia, EU, NA; Advanced countries: East Asia, EU, NA.
Source: Calculated by the authors using Stata 17.

Consequently, the World Trade Organization has been mandated to integrate developing countries into the trading system [15].

Evidence suggests that a better quality of infrastructure, such as faster internet connection and blockchain digital technology, is more likely to yield more direct trading [45]. Additionally, the need for high-quality infrastructure has grown during the COVID-19 pandemic. Social restriction policies to reduce the spread of the virus require high-speed internet access and telephone and electricity networks because people must work or school from home [44,48,67]. Furthermore, trade access requires high-quality infrastructure to facilitate transactions, leading to the era of digital technology. Moreover, the increase in economic integration resulting from increased trade may positively affect the quality of institutions and infrastructure [18]. Therefore, our estimation results imply that infrastructure and institutional quality are crucial for GVC participation, even after addressing possible omitted variables and endogeneity problems by employing GMM-based panel data estimators.

7. Conclusion and recommendations

International trade is now leading to value-added trade, which is captured in GVCs. This trade pattern allows developing countries to catch up with advanced countries because each country can specialize in certain stages of production. This study investigates the speed of convergence in GVC participation using the recent ADB MRIO database for the 2010–2019 period. We propose the forward and backward GVC participation approach to trace DVA and FVA contributions and to overcome overvaluation in gross exports. Furthermore, we consider which countries reach convergence faster in terms of forward and backward linkage. We scrutinize stochastic, σ, and β-convergence using SYS-GMM. In addition, we analyze FDI as a driver of GVC participation, with institutional and infrastructure variables as control variables. We also analyze the early effect of the COVID-19 pandemic on the convergence rate.

The study offers several contributions: First, we examine whether ASEAN countries have converged in GVCs, using both forward and backward linkages. Second, we analyze the speed of convergence and the countries that have faster convergence in terms of forward or backward linkage. Third, we use econometric methods to test and verify the existence of convergence in GVC participation. Fourth, we analyze the effect of the early COVID-19 pandemic on the catching-up process.

The findings illustrate convergence in forward- and backward-linkage GVC participation; however, the convergence speed varies between countries. ASEAN countries experience faster convergence than advanced countries in forward GVC participation. In contrast, advanced countries experience faster convergence in backward GVC participation, both in the main result and in the robustness tests. Furthermore, value-added export developing countries exhibit a similar pattern to that of advanced countries by broad sectors, following the flying geese paradigm. The SYS-GMM conditional convergence regression results reveal that FDI plays a significant role in GVC participation. Expectedly, the positive institutional and infrastructure coefficient is consistent with the forward and backward GVC participation models. Furthermore, the COVID-19 pandemic reduced GVC participation on average.

To catch up with advanced countries, the governments of ASEAN countries need to develop leading sectors in terms of backward linkages, without ignoring forward linkages. These efforts can increase GVC participation. FDI in ASEAN countries is more focused on the upstream industry, considering that these countries have a high convergence speed in forward linkage. However, the governments must improve institutions and infrastructure, and prepare for the rise of new digital technologies that exacerbate the dichotomy between winners and losers among countries, while the ASEAN countries remain on the edge. Further research is recommended to determine the leading sectors' positions regarding final use, to increase the value-added contribution.

Author contribution statement

Josephine Wuri: conceived and designed research; literature review; verified the analytical methods; collected the data; analysis tools or data; wrote the paper.

Tri Widodo: the conception of the study; developed the theory; literature review; review and editing; supervised the findings of this work.

Amirullah Setya Hardi: the conception of study; analyzed and interpreted the data; review and editing; supervised the findings of this work.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

Acknowledgments

The authors are thankful to the ADB team to provide the required data. We also would like to thank anonymous reviewers for their valuable comments in improving this article.

Appendix A

Table 8
List of Countries in the ADB Multi-Regional Input Output.

No	Group	Countries
1	ASEAN	Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Brunei Darussalam, Lao PDR, Cambodia
2	East Asia	People's Republic of China, Japan, Republic of Korea
3	EU	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Sweden
4	NA	United States, Canada

Source: Authors' Compilations

Appendix B

Table 9
List of Sectors in the ADB Multi-Regional Input-Output Tables.

Code	Sector	Broad Sector
c1	Agriculture, hunting, forestry, and fishing	Primary
c2	Mining and quarrying	Primary
c3	Food, beverages, and tobacco	Low-technology manufacturing
c4	Textiles and textile products	Low-technology manufacturing
c5	Leather, leather products, and footwear	Low-technology manufacturing
c6	Wood and products of wood and cork	Low-technology manufacturing
c7	Pulp, paper, paper products, printing, and publishing	Low-technology manufacturing
c8	Coke, refined petroleum, and nuclear fuel	Medium-and high–technology manufacturing
c9	Chemicals and chemical products	Medium-and high–technology manufacturing
c10	Rubber and plastics	Low-technology manufacturing
c11	Other nonmetallic minerals	Medium-and high–technology manufacturing
c12	Basic metals and fabricated metal	Medium-and high–technology manufacturing
c13	Machinery, NEC	Medium-and high–technology manufacturing
c14	Electrical and optical equipment	Medium-and high–technology manufacturing
c15	Transport equipment	Medium-and high–technology manufacturing
c16	Manufacturing, NEC; recycling	Low-technology manufacturing
c17	Electricity, gas, and water supply	Low-technology manufacturing
c18	Construction	Low-technology manufacturing
c19	Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel	Business services
c20	Wholesale trade and commission trade, except of motor vehicles and motorcycles	Business services
c21	Retail trade, except of motor vehicles and motorcycles; repair of household goods	Business services
c22	Hotels and restaurants	Business services
c23	Inland transport	Business services
c24	Water transport	Business services
c25	Air transport	Business services
c26	Other supporting and auxiliary transport activities; activities of travel agencies	Business services
c27	Post and telecommunications	Business services
c28	Financial intermediation	Business services
c29	Real estate activities	Business services
c30	Renting of M&Eq and other business activities	Business services
c31	Public administration and defense; compulsory social security	Personal and public services
c32	Education	Personal and public services
c33	Health and social work	Personal and public services
c34	Other community, social, and personal services	Personal and public services
c35	Private households with employed persons	Personal and public services

Source: ADB MRIO database

Appendix C

Table 10
List of Abbreviation

Abbreviation	Meaning
GVC	Global Value Chain
FDI	Foreign Direct Investment
FTA	Free Trade Area
DVA	Domestic Value Added
DVA_FIN	Domestic Value Added_Final
DVA_INT	Domestic Value Added_Intermediate
DVA_INTrex	Domestic Value Added_Intermediate Reexport
RDV_G	Return Domestic Value Added
VS	Vertical Specialization
FVA	Foreign Value Added
FVA_FIN	Foreign Value Added_Final
FVA_INT	Foreign Value Added_Intermediate
DDC	Domestic Double Counting
FDC	Foreign Double Counting
PDC	Pure Double Counting
GVCB	Backward Linkage Global Value Chains Participation
GVCF	Forward Linkage Global Value Chains Participation
GMM	Generalized Method of Moment
FD-GMM	First-Difference Generalized Method of Moment
SYS-GMM	System Generalized Method of Moment
MRIO	Multi-regional Input-Output
ADB	Asian Development Bank
ASEAN	Association of Southeast Asian Nations
US	United States
EU	European Union
NA	North America
NAFTA	North American Free Trade Agreement
AFTA	ASEAN Free Trade Area
ACFTA	ASEAN- China Free Trade Area
WDI	World Development Indicators
WGI	Worldwide Governance Indicators

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