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The COVID-19 Pandemic and the World Trade Network

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Abstract: *Global trade is expected to suffer a significant contraction as a result of the COVID-19 pandemic. Did the relative importance of countries in the world trade network change as a result of the pandemic? The answer to this question is particularly important for Association of Southeast Asian Nations (ASEAN) countries because of their strong trade linkages with China, where the COVID-19 virus originated. This paper examines how the world trade network has changed since the COVID-19 pandemic, with a particular focus on ASEAN countries. Tracking the changes in centrality from January 2000 to June 2020, we find no evidence that centrality changed significantly after the pandemic started for most ASEAN countries. Our results suggest that the relative importance of the ASEAN countries in the world trade network is unchanged and will remain unchanged even after the pandemic.*

Keywords: International trade, COVID-19 pandemic, Network, Centrality

JEL Classification: F14, F40

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1. Introduction

The COVID-19 pandemic has had significant negative impacts on the global economy. According to the International Monetary Fund (IMF) (2020a), global growth is projected at –4.4% in 2020. The IMF expects global trade in goods and services to suffer a much larger contraction of –10.4% this year due to the weaker demand. Moreover, the World Trade Organization (WTO) (2020) estimated much larger negative impacts for merchandise trade with a predicted growth of between –13% and –32% in 2020.

Such negative impacts on trade could vary between countries. The question arises: did the relative importance of countries in the world trade network change as a consequence of the pandemic? The answer to this question is particularly important for Association of Southeast Asian Nations (ASEAN) countries because of their strong trade linkages with China, where the COVID-19 virus originated. More generally, the answer to this question is important because of the complexity of the world trade network, as well as the heterogeneous impacts of the pandemic across countries.

Given this context, this study asks how the world trade network has changed since the COVID-19 pandemic, with a particular focus on the ASEAN countries. To clarify the relative importance of each country in the world trade network, this study employs a network analysis. A number of studies have analysed the international trade network using network analysis.[1] For example, De Benedictis and Tajoli (2011) examined the changes in the network of international trade between 113 countries from 1960 to 2000. They found that the centrality of the network changed from European countries to the United States over the period.

[1] Several studies, such as Smith and White (1992) and Garlaschelli and Loffredo (2004), have applied network analysis to international trade data, but they did not provide an economic basis for their analyses.

These previous studies have made a significant contribution to developing a deeper understanding of trade patterns. However, to the best of our knowledge, only Vidya and Prabheesh (2020) have examined changes in the trade network after the COVID-19 pandemic. Moreover, although they found changes in centrality measures after the pandemic, their study involved a simple descriptive analysis, and no statistical tests were provided. Moreover, they focused only on the top-15 global trading countries.[2] Thus, most of the ASEAN countries were excluded from their study and the changes in the relative importance of the ASEAN countries in the world trade network remains unclear.[3] This paper contributes to the literature by extending the analysis to ASEAN countries and by employing formal statistical analysis to evaluate the significance of the changes in the international trade network after the pandemic.

There are three advantages to employing a network analysis. First, the data requirement for the analysis is relatively low. Basically, only information on bilateral trade is required for the analysis, which means that it is easy to implement and replicate. Second, trade data are suitable for examining the current economic situation because they are available on a monthly basis. Finally, the network analysis is outstanding in terms of its visualisation abilities. It involves visualising the network of countries based on graph theory, which is helpful in capturing the relative importance of each country in a relatively easy manner.

To measure the relative importance of the ASEAN countries in the world trade network, we compute each country's centrality using bilateral trade data between

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[2] The top-15 global trading countries are Canada, China, France, Hong Kong, India, Indonesia, Italy, Japan, Germany, the Netherlands, Russia, Singapore, the Republic of Korea, the United Kingdom, and the United States.

[3] In this connection, Hayakawa and Mukunoki (2020) estimated a gravity model using data for 186 countries. One of their important findings was that the negative impacts of the pandemic are particularly evident in exports from developing countries. Although they presented interesting findings, the network structure of trade is beyond the scope of their study.

January 2000 and June 2020. Then, we investigate whether the centrality changed significantly after the pandemic, employing the econometric framework of structural breaks. We find statistically significant breakpoints in the changes in centrality before 2020 for most ASEAN countries. This result suggests that the trade shock after the pandemic is temporary rather than perpetual.

The paper is organised as follows. The next section explains the methodology and data used in this study. Section 3 presents robustness checks and discusses the implications of the results. Section 4 provides our conclusions.

2. Methodology and Data

2.1. Methodology

2.1.1. Centrality

As noted above, this study employs network analysis. In this framework, each country is represented as a node, whilst the trade relationship between countries is represented as a link. Thus, the world trade network is represented by nodes and links, which make up a graph. The relative importance of each node is represented by centrality measures. Measures of centrality include closeness centrality, which is based on the distance between nodes, and degree centrality, which is based on the number of links. However, because countries generally trade with many countries simultaneously, these centrality measures are not necessarily useful for analysis of the world trade network.

Several recent studies such as Acemoglu et al. (2012) and Carvalho (2014) proposed theoretical models in which the influence of individual firms or sectors on aggregate outcomes is determined by their eigenvector centrality, which is also called Bonacich centrality.[4] However, eigenvector centrality is not applicable to

[4] Behrens et al. (2007) theoretically investigated the relationship between eigenvector centrality and

directed graphs; therefore, it is not applicable to analysing the world trade network because trade has a direction (from exporting countries to importing countries).

To overcome this problem, this study utilises PageRank centrality, which was originally developed to evaluate the ranking of webpages (Page et al., 1999). PageRank centrality is a variant of eigenvector centrality but has the following two advantages. First, like eigenvector centrality, PageRank centrality considers not only the number of edges that a node has but also the number of edges that other directly connected nodes have. Indeed, as Kiyota (2020) showed, PageRank centrality is consistent with the index of forward linkages in input–output analysis. Second, unlike eigenvector centrality, this centrality is applicable to a directed graph. This is another desirable property for the analysis of trade.

Let the number of nodes be n. We denote the adjacency matrix as A:

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{pmatrix}, \tag{1}$$

where:

$$a_{ij} = \begin{cases} 1, & \text{if there is a link from node } i \text{ to node } j; \\ 0, & \text{othewise.} \end{cases} \tag{2}$$

Now, let us introduce time dimension t. Let the PageRank centrality be PR_{it} for country i at time t. Then, it is defined as:

$$PR_{it} = \psi \sum_{j=1}^{n} a_{ijt} \frac{PR_{jt}}{k_{jt}} + \chi, \tag{3}$$

where ψ and χ are positive constants and k_{jt} is the outdegree. In computing PageRank centrality, we use the trade value (exports + imports) as a weight. Equation (1) thus means that PageRank centrality for country i becomes higher if

international trade.

1) the number of country i's partners increases; 2) country i's trade increases; and 3) PageRank for country i's partner increases. Conventionally, we set $\psi = 0.85$ and $\chi = 1$. To make comparisons between years, we also adjust the PageRank centrality such that its total equals one. This paper examines how this centrality measure changes after the COVID-19 pandemic to check the relative importance of ASEAN countries within the world trade network.

2.1.2. Structural break

Our main research question is whether the relative importance of the countries in the world trade network changes as a result of the pandemic. Note that such changes occur over the analysis period due to, for example, each country's economic growth. Thus, we investigate whether countries experienced statistically significant changes in their centrality paths, employing a structural change framework.[5] We employ the approach developed by Zivot and Andrews (1992) and extended by Perron and Vogelsang (1992). Their methodology is summarised as follows.

We denote an outcome variable of country i as y_t (suppressing the country subscript i). Although our main outcome variable is PageRank centrality, we also utilise trade as an outcome variable in the preliminary analysis to check the impacts on trade. Consider that the time series of outcome y_t experiences one structural break during the sample. There are two types of model that can capture the structural break: an additive outlier (AO) model, which captures a sudden change, and an innovational outliers (IO) model, which captures a gradual shift in the mean of the series.

The AO model consists of the following two steps. In the first step, we

[5] A recent study by Constantinescu, Mattoo, and Ruta (2020) employed a similar structural change framework to examine global trade patterns over the past four decades.

estimate the following regression equation:

$$y_t = \mu + \delta DU_t + \tilde{y}_t, \tag{4}$$

where:

$$DU_t = \begin{cases} 1, & \text{if } t > T_b; \\ 0, & \text{otherwise,} \end{cases} \tag{5}$$

where T_b is the time of the unknown breakpoint to be located by grid search; and $\tilde{y}_t$ denotes the residuals. In the second step, the residuals from this regression are used as the dependent variable for the following equation:

$$\tilde{y}_t = \sum_{\tau=1}^{d} \omega_\tau DT_{b,t-\tau} + \alpha \tilde{y}_t + \sum_{\tau=1}^{d} \theta_\tau \Delta \tilde{y}_{t-\tau} + \varepsilon_t, \tag{6}$$

where:

$$DT_{bt} = \begin{cases} 1, & \text{if } t = T_b + 1; \\ 0, & \text{otherwise.} \end{cases} \tag{7}$$

The lag order d is also unknown. The second regression is estimated over feasible values of T_b to search for the minimal t-statistic to test whether the autoregressive parameter $\alpha = 1$ (i.e. the strongest rejection of the unit root null hypothesis) for all of the break time combinations, whilst d is determined by a set of sequential F-tests.[6] The significance level of this minimal t-statistic is investigated based on the critical values provided by Perron and Vogelsang (1992).

In contrast, the IO model is based on the one-step procedure. The following regression equation is estimated:

$$y_t = \mu + \delta DU_t + \phi DT_{bt} + \alpha y_{t-1} + \sum_{\tau=1}^{d} \theta_\tau \Delta y_{t-\tau} + \varepsilon_t. \tag{8}$$

As in the AO model, the regression equation is estimated over feasible values of T_b to search for the minimal t-statistic to test whether the autoregressive

[6] We set the maximum lag number as 12 to reduce the computational burden and to account for seasonality. Note that there is no intercept because the mean of $\tilde{y}_t$ is zero.

parameter $\alpha = 1$ (i.e. the strongest rejection of the unit root null hypothesis) for all the break time combinations, whilst d is determined by a set of sequential F-tests. Note that it is necessary to choose some trimming value because the test is not defined at the limits of the sample (Clemente, Montañés, and Reyes, 1998). To adopt the largest window possible, we set the trimming value as 0.5% (i.e. the first and the last observations are dropped from the sample).

2.1.3. Hypothesis

As mentioned above, it is not easy to predict how the trade network has changed since the pandemic began because of the complexity of the world trade network as well as the heterogeneous impacts of the pandemic across countries. Nevertheless, several studies, such as Obashi (2010) and Ando and Kimura (2012), have argued that the production networks in East Asia are stable and resilient against demand/supply shocks, such as the global financial crisis and the Great East Japan Earthquake. Thus, we hypothesise that the relative importance (measured by PageRank centrality) of the ASEAN countries in the world trade network did not change following the COVID-19 pandemic. In turn, this would mean that δ is insignificant.

2.2. Data and descriptive analysis

In measuring the trade network, we use monthly bilateral trade data from the IMF's *Direction of Trade Statistics* for the period from January 2000 to June 2020 (the latest available is October 2020) for 204 countries.[7] That is, a_{ij} in the adjacency matrix is measured by the imports of country i from country j. Imports are measured by the cost, insurance, and freight prices. The imports do not cover services trade. For each country, the total number of observations is 246 (= 12

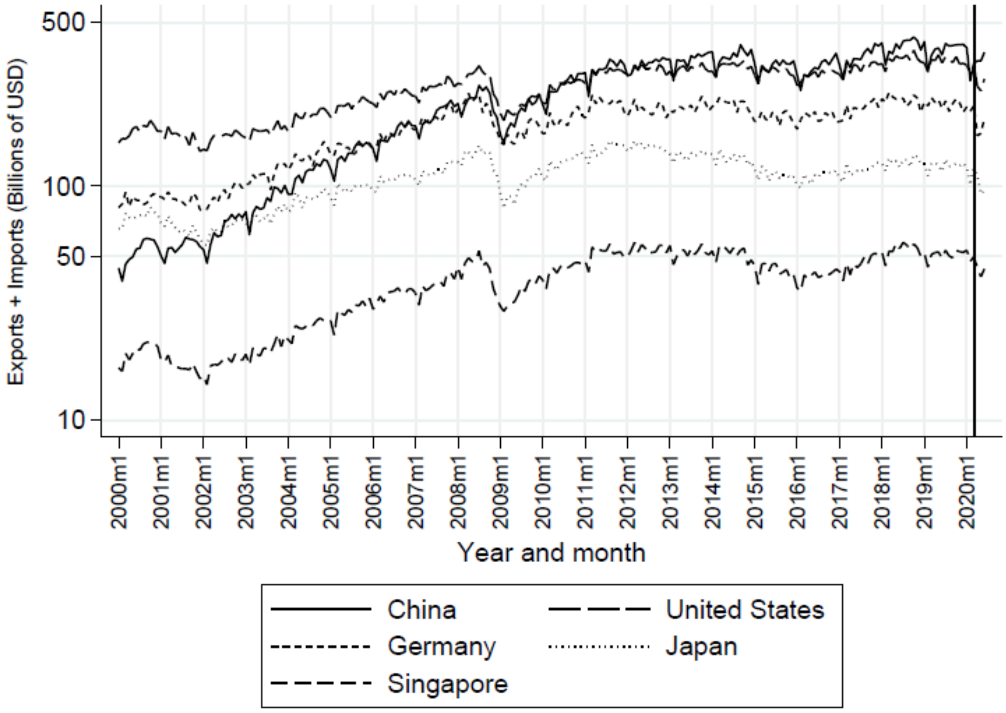
[7] Taiwan is not included in the *Direction of Trade Statistics.*

months × 20 years + 6 months). Whilst our main focus is the 10 ASEAN countries (i.e. Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam), we also compute the PageRank centrality for four major trading countries (i.e. China, Germany, Japan, and the United States) for reference.

Figure 1 presents the changes in the overall trade for four major trading countries (i.e. China, Germany, Japan, and the United States) and one of the major trading ASEAN countries, Singapore, from January 2000 to June 2020.[8] The overall trade is defined as the sum of exports to and imports from the world. We highlight two findings in this figure. First, overall trade dropped when the COVID-19 pandemic started (around March 2020) but it increased again around June 2020. Second, compared with the four major trading countries, the overall trade of Singapore, as our representative ASEAN country, is rather small. This implies that it would be difficult to determine the pattern of trade by comparing the ASEAN countries in this manner with the four major trading countries given the differences in the scale of trade. In what follows, we present the figures for ASEAN countries separately.

[8] These four major trading countries have been ranked in the top four countries in PageRank centrality in the world trade network since 2001 (Kiyota, 2021).

Figure 1: Trade Patterns for Major Trading Countries, January 2000–June 2020



Note: The vertical axis indicates the value of overall trade (exports + imports) in log terms. The solid line indicates March 2020, when the COVID-19 pandemic started in many countries.
Source: IMF (2020b).

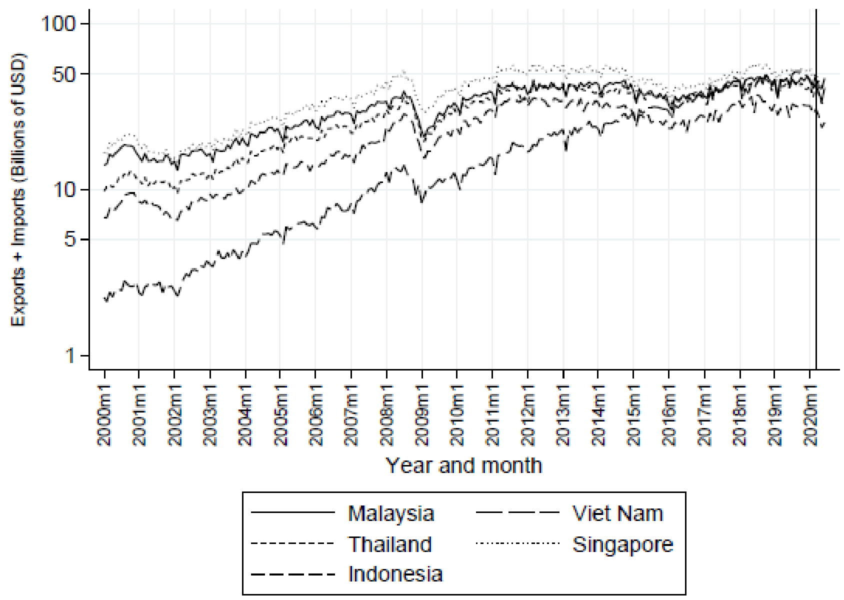
Figure 2 presents the changes in the overall trade for ASEAN countries for January 2000–June 2020. For ease of exposition, we divide the 10 ASEAN countries into two groups based on the scale of trade.[9] Panel A indicates the overall trade for Indonesia, Malaysia, Singapore, Thailand, and Viet Nam, whilst Panel B presents the overall trade for Brunei, Cambodia, Lao PDR, Myanmar, and the Philippines. Similar to Figure 2, we find increases in trade value after the sharp drop when the pandemic started for all ASEAN countries. It is interesting to note that the overall trade for Myanmar has large values in September–October 2014. Although

[9] As the vertical axis indicates, the scale of trade differs between the four major trading countries and the ASEAN countries, and between the ASEAN countries in Panels A and B.

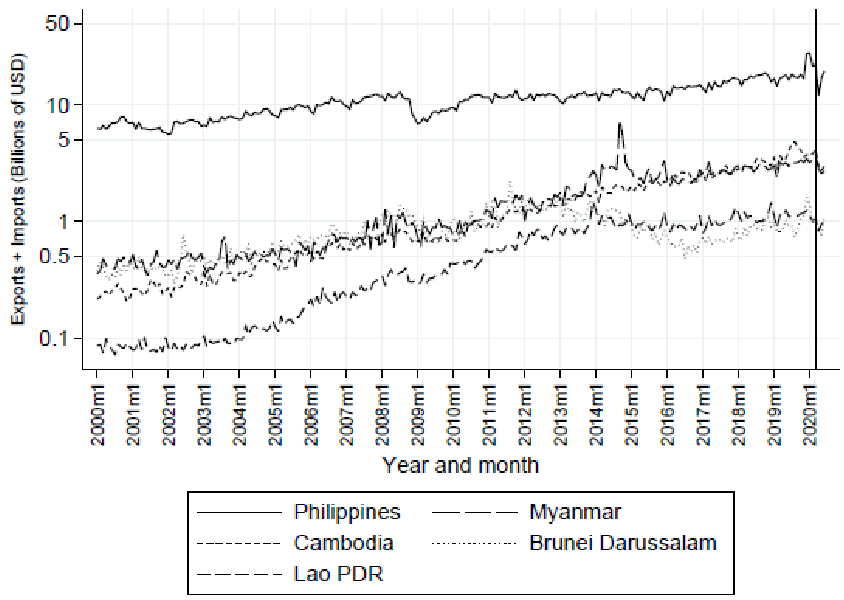
this is due to the increases in exports to China, we could not identify the specific reason for this and, thus, we must be cautious in interpreting the changes in trade patterns for Myanmar during this period.

Figure 2: Trade Patterns for ASEAN Countries, January 2000–June 2020

Panel A



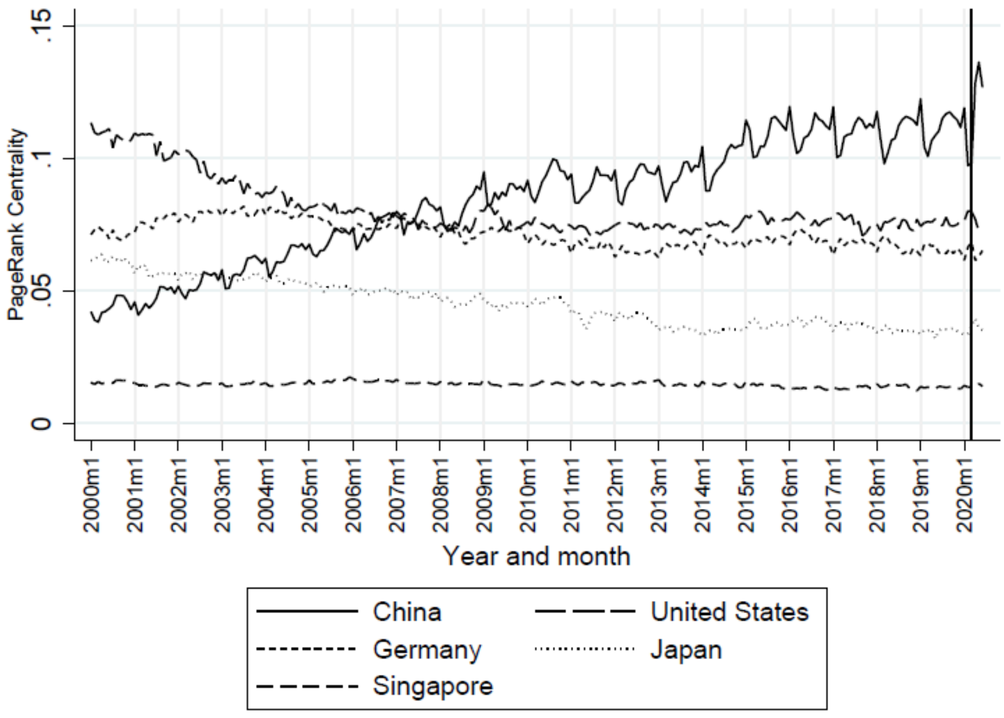
Panel B



Note: The vertical axis indicates the value of overall trade (exports + imports) in log terms. The solid line indicates March 2020, when the COVID-19 pandemic started in many countries.
Source: IMF (2020b).

Figure 3 presents the PageRank centrality for the major four countries and Singapore between January 2000 and June 2020. This figure indicates that the changes in PageRank centrality differ across countries after the pandemic. For China and Germany, PageRank centrality dropped around the time that the pandemic started but increased around June 2020. In contrast, for Japan and the United States, PageRank centrality dropped and did not increase after the start of the pandemic. For Singapore, it is difficult to determine the change because the value is small compared with the four major countries. Thus, we report the results for the ASEAN countries separately from the four major trading partners below.

Figure 3: PageRank Centrality for Major Trading Countries, January 2000–June 2020



Note: The vertical axis indicates PageRank centrality. The solid line indicates March 2020, when the COVID-19 pandemic started in many countries.
Source: Author’s estimation based on IMF (2020b).

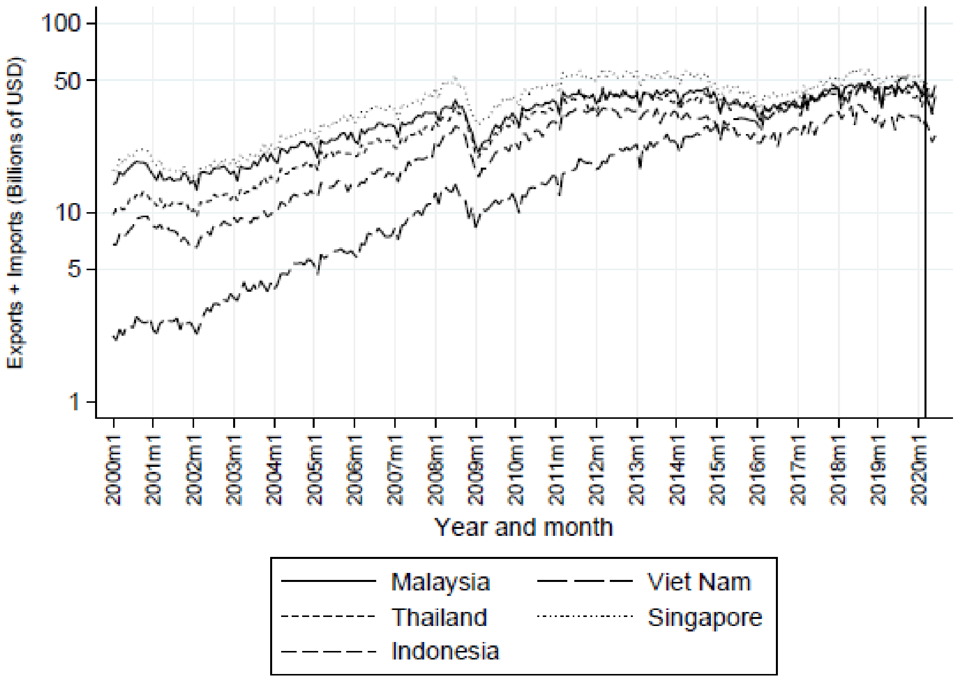
Figure 4 presents the PageRank centrality for the ASEAN countries for January 2000–June 2020. Similar to overall trade, we divide the 10 ASEAN countries into two groups based on the scale of centrality for ease of exposition.[10] Panel A indicates the PageRank centrality for Indonesia, Malaysia, Singapore, Thailand, and Viet Nam, whilst Panel B presents the overall trade for Brunei, Cambodia, Lao PDR, Myanmar, and the Philippines. Figure 4 also indicates that the changes in PageRank centrality differ between ASEAN countries. Whilst PageRank centrality declined after the pandemic started for Indonesia, Singapore, and Thailand in Panel A, and for Brunei, Cambodia, and Myanmar in Panel B, it increased for other countries. These results imply that it is not necessarily clear whether the relative importance of ASEAN countries in the world trade network changed after the pandemic. To address this issue further, the next section employs regression analyses. For Myanmar, it is important to note that PageRank centrality exhibits extremely high values for September–October 2014, which should be treated with caution.

[10] Like the size of trade, PageRank centrality differs between the four major trading countries and the ASEAN countries, and between ASEAN countries in Panels A and B.

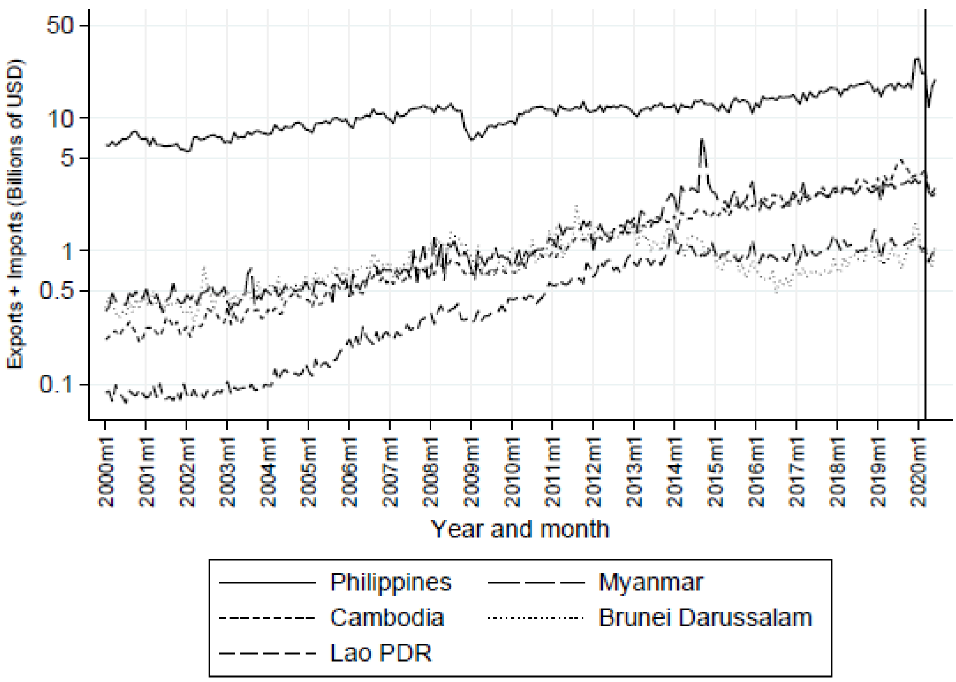
Figure 4: PageRank Centrality for ASEAN Countries,

January 2000–June 2020

Panel A



Panel B



Note: The vertical axis indicates PageRank centrality. The solid line indicates March 2020, when the COVID-19 pandemic started in many countries.
Source: Author's estimation based on IMF (2020b).

3. Estimation Results

3.1. Preliminary analysis: Structural break in trade

Before analysing the centrality, we determine whether we observe a structural break in trade after the pandemic. We estimate equations (4) and (6) for the AO model and equation (8) for the IO model using aggregate bilateral trade (exports + imports) as an outcome variable.[11] This enables us to investigate whether the structural break in the centrality coincides with the changes in the aggregate trade volume.

Table 1 presents the results for the AO model. We highlight two findings. First, a structural break is confirmed in all countries, as indicated by the significant coefficients. Moreover, all the coefficients are positive. These results imply that the ASEAN countries experienced a positive structural change in trade in the sample period. Second, the breakpoint varies across countries, ranging from December 2004 (Singapore) to October 2015 (the Philippines). All the breakpoints are located before 2020. This result implies that the trade shock from the pandemic is not necessarily regarded as a point of structural change.

Table 1: Estimation Results: Additive Outliers Model for Trade

	BRN	KHM	IDN	LAO	MYS
Break point	2005m4	2010m12	2006m12	2007m7	2005m12
y_{t-1}	0.314***	0.660***	0.430***	0.785***	0.306***
	[19.029]	[28.094]	[31.244]	[31.194]	[27.415]
	MMR	PHL	SGP	THA	VNM
Break point	2010m12	2015m10	2004m12	2006m12	2009m12
y_{t-1}	0.580***	0.226***	0.350***	0.386***	0.711***
	[31.019]	[14.793]	[28.981]	[29.239]	[25.765]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. The breakpoint indicates the estimated month and year when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

[11] The estimation is based on the Stata commands clemao1 and clemio1 developed by Christopher F. Baum. For more details, see Baum (2005).

Table 2 presents the results for the AO model. We highlight two findings. First, a structural break is confirmed in all countries, as indicated by the significant coefficients. Moreover, all the coefficients are positive. These results imply that the ASEAN countries experienced a positive structural change in trade in the sample period. Second, the breakpoint varies across countries, ranging from December 2004 (Singapore) to October 2015 (the Philippines). All the breakpoints are located before 2020. This result implies that the trade shock from the pandemic is not necessarily regarded as a point of structural change.

Table 2: Estimation Results: Innovative Outliers Model for Trade

	BRN	KHM	IDN	LAO	MYS
Break point	2005m1	2010m1	2002m1	2005m1	2009m1
y_{t-1}	0.029	0.028***	0.027***	0.037***	0.016**
	[1.649]	[3.105]	[2.884]	[2.957]	[2.487]
	MMR	PHL	SGP	THA	VNM
Break point	2010m1	2009m3	2004m1	2003m1	2009m1
y_{t-1}	0.051**	0.016**	0.020**	0.018**	0.010
	[2.547]	[2.216]	[2.372]	[2.272]	[1.236]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. The breakpoint indicates the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

These results together suggest that although there was a large decline in overall trade after the pandemic, it is not necessarily regarded as a breakpoint between January 2000 and June 2020. Thus, the shock from the pandemic can be regarded as a temporary one. However, the relative importance of the ASEAN countries in overall trade may still change after the pandemic. The next section addresses this issue.

3.2. Baseline results: Structural break in centrality

Now, we estimate equations (4) and (6) for the AO model and equation (8) for the IO model using PageRank centrality as an outcome variable. Table 3 presents the results for the AO model. There are four notable findings. First, the structural break is confirmed in all countries, as indicated by the significant coefficients. However, the signs of the coefficients vary across countries. Whilst seven countries have positive signs, Brunei, the Philippines, and Singapore have negative signs. The results suggest that the direction of structural change is different between countries.

Table 3: Estimation Results: Additive Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Break point	2013m12	2014m9	2008m9	2013m8	2020m2
y_{t-1}	-0.00025***	0.00052***	0.00050***	0.00018***	0.00139***
	[-19.975]	[29.432]	[8.505]	[32.431]	[4.394]
	MMR	PHL	SGP	THA	VNM
Break point	2014m7	2007m7	2015m1	2008m2	2015m2
y_{t-1}	0.00045***	-0.00134***	-0.00130***	0.00186***	0.00831***
	[13.390]	[-24.292]	[-12.821]	[16.658]	[34.127]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. The breakpoint indicates the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

Second, in line with the results for trade in Table 1, the breakpoint varies between countries, ranging from February 2008 (Thailand) to February 2020 (Malaysia). Amongst the 10 countries, only Malaysia has a breakpoint in 2020. This result seems to suggest that Malaysia experienced a structural change when the pandemic started. However, note that the shock is positive rather than negative. We will discuss this point again with the results of the IO model.

Third, the estimated breakpoints differ for the trade and centrality results. For example, for Brunei (see Table 1), the estimated breakpoint in trade is April 2005, whereas for centrality it is December 2013. Indeed, none of the countries has the same breakpoint for trade and centrality. The results imply that significant changes in the aggregate bilateral trade do not necessarily mean changes in the relative importance of the country.

Finally, it is interesting to note that the estimated breakpoint for Myanmar is July 2014, which is close to the period when the outliers are confirmed (Figure 4). Thus, the estimated structural break for Myanmar may be affected by the existence of outliers.

Table 4 indicates the results for the IO model. For two of the 10 countries, the coefficients are insignificant. Nevertheless, the signs correspond with those of the AO model. Although the estimated breakpoints in the IO model for each country are different from those in the AO model, they are very similar. For example, for Brunei, the breakpoints are December 2013 and January 2014 for the AO and IO models, respectively. Similarly, those for Cambodia are September 2014 and October 2014 for the AO and IO models, respectively. These results suggest that in contrast to aggregate bilateral trade, for centrality, both the AO and IO models estimate similar breakpoints.

Table 4: Estimation Results: Innovative Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Break point	2014m1	2014m10	2008m5	2013m4	2019m1
y_{t-1}	-0.00007**	0.00004**	0.00010*	0.00002**	0.00041***
	[-2.588]	[2.407]	[1.743]	[2.583]	[3.254]
	MMR	PHL	SGP	THA	VNM
Break point	2014m8	2007m8	2012m12	2008m4	2014m2
y_{t-1}	0.00014***	-0.00025***	-0.00032***	0.00015	0.00023*
	[3.939]	[-4.657]	[-2.975]	[1.516]	[1.911]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. Breakpoint indicates the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

For Malaysia, in contrast to the AO model results, the IO model estimated that the breakpoint occurred in January 2019. This indicates that the structural break occurred before the pandemic started if it involves a gradual rather than a sudden change. Although we confirmed that a structural break occurred in February 2020 in the AO model, it is sensitive to the choice of model. Thus, it is difficult to assert definitively that a structural change occurred after the pandemic started. It is also interesting to note that the breakpoints are concentrated in the period between January 2009 and January 2010 for five of the 10 countries. This suggests that significant changes are more likely to be related to the global financial crisis than to the pandemic.

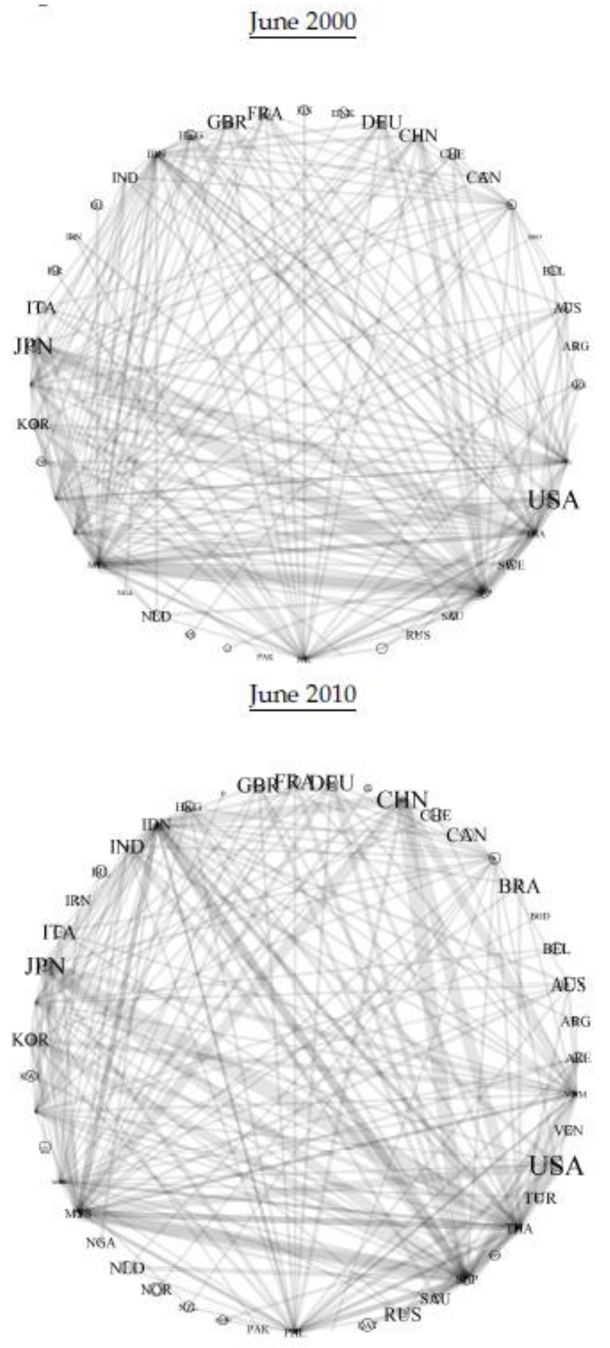
As mentioned above, one of the key advantages of network analysis is the ability to present the results visually. However, it is difficult to present meaningful results for the trade network for all ASEAN countries and their partner countries given that each country trades with many countries. Therefore, we focus on the top-20 partner countries for each ASEAN country and compute their PageRank centrality. Trade between non-ASEAN countries is excluded to focus on trade by ASEAN countries.

Figures 5 and 6 present the trade networks of the ASEAN countries in June 2000, 2010, 2019, and 2020.[12] The visualisation is based on the circle layout algorithm. Each country is located on the circle in alphabetical order by International Organization for Standardization (ISO) codes. The location of the countries changes over the period because of changes in the top-20 partner countries. The size of the ISO code and node represent the size of the country's gross domestic product (GDP) and per capita GDP, respectively.[13] Note that the location of nodes and the length of edges do not have any meaning because they depend upon the

[12] We also present the results for March 2019 and 2020 in Figure A1 in the Appendix for reference.
[13] For the ISO code, see Table A1 in the Appendix.

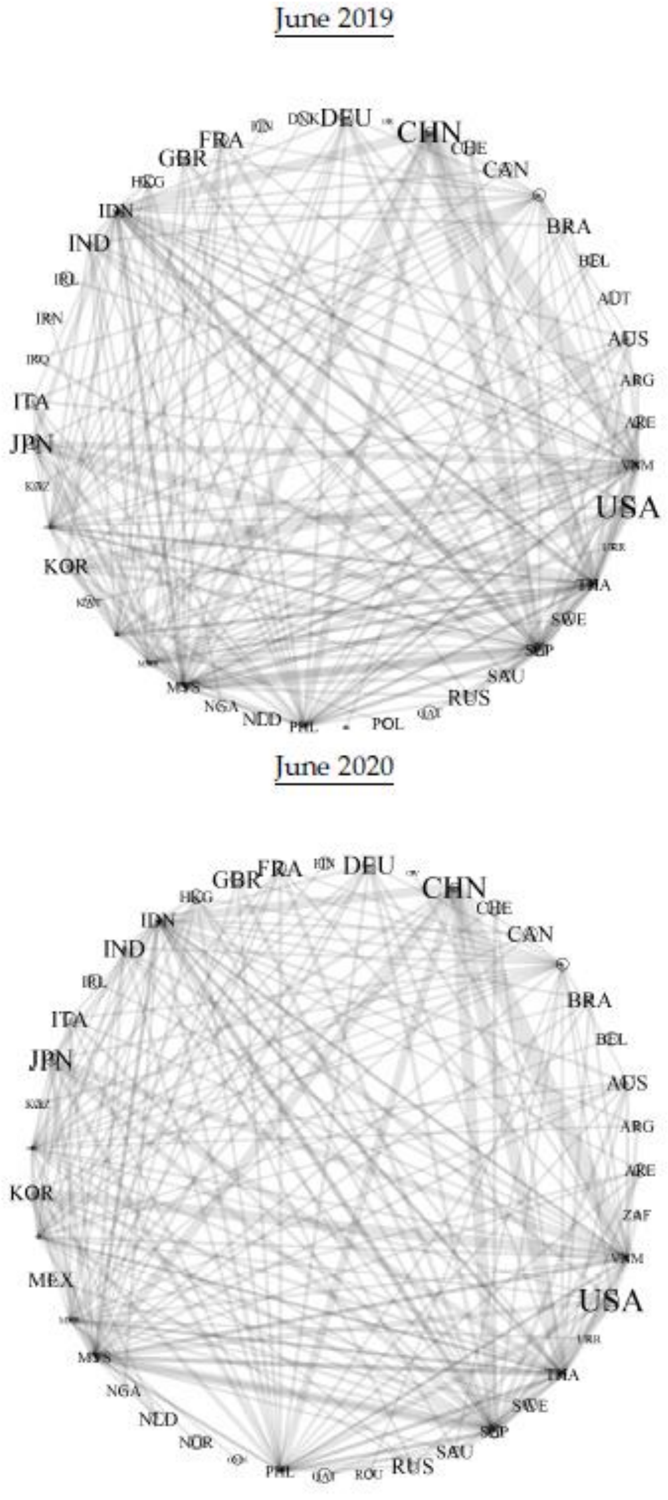
algorithm employed to depict the figure. The important issue here is which nodes are connected with each other.

Figure 5: Trade Network of ASEAN Countries, 2019



Note: The size of the International Organization for Standardization (ISO) code and node represent the size of each country's gross domestic product (GDP) and per capita GDP, respectively. The network is based on three major trading partners.
Source: Author’s estimation based on IMF (2020b).

Figure 6: Trade Network of ASEAN Countries, 2020



Note: The size of the International Organization for Standardization (ISO) code and node represent the size of each country's gross domestic product (GDP) and per capita GDP, respectively. The network is based on three major trading partners.
Source: Author's estimation based on IMF (2020b).

Figure 5 indicates that the connection with China increased from June 2000 to June 2010 in many ASEAN countries, including Indonesia, Malaysia, Singapore, and Thailand. Figure 6 indicates that such connections with China became much larger in June 2019. The network graphs in June 2019 and June 2020 are almost identical. This supports our result that there is no significant change in the trade network of the ASEAN countries before or after the pandemic.

In sum, although we found statistically significant breakpoints in the changes in centrality between February 2000 and May 2020 for most ASEAN countries, they generally occur prior to 2020. These results suggest that the trade shock following the pandemic is temporary rather than perpetual. This indicates the resilience of the trade pattern for almost all the ASEAN countries. However, these results may not hold for major trading countries, and our results may be sensitive to the choice of functional form, an issue addressed in more detail in the next subsection.

4. Discussion

4.1. Results for major trading countries

Our baseline results indicate that the structural changes in centrality occurred before the pandemic started. There may be concerns regarding the external validity of this result; that is, the results may change if we focus on major trading countries. To address this concern, we estimate the same AO and IO models for the four major trading countries mentioned in subsection 2.2: China, Germany, Japan, and the United States.

Table 5 presents the estimation results. The upper part of the table shows the results of the AO model, whilst the lower part contains those for the IO model. We highlight four findings. First, the estimated coefficients of the AO model are significantly positive for China and significantly negative for the United States, Germany, and Japan. This result implies that except for China, the major trading countries experienced negative structural changes in centrality during the sample period. Second, for the IO model, the estimated coefficients become insignificant for China, but the same signs and significance levels are maintained for the other countries. Moreover, like the results for ASEAN countries in Tables 3 and 4, the estimated breakpoints are quite similar between the AO and IO models. This suggests that the results of the IO model are generally consistent with those of the AO model.

Table 5: Estimation Results: Major Trading Countries

Additive Outliers Model				
	CHN	USA	DEU	JPN
Break point	2009m2	2003m3	2008m2	2010m8
y_{t-1}	0.0383***	-0.0259***	-0.0082***	-0.0147***
	[23.739]	[-31.273]	[-20.626]	[-26.991]
Innovative Outliers Model				
	CHN	USA	DEU	JPN
Break point	2008m3	2002m3	2009m10	2010m9
y_{t-1}	0.0002	-0.0019***	-0.0013***	-0.0010***
	[0.241]	[-2.631]	[-3.444]	[-3.034]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. Breakpoints indicate the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

Third, all the estimated breakpoints occur prior to 2020 for these four countries. This result means that the trade shock following the pandemic is not regarded as a breakpoint in terms of changes in centrality. In the previous subsection, we found that the majority of breakpoints occurred before 2020 for the ASEAN countries. Thus, our results suggest that the same is true for the major trading countries.

Finally, it is interesting to note that the estimated breakpoints were between March 2008 and September 2010 for China, Germany, and Japan. The global financial crisis may have significant effects on the importance of these countries in the world trade network. This result is in line with the results of the IO model for the ASEAN countries (Table 4). In contrast, the estimated breakpoints for the United States were March 2003 and March 2002 in the IO and AO models, respectively. Although we cannot argue for causality in a precise manner, this result seems to suggest that China's entry into the WTO, which occurred in December 2001, immediately before these breakpoint dates, may have influenced the decline in the relative importance of the United States in the world trade network.

4.2. Multiple structural breaks

Another concern relating to our baseline analysis is that both the AO and IO models assume a single structural change during the sample period. However, because the sample covers more than 20 years, there may be more than one structural change in each country. To address this issue, we employ the test developed by Clemente, Montañés, and Reyes (1998) that allows for the estimation of two events within the observed history of a time series. The estimation procedure of the double-break model is almost the same as that of the single-break model. For the AO model, the first-step regression equation is written as:

$$y_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \tilde{y}_t, \tag{9}$$

where:

$$DU_{mt} = \begin{cases} 1, & \text{if } t > T_{bm}; \\ 0, & \text{otherwise,} \end{cases} \tag{10}$$

where $m = 1, 2$. As for the single breakpoint model, T_{b1} and T_{b2} are the breakpoints to be located by grid search. The corresponding second-step equation is:

$$\tilde{y}_t = \sum_{\tau=1}^{d} \omega_{1\tau} DT_{b1,t-\tau} + \sum_{\tau=1}^{d} \omega_{2\tau} DT_{b2,t-\tau} + \alpha \tilde{y}_t + \sum_{\tau=1}^{d} \theta_\tau \Delta \tilde{y}_{t-\tau} + \varepsilon_t, \tag{11}$$

where:

$$DT_{bm,t} = \begin{cases} 1, & \text{if } t = T_{bm} + 1; \\ 0, & \text{otherwise,} \end{cases} \tag{12}$$

for $m = 1, 2$. The second regression is estimated over feasible values of T_{bm} and d. For the IO model, the regression equation is written as:

$$\begin{aligned} y_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \phi_1 DT_{b1,t} + \phi_2 DT_{b2,t} + \alpha y_{t-1} \\ + \sum_{\tau=1}^{d} \theta_\tau \Delta y_{t-\tau} + \varepsilon_t. \end{aligned} \tag{13}$$

The locations of T_{bm} and d are determined by the grid search. As in the baseline single-break analysis, we set the trimming value at 0.5%.

Table 6 presents the estimation results of the AO model with two breaks.[14] There are two notable findings. First, the significance and the signs of the estimated coefficients vary across countries. Second, the breakpoints are different between countries. Moreover, the two breakpoints do not necessarily coincide with the breakpoint estimated by the single-break AO model. Nonetheless, all the breakpoints occur before 2020. This means that even if we allow for two structural

[14] The estimation is based on the Stata commands clemao2 and clemio2 developed by Christopher F. Baum. For more detail, see Baum (2005).

breaks, the trade shock after the pandemic is not identified as a structural breakpoint.

Table 6: Estimation Results for Two Structural Breaks: Additive Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Break point 1	2004m9	2012m3	2009m9	2008m9	2011m6
y_{t-1}	0.00005***	0.00024***	0.00090***	0.00006***	-0.00065***
	[3.657]	[13.013]	[11.309]	[11.253]	[-6.034]
Break point 2	2013m12	2015m9	2012m10	2013m8	2014m9
y_{t-1}	-0.00027***	0.00035***	-0.00060***	0.00014***	0.00084***
	[-20.356]	[15.812]	[-7.285]	[24.757]	[7.017]
	MMR	PHL	SGP	THA	VNM
Break point 1	2013m11	2008m5	2005m10	2006m4	2012m2
y_{t-1}	0.00037***	-0.00157***	0.00009	0.00151***	0.00399***
	[4.349]	[-31.167]	[0.888]	[15.398]	[20.075]
Break point 2	2014m7	2014m10	2015m1	2015m4	2015m10
y_{t-1}	0.00010	0.00041***	-0.00134***	0.00132***	0.00538***
	[1.207]	[7.343]	[-12.200]	[12.657]	[23.103]

Note: Countries are represented by their ISO codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. Breakpoints indicate the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

Table 7 presents the results for the IO model. As for the results of the AO model, the signs and significance levels of the estimated coefficients differ between countries, and the breakpoints vary across countries. The estimated breakpoints are not necessarily the same between the single- and double-break models. Again, all the estimated breakpoints are located prior to 2020. In short, the estimated breakpoints are sensitive to the choice of the models and the number of possible breaks. However, we cannot find evidence to support the relative importance of the ASEAN countries in world trade changing after the pandemic. Thus, our main messages continue to hold even when the analysis takes into account the existence of two structural breaks.

Table 7: Estimation Results for Two Structural Breaks: Innovative Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Break point 1	2013m4	2012m4	2009m10	2008m5	2011m9
y_{t-1}	-0.00007***	0.00004***	0.00034***	0.00001***	-0.00026**
	[-2.841]	[3.316]	[3.080]	[2.868]	[-2.301]
Break point 2	2014m7	2015m5	2012m12	2013m10	2014m6
y_{t-1}	-0.00002	0.00005***	-0.00026***	0.00003***	0.00036***
	[-0.721]	[2.624]	[-2.888]	[2.922]	[2.966]
	MMR	PHL	SGP	THA	VNM
Break point 1	2014m1	2007m8	2012m12	2006m5	2011m4
y_{t-1}	0.00029***	-0.00033***	-0.00026**	0.00029***	0.00024***
	[5.767]	[-5.714]	[-2.225]	[2.634]	[2.683]
Break point 2	2014m8	2014m3	2015m9	2014m10	2014m11
y_{t-1}	-0.00009*	0.00011***	-0.00028*	0.00029***	0.00031**
	[-1.673]	[3.219]	[-1.669]	[2.916]	[2.146]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. Breakpoints indicate the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

4.3. Shorter period

We use a relatively longer time-series (i.e. January 2000–June 2020) to examine a structural break in centrality measures. One may be concerned that the longer time-series makes it harder to pick up structural breaks during the pandemic, especially since the pandemic data is available only for a few months. In order to address such a concern, we focus on the shorter period. We focus on the past five years, starting from January 2015, and then estimate the AO and IO models.

Tables 8 and 9 present the estimation results for the AO and IO models, respectively. Table 8 indicates that amongst the 10 countries, Indonesia and Malaysia have a breakpoint in 2020. Even though Indonesia and Malaysia seem to show a structural change when the pandemic started, the shock is positive rather than negative. It is also interesting to note that the result for Malaysia is consistent with the finding of the baseline results (Table 3).

Table 8: Estimation Results for Shorter Period: Additive Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Break point	2019m9	2019m3	2020m2	2019m1	2020m2
y_{t-1}	0.00012***	0.00024***	0.00061***	0.00006***	0.00119***
	[5.575]	[5.385]	[2.799]	[5.683]	[4.128]
	MMR	PHL	SGP	THA	VNM
Break point	2019m3	2017m12	2015m8	2017m12	2019m2
y_{t-1}	0.00021***	-0.00016***	-0.00103***	-0.00052***	0.00281***
	[6.792]	[-3.646]	[-4.288]	[-3.144]	[7.039]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. Breakpoints indicate the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

Table 9: Estimation Results for Shorter Period: Innovative Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Break point	2019m11	2019m4	2020m3	2017m10	2019m1
y_{t-1}	0.00018***	0.00029***	0.00021	0.00004***	0.00049***
	[6.191]	[6.290]	[0.591]	[4.051]	[2.776]
	MMR	PHL	SGP	THA	VNM
Break point	2019m5	2017m9	2015m9	2017m8	2019m5
y_{t-1}	0.00015***	-0.00009**	-0.00050*	-0.00038***	0.00089**
	[3.543]	[-2.310]	[-1.986]	[-2.744]	[2.533]

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in brackets indicate *t*-statistics. Breakpoints indicate the estimated year and month when the structural breaks are identified.
Source: Author's estimation based on IMF (2020b).

Table 9 indicates that for Malaysia, in contrast to the AO model results, the IO model estimated that the breakpoint occurred in January 2019. Like the baseline results, the structural break occurred before the pandemic started if it involves a gradual rather than a sudden change. Even though we confirmed that a structural break occurred in February 2020 in the AO model, it is sensitive to the choice of model. Table 9 also indicates that for Indonesia, the estimated breakpoint in the IO model was March 2020, which is close to the point in the AO model (February 2020). However, the coefficient is statistically insignificant. These results suggest that even if we limit our analysis to between January 2015 and June 2020, our main messages continue to hold: centrality did not change significantly after the pandemic started for most ASEAN countries.

4.4. Alternative approach

A further concern with our analysis is that the changes in centrality follow nonlinear trends. Because our baseline analysis accommodates only a linear trend, the main results may not hold if the analysis accounts for nonlinear trends. To address this issue, following Ben-David and Papell (1997) and Abu-Bader and Abu-Qarn (2010), we estimate the following version of the augmented Dickey-Fuller regression that accommodates both linear and nonlinear trends:

$$y_t = \mu + \beta_1 t + \beta_2 t^2 + \delta DU_t + \phi_1 DT_t + \phi_2 DT_t^2 + \sum_{\tau=1}^{d} \theta_\tau \Delta y_{t-\tau} + \varepsilon_t, \tag{14}$$

where y_t is the PageRank centrality; DU_t is the break dummy variable, which is the same as in the baseline analysis; and DT_t captures the changes in the trend after the breakpoint. Then, we have:

$$DT_t = \begin{cases} t = T_b, & \text{if } t > T_b; \\ 0, & \text{otherwise,} \end{cases} \tag{15}$$

where T_b is the time of the breakpoint, that is, the period in which the change in the trend function parameters occurs. For the lag d, we use a 12-month lag (i.e. $d = 12$) to account for seasonality.

Conducting the test involves the following steps. First, before estimating equation (14), we examine whether the PageRank centrality contains a unit root based on the Phillips and Perron's (1988) test, the null hypothesis of which is that

PageRank centrality does contain a unit root.[15] We find that the null hypothesis is rejected for all ASEAN countries except for Viet Nam. Second, we conducted Vogelsang's (1997) sup-Wald (or sup W_t) test, estimating equation (14). Sup W_t is the maximum of the standard F-test statistics times three for each year for testing the null hypothesis $\delta = \phi_1 = \phi_2 = 0$ over all possible trend breaks. The month and year when the maximum is identified are regarded as the breakpoint. Finally, we investigate the significance level of sup W_t based on the critical values calculated in Vogelsang (1997).[16]

Table 10 presents the regression results of equation (14). Breakpoints are found in 2020 only for Indonesia and the Lao PDR. For other countries, breakpoints occur prior to 2020. This implies that the relative importance of ASEAN countries did not change just before or after the pandemic for most ASEAN countries. In short, our main messages are largely unchanged even if we employ an alternative approach.

Table 10: Estimation Results for Shorter Period: Innovative Outliers Model for Centrality

	BRN	KHM	IDN	LAO	MYS
Unit-root test	Reject***	Reject**	Reject***	Reject***	Reject***
Break point	2011m8	2019m6	2020m4	2020m3	2014m12
Sup W_t	28.5***	109.1***	20.3**	19.4**	25.4***
	MMR	PHL	SGP	THA	VNM
Unit-root test	Reject***	Reject*	Reject***	Reject***	Not reject
Break point	2014m9	2007m10	2017m8	2014m12	2018m2
Sup W_t	122.1***	26.5***	17.2*	25.1***	44.5***

Note: Countries are represented by their International Organization for Standardization (ISO) codes (see Table A1 in the Appendix). The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Author's estimation based on IMF (2020b).

[15] The alternative is that PageRank is generated by a stationary process. We include a trend variable in the regression. The test is based on the Stata command pperron.
[16] For Viet Nam, the critical values are obtained from Vogelsang (1997, Table 2, $p = 2$ & $\lambda^* = 0.01$). For other countries, the critical values are obtained from Vogelsang (1997, Table 1, $p = 2$ & $\lambda^* = 0.01$).

5. Concluding Remarks

Global trade was expected to suffer a significant contraction as a result of the COVID-19 pandemic. Such negative impacts on trade could vary between countries. Consequently, we wished to investigate whether the relative importance of the countries in the world trade network changed as a result of the pandemic. We considered that the answer to this question is particularly important for ASEAN countries because of their strong trade linkages with China, where the COVID-19 virus originated. More generally, the answer to this question is important because of the complexity of the world trade network and the heterogeneous impacts of the pandemic across countries.

This paper examined how the world trade network changed after the COVID-19 pandemic, particularly focusing on ASEAN countries. Tracking the changes in centrality from January 2000 to June 2020, we found no evidence that centrality changed significantly after the pandemic started for most ASEAN countries. Our results suggest that the relative importance of the ASEAN countries in the world trade network remains unchanged even after the pandemic.

If we view the results optimistically, the COVID-19 pandemic has not had a destructive impact on the world trade network. Rather, the effects are temporary and limited. World trade is strong enough to resist the threat from the pandemic. This seems to be a positive message, although caution is required because our analysis focuses on a very short period after the pandemic due to the limited availability of the data.

Before closing this study, we point out several future research directions that we did not analyse in this study. First, extending the analysis to a longer period is an important avenue for future research. As mentioned above, this study covers only the four months after the pandemic started (i.e. March–June 2020) due to the limited availability of the data. However, the effect of the pandemic may be more evident in the medium-to-long run. For example, Jordà, Singh, and Taylor (2020) argued that significant macroeconomic after-effects of pandemics persist for decades due to reductions in the relative labour supply and/or a shift to greater precautionary savings. It may be premature to reach definitive conclusions at this point, and it remains important to keep careful track of the effects of the pandemic on global trade.

Second, it is important to examine the impact of the pandemic at a more detailed product level. Our analysis focused on the aggregate bilateral trade, but even if aggregate trade did not change significantly, the composition of trade might change as a result of the pandemic. Finally, it would be interesting to investigate the effects on services trade. As a result of the pandemic, the mobility of people has been restricted to a greater degree than that of goods, with more limits between countries than within each country. Such restrictions would have significant effects on some services trade, such as tourism services. We plan to include these issues in our future research agenda.

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Appendix

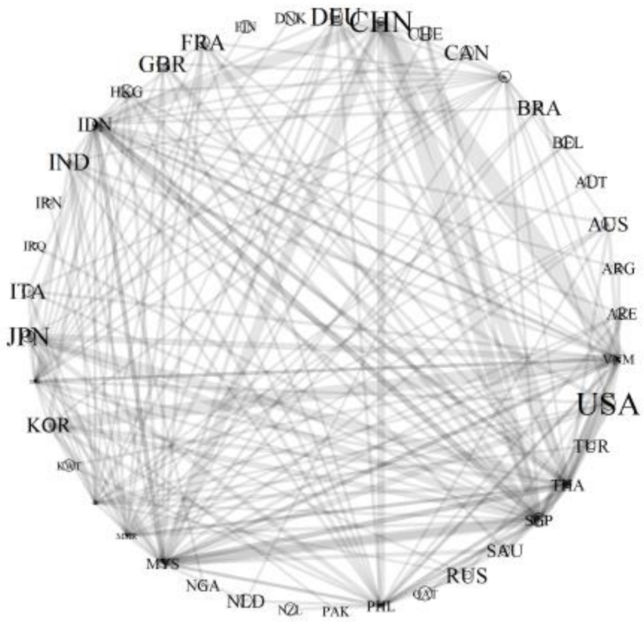
Table A1: Country Code

ISO	Country	ISO	Country
	ASEAN countries		
BRN	Brunei Darussalam	MMR	Myanmar
KHM	Cambodia	PHL	Philippines
IDN	Indonesia	SGP	Singapore
LAO	Lao People's Democratic Republic	THA	Thailand
MYS	Malaysia	VNM	Viet Nam
	Major trading countries		
CHN	China	JPN	Japan
DEU	Germany	USA	United States

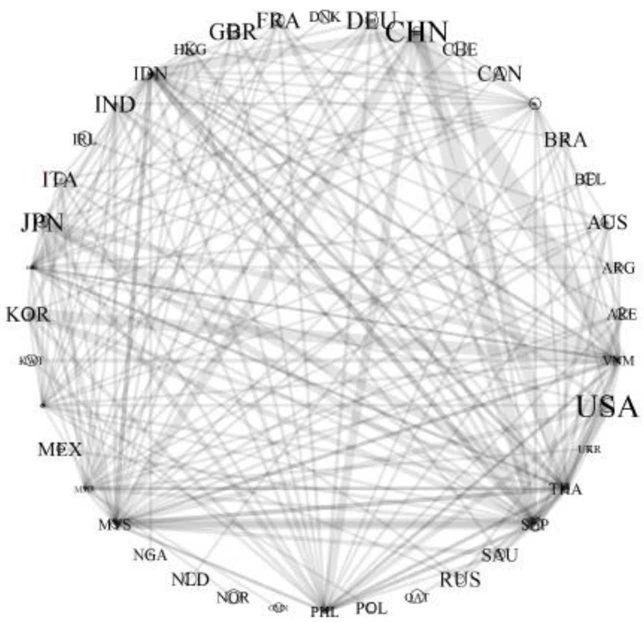
Note: ISO indicates the three-digit code developed by the International Organization for Standardization.
Source: Author's estimation based on IMF (2020b).

Figure A1: Trade Network of ASEAN Countries, March 2019 and March 2020

March 2019



March 2020



Note: The size of the International Organization for Standardization (ISO) code and node represent the size of a country's gross domestic product (GDP) and per-capita GDP, respectively. The network is based on three major trading partners.
Source: Author's estimation based on IMF (2020b).

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