Spatio-temporal heterogeneity in the international trade resilience during COVID-19: a complex network approach[1]

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[1] **Abbreviation used in this article:** ITN – International trade network; YoY: Year-on-Year; ADVEC - Advanced Economies; EU - European Union; DA - Emerging and Developing Asia; EDE - Emerging and Developing Europe; APQ - Asia and Pacific; WE - Latin America and the Caribbean; SSA - Sub-Saharan Africa; EAQ - East Asia; SEQ - Southeast Asia; MECA - Middle East and Central Asia; USA - United States; CHN - mainland China; JPN - Japan; DEU - Germany; IND - India; GBR - United Kingdom; FRA - France; ITA - Italy; BRA - Brazil; CAN - Canada; RUS - Russian Federation; KOR - Korea, Rep. of; ESP - Spain; AUS - Australia; MEX - Mexico; IDN - Indonesia; NLD - Netherlands, The; SAU - Saudi Arabia; TUR - Turkey; CHE - Switzerland; TWN - Taiwan Province of People Republic of China.

ABSTRACT

The COVID-19 pandemic and subsequent lockdowns have created immeasurable health and economic crises, leading to unprecedented disruptions to world trade and supply chains. The COVID-19 pandemic shows diverse impacts on different economies and markets that suffer and recover at different rates and degrees. This research aims to evaluate the spatio-temporal heterogeneity of strengths and vulnerabilities of international trade networks in the current crisis to understand the global production resilience and prepare for the future crisis. We applied a series of complex network analysis approaches to the monthly international trade networks at the world scale, regional scale, and country scale for the pre- and post- COVID-19 outbreak period from 2018 to 2021. The spatio-temporal patterns indicate that countries and regions with an effective COVID-19 containment such as East Asia show the strongest resilience, especially mainland China, followed by high-income countries (e.g., European Union), whereas low-income countries (e.g., Africa) show high vulnerability. The overall findings elicit the hidden global trading disruption, recovery, and growth due to the adverse impact of the COVID-19 pandemic.

Keywords: COVID-19; International Trade Network; Resilience; Vulnerability

1 INTRODUCTION

The COVID-19 pandemic has caused an unprecedented disruption to the global economy and world trade, bringing economic activity to a near-standstill as countries imposed social distancing and travel restrictions to halt the virus spread. The International Monetary Fund (IMF) estimates that the global economy shrank by 4.9% in 2020 (International Monetary Fund, 2020), which is the most serious global economic crisis since the Great Depression of the 1930s. COVID-19 has hit global supply chains badly because many factories were closed and production has halted. Exports and imports have been significantly affected due to the consumption slowdown in the world. Different countries have been experiencing different waves of COVID-19 and its variants, thereby resulting in the fragmentation of global trade and supply linkages.

Two years after the onset of the COVID-19 pandemic, the global economy stages its most robust post-recession recovery in 80 years with 5.6 percent growth in 2021 (The World Bank, 2021b). Though the total trade flows have surpassed pre-pandemic levels, the COVID-19 shows considerably diverse impacts across countries and regions. For example, the outlook for advanced economies has been expected to recover fast because of additional fiscal and monetary support as well as broader and faster vaccine roll-out (International Monetary Fund, 2021a). The economic prospects for the low-income developing countries are not promising because of the low vaccination percentage and tighter financing conditions (International Monetary Fund, 2021a; The World Bank, 2022). China experienced a sharp fall in exports during Feb 2020 with a quick recovery back to normal by Mar 2020, whereas the USA and European Union production had a later recovery in which there was a gap from historical trend volumes (OECD, 2022). Considering a high degree of uncertainty in the length and severity of the outbreak, as well as the trajectory of the recovery in the global economy, it is important to have a better understanding of the strengths and vulnerabilities of international trade networks (ITNs) in the context of the current crisis to evaluate global production resilience and be prepared for the future crisis.

Therefore, this research will address the following questions regarding the impacts of the COVID-19 pandemic: (1) How have the trade networks been impacted due to the pandemic? (2) How have the trade density and interconnectedness for inter-region and intra-region declined and recovered? (3) How has the nature of globalization and regionalization in terms of the ITNs shifted over time? To answer the above questions, this research applies complex network analysis approaches on the monthly ITNs for the pre- and post- COVID-19 outbreak periods from Jan 2018 to Dec 2021. More specifically, the research studies the statistical properties, structure, and dynamics of the ITNs in terms of the overall values before and after the COVID-19 outbreak at the world, regional, and country scales.

Our study contributes to the literature on the impacts of COVID-19 on international trade. Conceptual analysis (Saif et al., 2021), model prediction (Eppinger et al., 2020; Guan et al., 2020), case study (Gereffi, 2020), and empirical data analysis (Barbero et al., 2021; Hayakawa & Mukunoki, 2020, 2021a, 2021b, 2021c; Kiyota, 2022; Liu et al., 2022; Meier & Pinto, 2020; Mena et al., 2022; Verschuur et al., 2021; Zhang et al., 2021) have been used to study the impacts of COVID-19 on

international trade. Those existing empirical research can be divided into 2 categories. The first category examines bilateral trade relationships using the gravity model and employs various variables (i.e., health-related policies) as a proxy for the COVID-19 damages such as the numbers of COVID-19 cases and deaths (Barbero et al., 2021; Hayakawa & Mukunoki, 2020, 2021a, 2021b, 2021c). Although gravity equations have been widely applied in international trade studies, the analysis of bilateral trade flows between two countries ignores the broader global trade network interdependence (Granovetter, 1985; Luo et al., 2014; Luo & Yuan, 2021). The second category conducted in this area from a complex network analysis perspective (Kiyota, 2022; Vidya & Prabheesh, 2020). However, these research analyzed only a limited number of countries or for a short time period (i.e., the first two quarters in 2020) (Antonietti et al., 2022; Kiyota, 2022; Vidya & Prabheesh, 2020). Thus, it is important to investigate the impacts of COVID-19 to fully understand the resilience of ITNs worldwide across a longer timeline covering the disruption, recovery, and even growth.

To fill the gaps, we use network measurements such as density and PageRank centrality to examine the impacts of the pandemic on dynamic trade properties at the global scale, regional scale, and country scale from Jan 2018 to Dec 2021. We further analyze the regionalization and globalization trends during the COVID-19 pandemic. In the end, we conclude our findings, suggest the future research, and discuss the lessons from the pandemic.

2 METHODS

2.1 Data

We collected international trade data from International Financial Statistics Database (International Monetary Fund, 2022) that includes monthly imports and exports for 177 countries or areas where the data are available from Jan 2018 to Dec 2021 in US dollars. We also collected the 2019 annual Gross Domestic Product (GDP) for those countries in US dollars from the IMF (International Monetary Fund, 2022), while the missing values for Cuba and North Korea are obtained from the World Bank (The World Bank, 2021a) and Trading Economics website (Trading Economics, 2021). According to World Economic Outlook (International Monetary Fund, 2021b),

ten geographical regions (see Appendix Table A. 1) with different levels of socio-economic development have been selected for our study (see Appendix Figure A. 1).

2.2 International Trade Network

ITN consists of countries as nodes and trade relationships (i.e., imports and exports) as edges in a graph. We define two types of directed ITNs (i.e., imports and exports) including a binary version and a weighted version. For a binary trade network, an edge indicates the existence of trade between two countries. We call it a trade linkage network. It can help us analyze whether the trading relationships have been broken or reconnected during COVID-19. We use the original trading volume to define the weight of edges in the weighted network in which we transform imports and exports into ITN trade matrices. We call it a trade volume network. It can help us analyze the dynamic changes of trading volume during COVID-19.

We compute three network measurements including trade density, trade volume, and PageRank centrality to analyze relative positions of different nodes in the network, the dynamic characteristics and structures of ITNs during pre and post COVID-19. Trade density is measured as the proportion of actual edges to possible edges, so it can represent the interconnectedness in the trade linkage network. Trade volume is computed directly by the sum of weights of edges for nodes at a trade volume network. For each node, import trade volume is the sum of weights of in-edges while the export trade volume is the sum of weights of out-edges. PageRank centrality measures the importance of each node based on the number of incoming relationships and the importance of the corresponding source nodes according to their incoming relationships. The formula to calculate PageRank centrality is as follow:

$$x_i = \alpha \sum_k^N \frac{a_{k,i}}{d_k} x_k + \beta,$$

where α and β are constants and d_k is the out-degree of node k if such degree is positive, or $d_k = 1$ if the out-degree of k is null. $a_{k,i}$ is the entry at row k and column i of the adjacent matrix A with:

$$A = (a_{i,j}).$$

We use Python module NetworkX to compute PageRank and take trade volume as edge weights.

2.3 Trade Resilience

Resilience is the capability of a system exposed to hazards to resist and recover from their effects in a timely and efficient manner (Christopher & Peck, 2004; Melnyk et al., 2014). This capability can be measured from two aspects: robustness representing the capability of a system to maintain its function during hazards, and responsiveness referring to the capability to return to its original status or even move to a better status (Melnyk et al., 2014; Mena et al., 2022). In the context of international trade, researchers have defined trade resilience of a country in a given month using year-on-year (YoY) monthly percentage (%) change in total trade volume (Mena et al., 2022). Accordingly, we extend the idea of YoY monthly percentage change to both trade volume and PageRank to evaluate trade resilience. For trade volume and PageRank, the YoY monthly percentage change is computed as the increasing or decreasing percentage of trade volume/PageRank in a certain month of 2020 or 2021 compared to the average value of trade volume/PageRank in the corresponding months of 2018 and 2019. We consider the average of trade volume or PageRank in both 2018 and 2019 as the baseline to minimize potential errors caused by emergency or other interference caused by using a single year. In terms of robustness and responsiveness, we define the former as the 1- YoY monthly percentage change and the latter as the time to recover after disruptions.

3 RESULTS

3.1 Pandemic Impact on International Trade Network

3.1.1 Global Scale

Figure 1 presents the YoY monthly percentage change in both trade volume network and trade linkage network. Global trade volume had been reducing since Jan 2020 and dropped sharply to its lowest point close to -30% in Apr 2020 and May 2020, due to the massive disruption in the global supply chain and international trade prohibitions and restrictions (Guan et al., 2020) caused by the pandemic outbreak. The total trade volume has recovered rapidly after the abrupt reduction

and reached the pre-crisis level around Sep 2020. From Sep 2020 to Nov 2020, trade volume has fluctuated in a small range around the pre-crisis level. Since Dec 2020, trade volume has an increasing growth rate even reaching to 20% from Sep 2021. The global trade linkage change shows different patterns: four percent of trade linkages has been broken in Apr and May 2020; the number of trade linkages has bounced back to pre-crisis levels in Jun 2020 and started to increase in Sep 2020; the maximum growth rate of the number of trade linkages is about 4%. Those findings suggest that trade linkages have been quickly reestablished after being broken while the trade volumes were still in contraction.

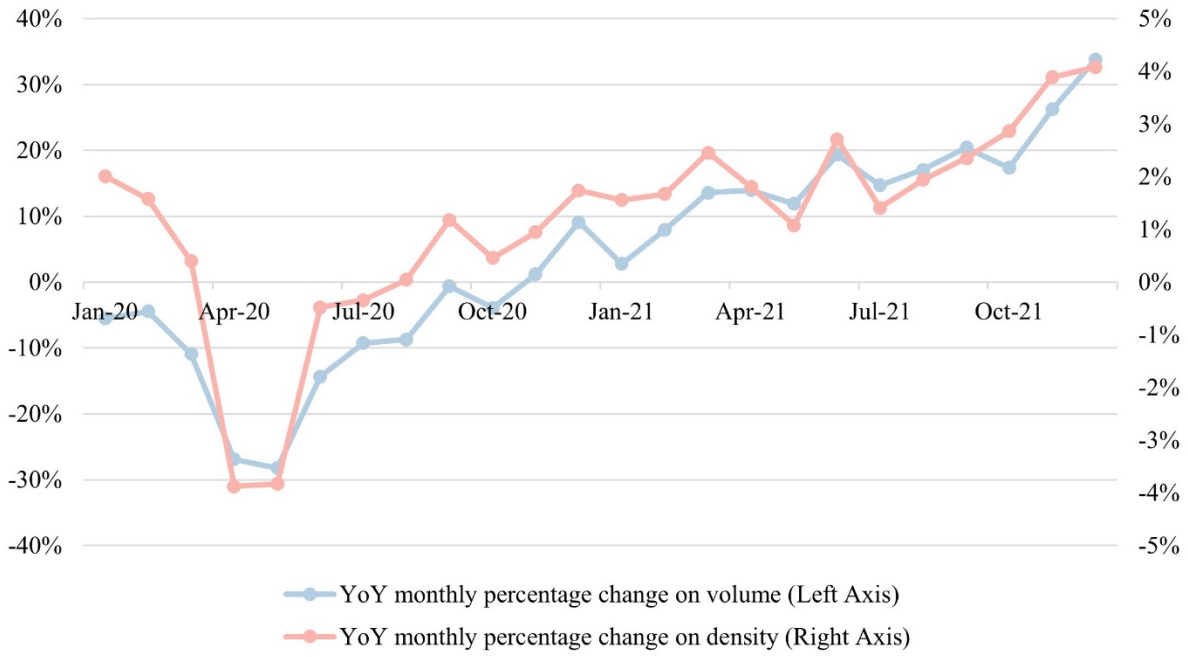

Figure 1 The impact of Covid-19 on global trade networks.

3.1.2 Regional Scale

Figure 2(a) and Figure 2(c) present the YoY monthly percentage changes in both import and export trade volumes in the global trade for each region which is sorted by the average GDP in 2019. All the regions were shrinking at the early stage of the pandemic, but different regions show dramatically diverse trade robustness and responsiveness. Exports show relatively more serious disruptions and stronger recovery than imports, though both show similar trending patterns.

The global export volume of East Asia (EAQ), Emerging and Developing Asia (DA), and Asia and Pacific (APQ) shows the strongest trade resilience compared to other regions, followed by European Union (EU), Advanced Economies (ADVEC), Southeast Asia (SEQ), Emerging and Developing Europe (EDE), Latin America and the Caribbean (WE), Sub-Saharan Africa (SSA), and Middle East and Central Asia (MECA). Specifically, the global export volume of EAQ, DA and APQ was reduced by 11%, 11%, and 18% respectively in Apr. and May 2020, while other regions went through at least a decline of 30%. Furthermore, DA first returned to its pre-crisis level in Jun. 2020, followed by EAQ and APQ in Jul 2020, when other regions were still in reduction. The majority of regions have shown increments after the full recovery to pre-crisis levels at the end of 2020. EAQ, DA, and APQ have been with a consistently high growth rate of more than 20% since Feb 2021. Economic advanced regions, including ADVEC and EU, have kept a consistent moderate increment rate in export trade around 10% since Mar 2021. The export growth of SEQ, WE, SSA, and EDE fell into the middle of the above two regions and the former three experienced a lower increment rate during the peak of Delta outbreak around Jul and Aug 2021 (Luo et al., 2021). MECA experienced the longest export decline until Apr 2021 and the lowest increment ranging from 1% May 2021 to 13% Oct 2021. All regions reach their peak of export growth in Dec 2021. Those regional patterns imply that an effective COVID-19 containment may play a major role in determining the export trade resilience, followed by economic development levels.

Compared to export volume, robustness and responsiveness of import volume tend to show more similar patterns across regions. All regions experienced a continuous import reduction from Jan 2020 to Aug 2020, in which EAQ has been affected the least, ADVEC, DA, APQ, SEQ and EDE have been moderately affected, while WE, MECA and SSA have the worst decline over Apr and May 2020. All regions have fully recovered at the end of 2020 and import increments over 2021 for all regions show a high correlation with export increments.

Given that mainland China has been included in EAQ, DA, and APQ, we present the changes in import and export trade volume in the global trade of these three regions excluding mainland China in Figure 2(b) and Figure 2(d). Comparing these three regions among those subfigures in Figure 2, it is obvious that the advantage of trade resilience has disappeared. These differences

indicate that mainland China experienced a sharp fall in exports during Feb 2020 with a quick recovery back to normal by Mar 2020, which played a leading role in determining regional trade resilience.

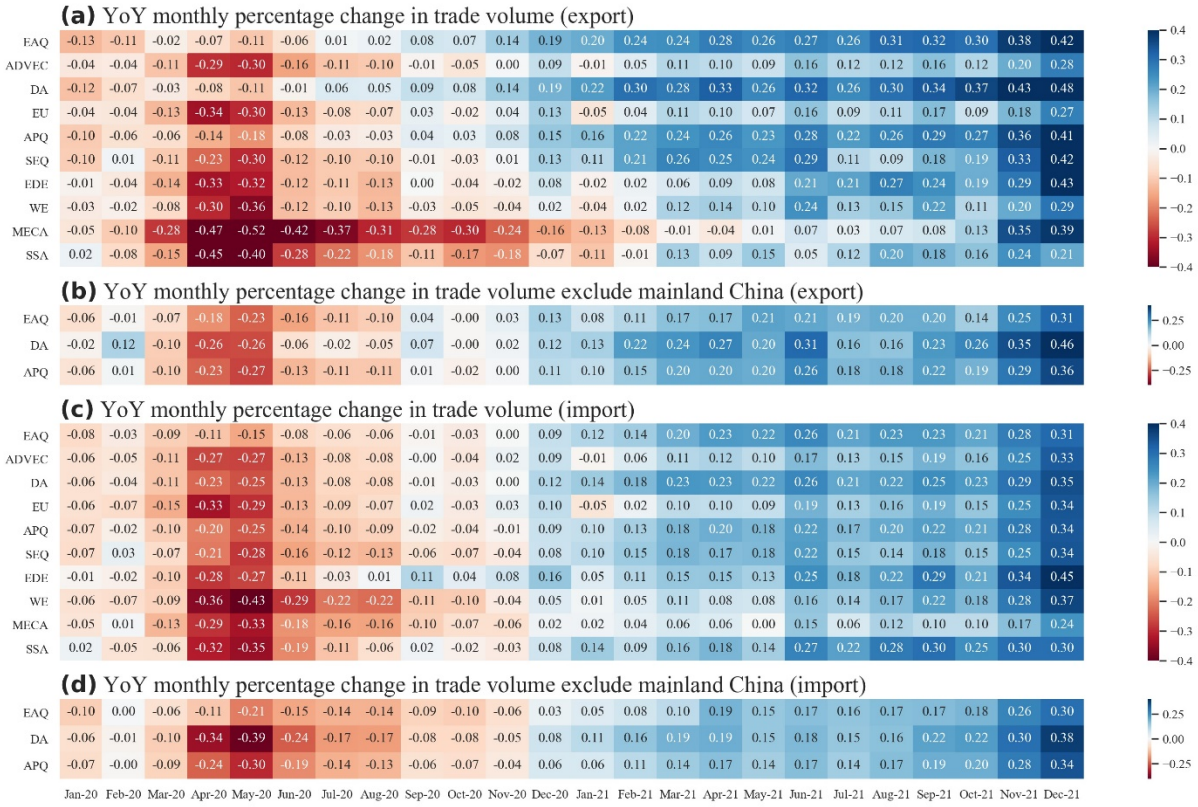

Figure 2 YoY monthly percentage change in trade volume including both imports and exports across regions. X-axis refers to months (e.g., Jan-20 means Jan. 2020), and y-axis are the regions sorted by the average GDP in 2019. The color scheme from red to blue indicates decline to growth of regional-scale trade volume.

Figure 3(a) and Figure 3(c) presents the regional YoY monthly percentage changes in the average PageRank for all countries. Considering mainland China's significant impact on corresponding regions, we also present the same changes of EAQ, DA and APQ excluding mainland China in Figure 3(b) and Figure 3(d). Figure 3 indicates which regions lead a shift towards the international trade center (positive values) or towards the trade edges (negative values) compared to the pre-Covid. We could observe some obvious patterns in terms of export PageRank centrality: 1) EAQ, DA, APQ, and SEQ keep in a continuous rise around 10%; 2) ADVEC and EU have a reduction around 5%; 3) EDE, WE, SSA and MECA have evolved back to pre-crisis levels. It indicate that

the global export PageRank centrality has shifted slightly from ADVEC and EU to EAQ, DA, APQ, and SEQ. Imports show a similar trend but less obvious extent as the exports. Figure 3(b) shows that mainland China plays a driver role in the regional export centrality shift.

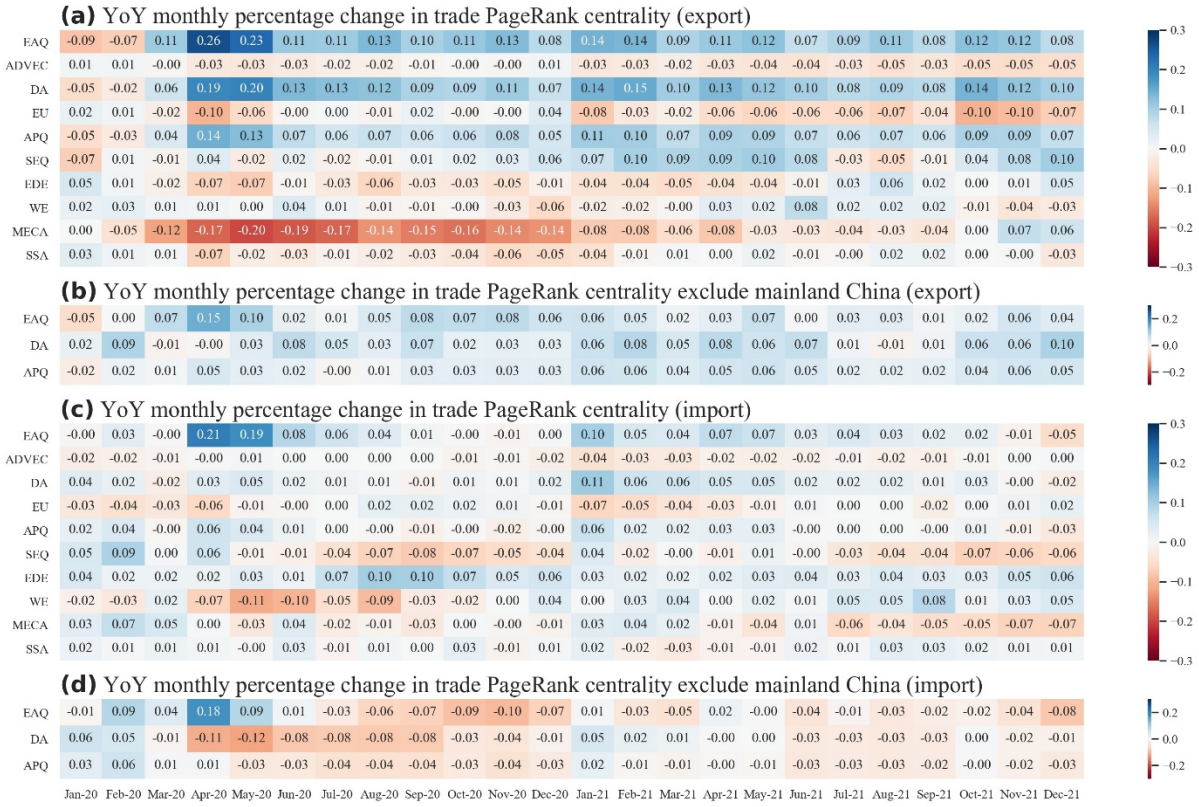

Figure 3 YoY monthly percentage change in trade PageRank centrality including both imports and exports across regions. X-axis refers to months, and y-axis are the regions sorted by the average GDP in 2019. The color scheme from red to blue indicates decline to growth of trade PageRank centrality at the regional scale.

3.1.3 Country Scale

We conduct the country-scale analyses from two aspects including all countries and the top 20 countries with the highest GDP. Figure 4 presents the YoY monthly percentage changes in both trade volume and PageRank centrality for all 177 countries sorted by GDP in 2019. Countries with higher GDP show a clear trend of disruption-recovery-growth on trade export volume compared to countries with lower GDP that shift around sharp fall and rise. It indicates that high-income countries maintain stronger trade robustness and responsiveness whereas low-income countries exhibit a sign of vulnerability when facing COVID-19. Compared to the export volume patterns,

more countries with high GDP show clear disruption-recovery-growth patterns. Relating to the comparison between export and import volume at the regional scale, both indicate that the global import across regions and countries present more resilience compared to the export during COVID-19.

The trade PageRank centrality changes at the country level do not show a clear pattern in terms of high and low GDP countries, but they show diverse patterns across different countries. It provides the evidence that more resilient countries during COVID-19 shift towards the international trade center whereas less resilient countries become peripheral and shift away from the international trade center. The export centrality for countries with the lowest GDP has hardly changed, suggesting that the pandemic has brought no opportunities but only disruptions to these countries.

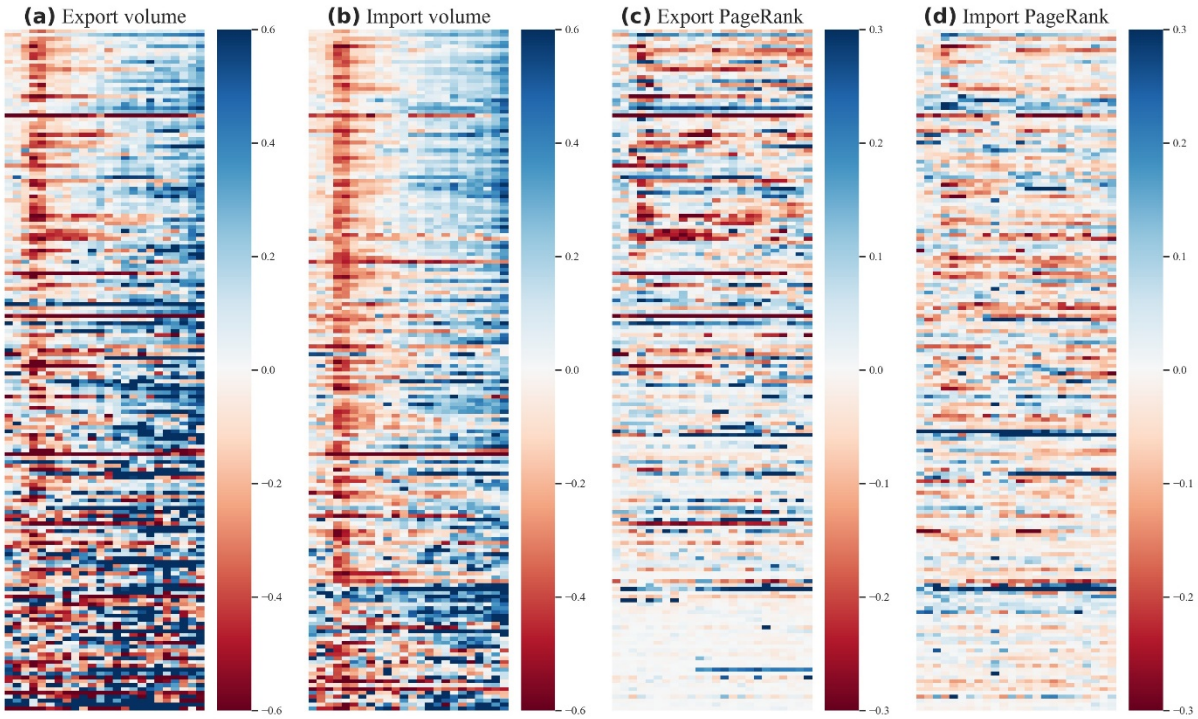

Figure 4 YoY monthly percentage change in both trade volume and PageRank centrality including both imports and exports. X-axis for each heatmap refers to months, ranging from Jan 2020 to Dec 2021. Y-axis are all the countries sorted by GDP from the highest to the lowest in 2019. The color scheme from red to blue indicates decline to growth of trade volume (the left two) and trade PageRank centrality (the right two) at the country-scale.

Figure 5 and Figure 6 focus on the top 20 countries with the highest GDP in 2019 and their highest importing and exporting countries over different time periods during COVID-19. According to

the above global-scale and regional-scale analyses, we selected four different time periods: 1) pre-Covid from 2018 to 2019; 2) disruption from Apr. 2020 to May 2020; 3) near recovery over Sep 2020; 4) growth from Nov 2021 to Dec 2021.

During the pre-Covid time period, United States, mainland China, and Germany are the largest export trade countries for the top 20 countries. During the disruption time period, we can observe some obvious shifts in terms of the largest export trade countries: Germany to the United States for Switzerland; the United States to mainland China for Japan; and the United States to mainland China for Germany. The first two shifts remain the same while the third one has shifted back after the disruption time period. The majority of the highest export volume has declined from Apr 2020 to May 2020, except the export volume of Australia and Brazil to mainland China as well as Switzerland to the United States. During the recovery time period, most links have recovered except the link from Saudi Arabia to mainland China and from the United Kingdom to the United State. During Nov and Dec 2021, all the links become wider except one from the United Kingdom to the United States.

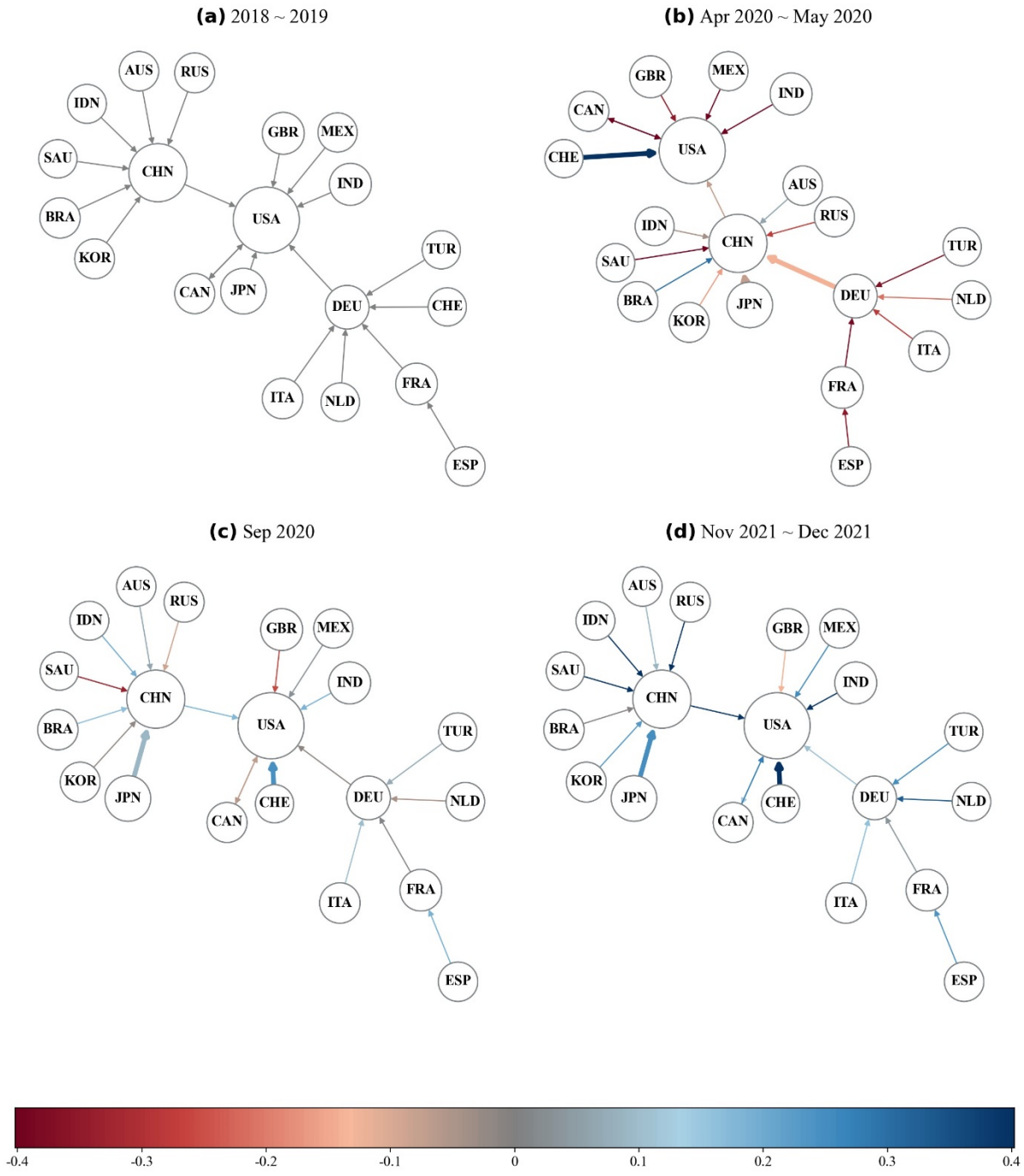

Figure 5 Top 20 countries in GDP and their highest exporting countries. Each node represents one country: USA - United States; CHN - mainland China; JPN - Japan; DEU - Germany; IND - India; GBR - United Kingdom; FRA - France; ITA - Italy; BRA - Brazil; CAN - Canada; RUS - Russian Federation; KOR - Korea, Rep. of; ESP - Spain; AUS - Australia; MEX - Mexico; IDN - Indonesia; NLD - Netherlands; SAU - Saudi Arabia; TUR - Turkey; CHE – Switzerland. Directed link from country A to country B indicates that B is the largest export trade country of A. The color of link indicates the average of YoY monthly percentage change in trade volume compared to the corresponding month from 2018 to 2019. The color scheme from red to blue

indicates decline to growth of trade volume between countries. The link with width indicates an emerging highest exporting pair between two countries compared to pre-COVID. The node size indicates the GDP in 2019 with a larger node size representing a higher GDP value.

There are twenty-one nodes including Taiwan province of China in Figure 6 because it is the largest import area to mainland China during the four time periods. Mainland China is the largest importing country for eight out of the top 20 countries during pre-COVID, eleven out of the top 20 countries from Apr to May 2020, nine out of the top 20 in Sep, and twelve out of the top 20 from Nov to Dec 2021. It implies that mainland China moved towards the center of import trade networks among the top 20 countries.

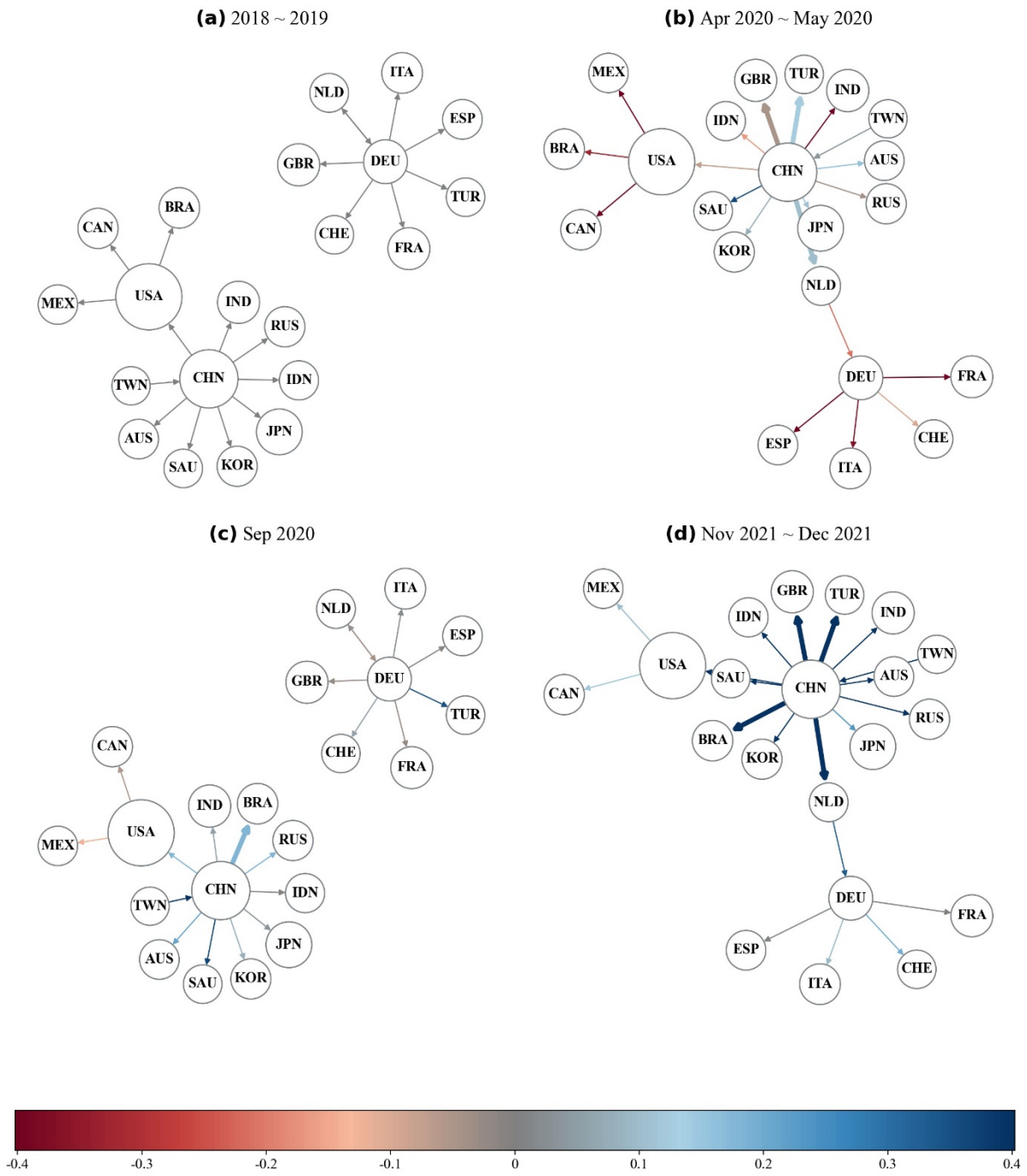

Figure 6 Top 20 countries in GDP and their highest importing countries or areas. Each node represents one country: USA - United States; CHN - mainland China; JPN - Japan; DEU - Germany; IND - India; GBR - United Kingdom; FRA - France; ITA - Italy; BRA - Brazil; CAN - Canada; RUS - Russian Federation; KOR - Korea, Rep. of; ESP - Spain; AUS - Australia; MEX - Mexico; IDN - Indonesia; NLD - Netherlands, The; SAU - Saudi Arabia; TUR - Turkey; CHE - Switzerland; TWN - Taiwan Province of People Republic of China. Directed link from country A to country B indicates that B is the largest trade importing country of A. The color of link indicates the average of YoY monthly percentage change in trade volume compared to the

corresponding month from 2018 to 2019. The link with width indicates an emerging highest importing pair between two countries compared to pre-COVID. The color scheme from red to blue indicates decline to growth of trade volume between countries or areas. The node size indicates the GDP in 2019 with a larger node size representing a higher GDP value.

3.2 Intra-Regional and Inter-Regional Interconnectedness

In this section, we analyze the intra-regional and inter-regional interconnectedness, defined as the YoY monthly percentage changes in terms of trade volume in Figure 7. Comparing Figure 2 to Figure 7(a), we can observe consistent patterns between intra-regional trade volume and global trade volume, implying the similar COVID-19 impacts. Specifically, EAQ is still the least affected region with almost no impact after Jan 2020, indicating the high resilience within EAQ. DA and APQ experienced a slight and momentary decline, followed by a strong recovery and growth. ADVEC and EU show a moderate decline and recovery. SEQ, EDE, WE, MECA, and SSA exhibited the most serious disruptions.

Figure 7(b) shows that all inter-regional trade volume. Given that some countries coexist into multiple regions such as Japan in both EAQ and ADVEC, we only calculate their trade volume between these countries and other countries from two regions once. All inter-regional trade volume involving EAQ, DA, and APQ exhibited high resilience with the least disruptions, as well as strong and quick recovery and growth. Inter-regional trade involving ADVEC and EU experienced moderate disruptions and quick recovery and growth, whereas inter-regional trade between the rest low-income regions (e.g., SEQ, EDE) show the most serious disruptions.

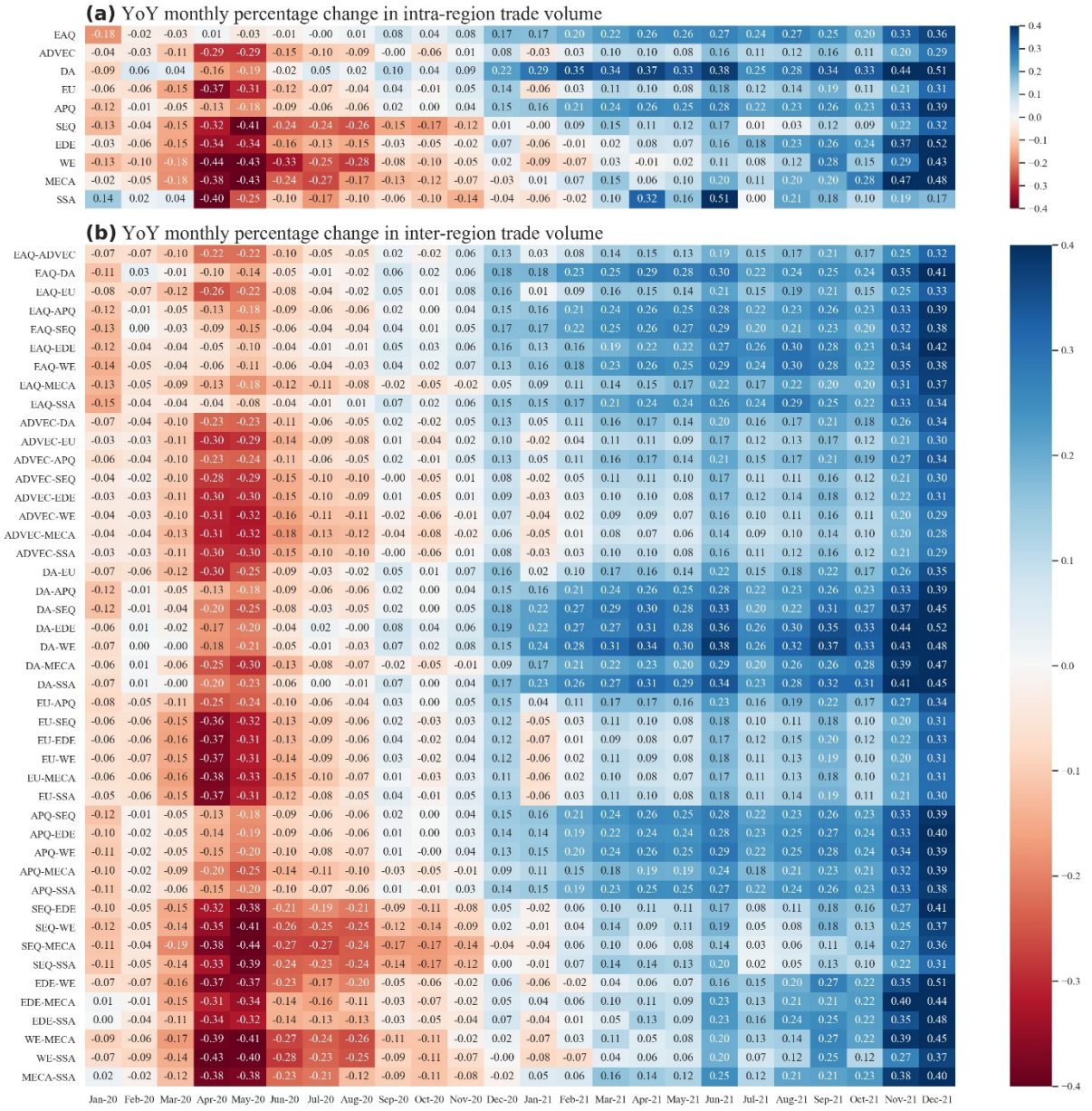

Figure 7 YoY monthly percentage change in both intra-region and intra-region trade volume. X-axis refers to months. In Figure 7 (a), y-axis refers to regions sorted by the average GDP in 2019. In Figure 7 (b), y-axis refers to the pairs of two regions. Those pairs are sorted by the average GDP from the large to the small by the first region, followed by the second region. The color scheme from red to blue indicates decline to growth of intra-region trade volume.

We further analyze the regionalization and globalization trends from 2020 to 2021. We define regionalization ratio as the proportion of intra-regional trade volume to the total trade volume. Figure 8 presents YoY monthly percentage change in regionalization ratio for both imports and exports from 2020 to 2021 compared to the regionalization ratio calculated by the average value

of 2018 and 2019. A positive value indicates a regionalization trend, whereas a negative value implies a globalization trend. In terms of exports, most regions including EAQ, ADVEC, DA, EU, APQ, and EDE do not exhibit obvious trends. SEQ went through a consistent decline of export regionalization ratio. It might be explained by an effective COVID-19 containment in SEQ that serves one of the major exporting places with increasing demand around the world (World Trade Organization, 2020, 2021a, 2021b). Both MECA and SSA experienced increasing export regionalization ratios during COVID-19, which reinforces that low-income countries move towards the trade network edges with their regional trading countries.

In terms of imports, DA, APQ, and EAQ exhibited slight regionalization trends, which indicates that those countries tend to increase their imports within regions due to more effective COVID-19 containment compared to the rest of the world (Chorzempa & Huang, 2021; Ma et al., 2021; Sachs, 2021). ADVEC and EU, as the high-income regions, show similar regionalization and globalization trends compared to pre-COVID. SEQ, EDE, and WE experienced import globalization trends in the most month during COVID-19, whereas MECA and SSA exhibited a mixed import regionalization and globalization over 2020 and 2021.

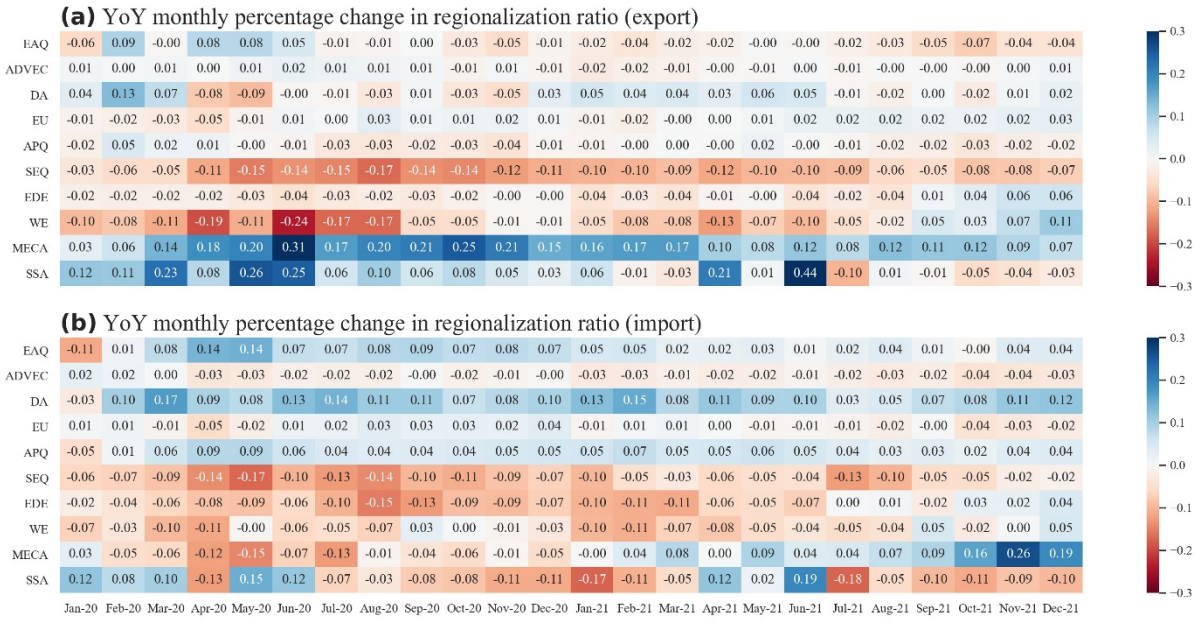

Figure 8 YoY monthly percentage change including both imports and exports in regionalization ratio. X-axis refers to months and y-axis is the regions sorted by the average GDP in 2019. The color scheme from red to blue indicates decline to growth of regionalization ratio.

4 CONCLUSION AND DISCUSSION

We built two ITNs (i.e., trade linkage, trade volume) from Jan. 2018 to Dec. 2021 to study the impacts of COVID-19 on the global, regional, and country scales. ITNs have gone through a disruption-recovery-growth during the pandemic, but trade impacts across regions and countries are highly diverse. At the global scale, ITNs plunged at the beginning of the pandemic, especially over Apr. and May 2020. ITNs began to recover and reached the pre-Covid level around Sep 2020, followed by a continuously increasing trend since then. At the regional scale, EAQ, DA, and APQ exhibited the strongest trade resilience, followed by ADVEC and EU. SEQ, EDE, WE show moderate resilience, followed by MECA and SSA with the high trade vulnerability. It indicates that regions with an effective COVID-19 containment and strong trade linkages with mainland China make major contributions to the stability of ITNs. The global centrality, especially on exports, has shifted slightly from ADVEC and EU to EAQ, DA, APQ, and SEQ. At the country scale, mainland China moves towards the center of trade networks consisting of the top 20 countries in terms of their GDP.

Our study has several limitations that can be improved for future research. First, we use the average values from 2018 and 2019 as the basis to analyze the impacts of COVID-19. It could be improved to use longer time period for pre-COVID to build a model and make projections for different values as the basis. Second, we only focus on the aggregate bilateral trade, but trade impacts across specific goods and products. It is worth exploring spatio-temporal trading disruption, recovery, and growth at a more detailed product level. Finally, it would be interesting to investigate such impacts on trade in services. The pandemic and travel restrictions have greater impacts on the mobility of people than that of goods, so they lead to significant effects on services trade like tourism.

COVID-19 spread across the world at a rapid pace, causing a tremendous impact on human health and economic loss. Though the outbreak began in China, to which the rest of EAQ, SEQ, and APQ are very closely connected by travel and trade, the success of those regions in suppressing the pandemic has been consistent since Spring 2020 (Sachs, 2021). Such a success guaranteed their strong trade resilience during COVID-19. In comparison, USA and EU have recorded very high

infection rates (Chorzempa & Huang, 2021), which could greatly impact international trade structures at the beginning of COVID-19 outbreak. Those advanced economies have recovered at a moderate rate with monetary support and wide vaccine roll-out. Low-income regions with low vaccination rates and tighter financing conditions exhibited the weak vulnerability. An important lesson for the world to learn from the pandemic is to take collective responsibility to protect health and economic prosperity in the face of the global challenges such as COVID-19 and climate change.

CODE AVAILABILITY

We would make the code availability after acceptance of the paper.

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APPENDIX A: DETAILS ABOUT REGIONS

Table A. 1 Names and Abbreviations of Analytic Regions

Abbreviation	Name
ADVEC	Advanced Economies
EU	European Union
DA	Emerging and Developing Asia
EDE	Emerging and Developing Europe
APQ	Asia and Pacific
WE	Latin America and the Caribbean
SSA	Sub-Saharan Africa
EAQ	East Asia
SEQ	Southeast Asia
MECA	Middle East and Central Asia

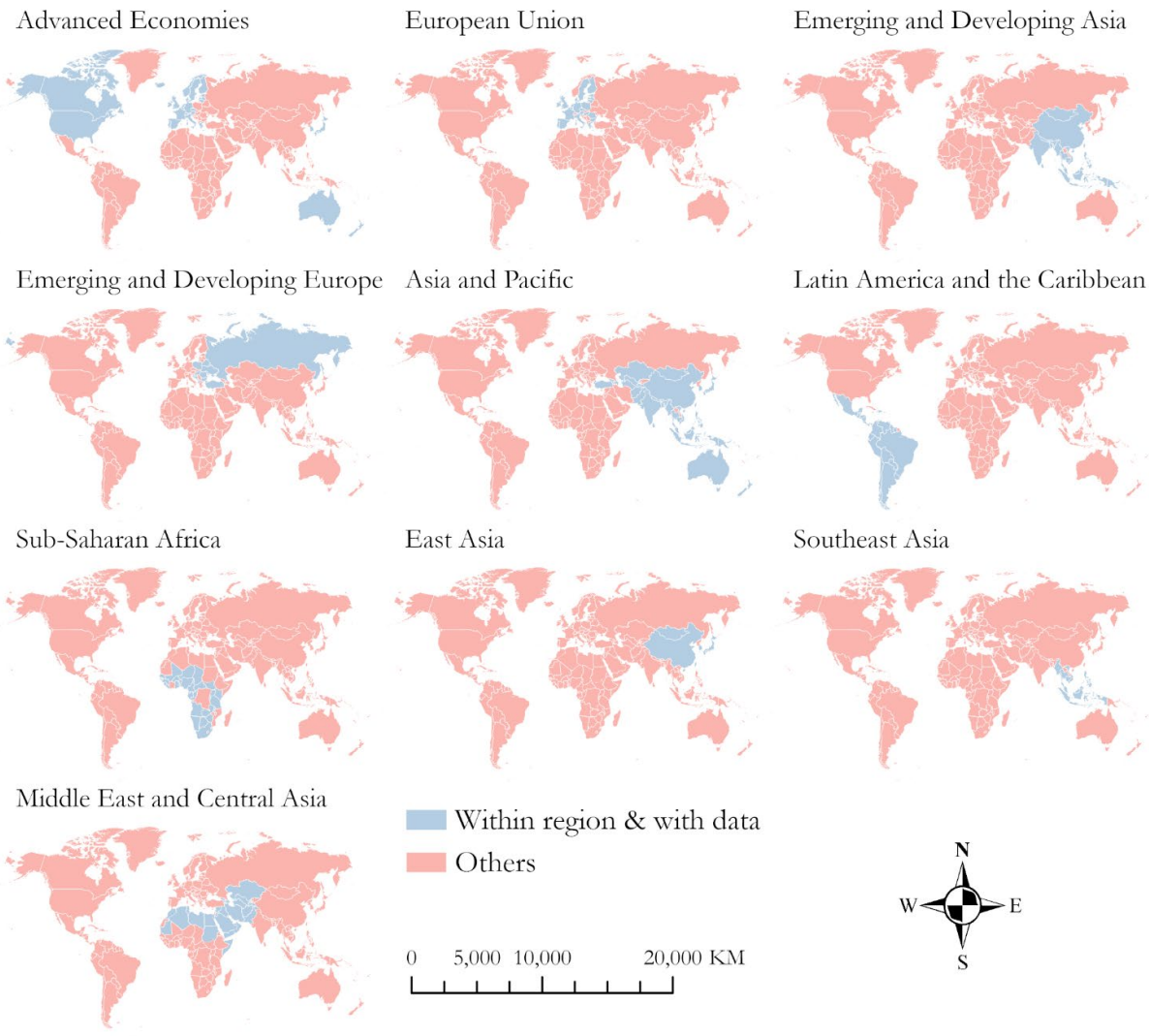

Figure A. 1 Countries or areas within each analytical region. Blue color indicates the corresponding countries within the analytical region. Red color indicates the countries outside of the analytical regions or without international trade data.