Special Issue 1

The Open Economies in East Asia

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Editor's Introduction to the Special Issue "The Open Economies in East Asia"

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This special issue is an outcome of a research project titled "Intra-Regional Trade, Investment, and Economic Interdependence in East Asia" at the Institute of Comparative Economic Studies at Hosei University. The primary focus of the research is the open economies of East Asian countries, where "East Asia" refers to the region encompassing the countries in the Association of Southeast Asian Nations (ASEAN), as well as China, Hong Kong, Japan, South Korea, and Taiwan.

East Asian countries have achieved remarkable development over the past 60 years or so. Consequently, living standards in many countries in the region have improved significantly, and East Asia's role in the global economy has expanded substantially. This phenomenon of rapid and sustained economic growth over a long period of time has been frequently referred to as the "East Asian miracle" in the literature.

Various common characteristics of East Asian economies can be identified depending on the perspective adopted, but one particularly noteworthy characteristic is their high degree of openness. East Asian countries have actively engaged in international trade and investment with both neighboring countries and regions outside East Asia—a trend that continues to this day. These international economic activities are closely tied to the remarkable economic development of the East Asian countries mentioned above. Although the relationship between international economic activities and economic growth is interactive, in the case of East Asia, it is evident that the former has significantly contributed to the latter. This observation aligns with the fundamental economic principle that trade promotes economic efficiency and prosperity.

It is worth emphasizing that due to the interconnection of regional economies through international trade and investment, East Asia has evolved into an organic economic zone rather than merely a geographic grouping. At the same time, these international economic activities have made the economies of East Asian countries more susceptible to changes in regional and global economies.

This overarching perspective forms the foundation of our research project. The papers in this issue provide detailed insights by empirically examining the open economies of East Asian countries from the standpoints of international macroeconomics, international trade, international investment, and economic development. They address research themes of significant relevance and importance in these fields. The following is a brief description of each paper.

The first paper, titled “Intra-regional Trade in Intermediate Goods and Macroeconomic Interdependence in East Asia: Analysis with Updated and Extended Data,” authored by Tuan Khai Vu, examines the relationship between the trade structure and regional macroeconomic interdependence in East Asia. The author begins by highlighting key features of East Asia’s trade structure. In recent decades, production and trade networks have emerged in East Asia and have become essential elements of the region’s dynamism. These networks are characterized by the division of production spanning multiple countries in East Asia, with multinational corporations strategically distributing production processes and facilities across the region. A notable aspect of this trade structure is the predominance of intra-regional trade in intermediate goods, such as components and parts of manufactured products, whereas trade with regions outside East Asia is more concentrated on final goods.

The central research question of the paper is how this trade structure influences macroeconomic interdependence between East Asian countries. This inquiry builds on the author’s previous research, which incorporates the aforementioned trade structure into a new open economy macroeconomic model. That research reveals the production linkages among countries in the region as a result of intra-regional trade in intermediate goods.

In the current paper, Vu seeks to empirically validate these theoretical findings using a vector autoregression (VAR) model with block exogeneity. The analysis demonstrates a strong relationship between the trade structure and intra-regional macroeconomic interdependence in East Asia. Two key findings stand out. First, positive U.S. GDP shocks lead to increased exports, imports, and GDP in most East Asian countries, with the magnitude of these effects on output rising in proportion to the share of intermediate goods in their exports within East Asia. Second, export shocks that raise exports also result in higher imports in many East Asian countries, and the contribution of these shocks to the variance of imports is positively correlated with the share of intermediate goods in total imports.

In the second paper, titled “Oil Price Fluctuations and Stock Market Linkages in Asia,” Hayato Nakata investigates how oil price fluctuations influence stock market correlations in ASEAN countries. This research is motivated by increasing economic interdependence in the era of globalization and the heightened impact of oil price shocks—one of the major global economic shocks—on countries worldwide. Moreover, the growing adoption of inflation-targeting monetary policy rules has led central banks to adjust their interest rates in response to oil price-induced changes in key domestic economic variables such as economic growth and inflation. These monetary policy reactions, in turn, may influence stock markets and intensify economic interdependence among countries.

ASEAN countries are particularly well-suited for this research. First, these nations are highly open economies, making them especially vulnerable to global shocks. Second, they exhibit significant diversity in various aspects, including oil production and consumption patterns, monetary policy frameworks, and exchange rate regimes.

A distinctive feature of the paper is the decomposition of structural shocks driving oil price fluctuations into oil supply shocks, oil demand shocks, and oil market-specific shocks. Nakata uses real stock return correlation coefficients to measure stock market linkages. To evaluate the influence of these shocks, he conducts counterfactual experiments by comparing the observed stock market correlations with the correlations that would have existed in the absence of the identified oil shocks. The key findings of the paper are as follows: First, on average, the stock market correlation coefficients among the ASEAN countries have fluctuated around 0.55, showing no clear long-term upward trends. Second, oil price shocks significantly influenced stock market correlations. Third, the effects of oil price shocks on stock market correlations differ before and after the 1997–1998 Asian Financial Crisis. Specifically, in the latter period, oil market-specific demand shocks more strongly amplify fluctuations in stock market correlations.

In the third paper, titled “The Effect of COVID-19 on Firm Behavior – the Case of Japan,” Yuting Chen and Bin Ni study the transmission of a large shock across countries from a microeconomic point of view. Specifically, as the title suggests, they investigate the effects of COVID-19 at the firm level, focusing on Japanese affiliates operating abroad as a case study.

The topic of the paper is highly relevant to East Asia, as many countries in this region—starting with Japan, followed by South Korea, Taiwan, Singapore, Malaysia, Thailand, and more recently China—have experienced sustained economic growth, resulting in the emergence of firms that achieved significant competitiveness in their domestic markets and eventually expanded internationally. These firms evolved into multinational corporations, making them susceptible to economic conditions in both their home countries and the host countries. Moreover, they serve as channels through which various shocks are transmitted across borders.

Chen and Ni focus on the effects of the preventive regulations imposed in the host countries where Japanese affiliates operate. They use a panel dataset of Japanese affiliates abroad, covering a period that includes both the pre- and post-COVID-19 outbreak phases. Their findings reveal that certain regulations—namely, school closures, restrictions on gatherings, and work-from-home orders—negatively impact affiliates’ local revenues and purchases. These negative effects extend to affiliates’ purchases from their home country (i.e., Japan), purchases from third countries, and purchases from their Japanese parent firms. Moreover, the observed negative impact is more pronounced for firms with both headquarters and foreign affiliates in the manufacturing sector.

In the fourth paper, titled “Premature Deindustrialization, Global Value Chains, and Dutch Disease in Asian Latecomer Economies,” Hiroyuki Taguchi and Ni Lar examine two significant challenges faced by developing countries worldwide, including those in East Asia: premature deindustrialization and the Dutch disease. Both of these issues are closely related to the open-economy characteristic of these countries. Premature deindustrialization refers to the phenomenon in which developing countries reach the peak share of their industrial sector when their income levels are below those achieved by advanced economies that developed earlier. Furthermore, this peak is often lower than what advanced economies have historically experienced. The Dutch disease, as analyzed in the paper, refers to the adverse economic effects arising from a natural resource boom. This causes the home country's currency to appreciate in real terms, thereby undermining the competitiveness of its export sector—including manufacturing—in the global market. This, in turn, can lead to a decline in the manufacturing sector and hinder long-term economic growth.

Taguchi and Lar adopt a panel data econometric model with country-fixed effects and estimate it using a data set comprising 15 Asian developing economies and spanning the period 1990-2021. They demonstrate the prevalence of premature deindustrialization in all Asian latecomer economies using China, Japan, and South Korea as benchmark cases. Furthermore, they extend their analysis to investigate the factors contributing to this premature deindustrialization and identify the Dutch disease and insufficient participation in global value chains as significant determinants. On average, these factors contribute approximately 10% and 40% to country-specific deindustrialization, respectively.

The last paper, titled “Revisiting the Dynamics of International Business Cycles: A New Approach,” authored by Tomoo Inoue and Tuan Khai Vu, quantifies the connectedness between East Asian countries and between East Asian countries and countries in other regions. Inoue and Vu develop a novel method for measuring connectedness by combining the framework of Diebold and Yilmaz to measure connectedness and the global vector autoregressive (GVAR) model.

The need to measure the interconnectedness between countries and regions has never been greater as globalization has made nations increasingly interdependent in the world today. The method proposed by Inoue and Vu contributes to this effort. A distinctive feature of their method is its capacity to incorporate a larger number of countries into the analysis while still producing time-varying indicators of connectedness. Furthermore, their method is sufficiently flexible to measure connectedness across different observational units, such as between individual countries, between countries and regions, or between regions.

Applying this method to a sample of 33 countries over the past 40 years, Inoue and Vu analyze connectedness for the world as a whole as well as for specific groups of countries, such as East Asia, ASEAN, the G7, and BRICS. Although the primary focus of their analysis is on the evolving influence of the Chinese economy over the sample period, they also examine Japan and South Korea for comparative purposes. Their main findings are as follows: First, in terms of total connectedness, global connectedness increased from 15% in the 1980s to over 22% in 2019, driven largely by the rise of the Chinese economy. Second, in terms of directional connectedness, within East Asia, Japan, China, and Singapore have been net transmitters of output shocks. Japan's influence peaked during the 1980s and 1990s, while China's dominance has grown steadily since the 2000s. Third, in terms of pairwise directional connectedness, South Korea has been primarily a net recipient of output shocks from China and Japan but has acted as a net transmitter to countries such as Australia and Malaysia.

Finally, I would like to thank all the aforementioned authors for their contributions to this issue. I am also grateful to the Institute of Comparative Economic Studies at Hosei University for its support and hospitality throughout the research project. I hope this special issue will enhance our understanding of East Asian economies.

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Intra-regional Trade in Intermediate Goods and Macroeconomic Interdependence in East Asia: Analysis with Updated and Extended Data[1]

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Abstract

Over the last few decades, a distinctive trade structure has emerged in East Asia, in which countries in the region trade intermediate goods extensively with themselves, while they trade more final goods with the rest of the world. This paper documents the facts about this trade structure in detail and empirically investigates its relationship with macroeconomic interdependence in East Asia using a VAR model and data from 11 major countries in the region. The analysis yields three key findings. First, in most East Asian countries, exports, imports, and GDP increase in response to a positive output shock occurring in the USA. Moreover, output is more influenced by USA output shocks in an East Asian country where exports to East Asia are more concentrated in intermediate goods. Second, both exports and imports of an East Asian country increase in response to a positive export shock in that country, with imports being more sensitive to such shocks when intermediate goods account for a larger share of its imports. Third, output shocks from China exert a stronger influence on East Asian economies compared to those from Japan.

Keywords: trade in intermediate goods, international macroeconomic interdependence, international production and trade network, East Asia, VAR.
JEL Classification Codes: F41, E32.

1. Introduction

Intra-regional trade in East Asia has been increasing steadily over the last few decades, and in recent years, it has accounted for approximately half of the region's total trade. A notable feature of this trade

[1] I thank a referee for helpful comments.

is the predominant share of trade in intermediate goods, which are primarily parts and components of industrial final goods. These intermediate goods are produced and traded between several blocs within the region such as Japan, China, the NIEs, and Association of Southeast Asian Nations (ASEAN) members. By contrast, in extra-regional trade, final goods are more important than intermediate goods. These patterns suggest a unique and interesting trade structure in East Asia: countries within the region trade intermediate goods extensively with each other, while their trade with the rest of the world predominantly comprises final goods.

How would this trade structure affect the international transmission of macroeconomic shocks in East Asia, or more broadly, the way countries in the region are interdependent? In a previous study (Vu 2016), I address this question by constructing a three-country theoretical macroeconomic model that incorporates the aforementioned East Asia's trade structure. I find that, because intermediate goods are used as inputs in the production of final goods, intra-regional trade in intermediate goods creates linkages in production between East Asian countries, significantly affecting the behavior of their exports, imports, output and other macroeconomic variables. For example, if the production of final goods in country *A* in East Asia increases due to an external shock, such as an increase in demand in the USA for final goods produced in East Asia, country *A*'s imports of intermediate goods from country *B* in East Asia will rise. If these intermediate goods in turn are produced using intermediate goods from elsewhere in East Asia, then country *B*'s imports of intermediate goods will also increase. In a similar fashion, this effect may propagate further to other countries in East Asia, resulting in increases in both exports and imports for many countries in the region.

In Vu (2018), I empirically examine the question raised above using a vector autoregressive (VAR) model. In this paper, I address the same issue but with updated data and additional countries. Specifically, I use a dataset spanning the period up to 2022, and in the VAR analysis, I include two additional countries, namely Malaysia and Vietnam. With the updated and extended dataset, more precise results can be expected. My primary aim is to examine whether the theoretical results found in Vu (2016) align with empirical evidence and to establish stylized facts about the macroeconomic interdependence between East Asian countries, given the trade structure described above.

This paper contributes to several strands of literature. The first relates to trade, particularly intra-regional trade, in East Asia; see Ando (2005), Fukao, Ishido, and Ito (2003), and Kimura (2006), among others. In this literature, the networks of production and trade formed in East Asia have been well recognized and analyzed, but mainly from a microeconomic perspective, i.e., at firm or industry level. By contrast, the present paper adopts an international macroeconomic perspective.

The second strand of literature empirically analyzes the effects of external shocks—such as oil shocks, USA monetary shocks, or world demand shocks—on East Asian economies. Relevant contributions include Allegret, Couharde, and Guillaumin (2012), Dungey and Vehbi (2015), Gimet (2011), Inoue, Kaya, and Oshige (2015), Maćkowiak (2007), Petri (2006), and Sato, Zhang, and

McAleer (2011). Despite the breadth of this literature, to the best of my knowledge, no study explicitly takes the East Asian trade structure into account when investigating the effects of shocks. This paper addresses this research gap.

The third strand of literature analyzes the international transmission of shocks in East Asia using theoretical open economy macroeconomic models that incorporate some characteristics of the regional trade structure. Notable contributions include Shioji (2006) and Teo (2009), both of whom build so called New Open Economy Macroeconomic (NOEM) models for East Asia. Vu (2016) is the first paper that introduces intra-regional trade in intermediate goods into a NOEM model for East Asia. This paper differs by employing an empirical approach to examine the issue.

The remainder of this paper is organized as follows. Section 2 summarizes key facts about East Asia's trade structure. Section 3 explains the empirical method involving a VAR with block exogeneity and describes the data used. Section 4 presents empirical results and analyzes the research question of the paper. The last section concludes the paper.

2. East Asia's trade structure: Stylized facts

In this section, I document key facts observed from data about the trade structure in East Asia. The results are summarized in Tables 1 through 5.

Trade openness in East Asia

Table 1 shows the trade openness of countries in East Asia and other regions of the world for the period 2000-2022. The trade openness is measured as the ratio of trade in goods and/or services to GDP. As seen from the table, the ratio of trade in goods and services to GDP of East Asia and Pacific is 0.60, which is lower than that for the European Union and Middle East & North Africa, but is higher than that for other regions or groups of countries in the world, such as Latin America & Caribbean, OECD members, the groups of high-income countries, middle-income countries, and low-income countries.

Looking in more detail at the country level, all the East Asian countries, except the two large economies China and Japan, are highly open to trade. This is true even when excluding the exceptional cases of the two city-states Hong Kong and Singapore, renowned for their entrepôt trade. For example, the ratios of trade in goods and services to GDP are 0.80, 1.25, 1.27, 1.42, and 1.63 for Korea, Thailand, Taiwan, Vietnam, and Malaysia, respectively, significantly exceeding those for other regions or groups of countries.

Additionally, Table 1 shows that trade in goods constitutes the majority of total trade across all countries or groups of countries. For East Asian countries, a quick calculation based on data in Table 1 reveals that, except for Singapore, trade in goods accounts for more than 80% of total trade. This justifies using data on trade in goods as a proxy for total trade in Sections 3 and 4.

The high degree of openness of East Asian countries suggests that these economies are more closely linked to their trade partners. Below I examine these trade partners and analyze the contents of trade between them and East Asian countries.

Major trade partners of East Asian countries

Table 2 presents the major trade partners of each of the 11 East Asian countries for the period 2000-2022. For most countries, the USA, China, and Japan are the three most important trade partners. For example, the USA is the most important export destination for China, Japan, the Philippines, Thailand, and Vietnam, with its share in total exports of these countries being 0.19, 0.21, 0.17, 0.14, and 0.19, respectively (these numbers are averages for the period 2000-2022). China is the largest import market for Hong Kong, Indonesia, Japan, Korea, Malaysia, the Philippines, and Vietnam, with its share in total imports of these countries being 0.45, 0.16, 0.22, 0.15, 0.12, and 0.23, respectively. Japan is the largest import market for China, Taiwan, and Thailand, with its share in total imports of these countries being 0.12, 0.20, and 0.18, respectively.

It can also be seen from Table 2 that East Asian countries trade extensively with themselves. For instance, six of Korea's ten major export markets are located in East Asia, collectively accounting for 0.45 of its exports. Similarly, seven of Malaysia's the ten largest import markets are also located in East Asia, accounting for 0.58 of the country's imports. These figures underscore the significance of intra-regional trade in East Asia.

Intra-regional trade in East Asia

Table 3 provides additional insights into intra-regional trade in East Asia. This table displays the share of intra-regional trade in total trade in goods for East Asia and several other regions from 1990 to 2022. In East Asia, the share of intra-regional trade increased in the first half of the 1990s and then stabilized at around 0.5. In other words, in recent years, about half of trade of East Asia is conducted within the region. This figure is higher than those for all other regions, except the EU.

Several factors contribute to the prominence of intra-regional trade in East Asia. One is geographic proximity, as suggested by the gravity model.[2] Another is the formation of production and trade networks within East Asia, in which intermediate goods are extensively traded among East Asian countries (see Kimura 2006). The following subsections provide further evidence of this intra-regional trade and trade in intermediate goods in East Asia.

[2] According to this model, given other things equal, a country tends to trade more with its neighboring partners than with those that are farther away.

Trade in East Asia by type of goods

Table 4 categorizes East Asia's trade for the period 2000-2022 into primary goods (or raw materials), intermediate goods,[3] and final goods. The rows represent exports, while columns represent imports for the corresponding region (or group). In intra-regional trade (i.e. trade between East Asia and East Asia), intermediate goods dominate, accounting for 0.64 of total trade, while final goods account for 0.32. (The remaining 0.04 is trade in primary goods.) On the other hand, in extra-regional trade (i.e. trade between East Asia and the rest of the world (ROW)), the share of intermediate goods is much smaller: 0.39 in East Asia's exports to ROW, and 0.43 in East Asia's imports from ROW. Furthermore, final goods dominate exports from East Asia to ROW, with a share of 0.59.

Table 5, structured similarly to Table 4, presents detailed data for each of the 11 East Asian countries. As evident, Korea, Taiwan, and many ASEAN members trade intermediate goods extensively with East Asian countries both as exports and imports. Compared with these countries, Japan's exports to East Asia are similarly highly concentrated in intermediate goods (with a share of 0.69), while its imports from East Asia are considerably less concentrated in intermediate goods (0.47). China exhibits an opposite pattern with Japan: the concentration of intermediate goods in its imports from East Asia, at 0.71, is comparable to other East Asian countries, but the concentration of intermediate goods in its exports to East Asia is considerably smaller (0.48). Additionally, exports from China to ROW are dominated by final goods, with a share of 0.66.

These observations documented above underscore a distinctive production and trade structure within East Asia, in which countries in the region produce and predominantly trade intermediate goods among themselves, while trading more final goods with ROW. In the subsequent sections, I will empirically analyze how this trade structure influences East Asian economies' response to various external and domestic macroeconomic shocks.

[3] Intermediate goods are defined as manufactured goods (processed or assembled) that are produced from primary goods but are not yet final products (RIETI 2015). In the case of East Asia, parts and components of final products in electrical machinery and general machinery industries account for about half of the volume of intra-regional trade in intermediate goods.

Table 1: Trade openness of countries in East Asia and other regions of the world

Country/Region/Group	Trade in goods and services (ratio to GDP)	Trade in goods (ratio to GDP)
Brunei Darussalam	1.05	0.88
Cambodia	1.25	0.98
China	0.46	0.40
Hong Kong SAR, China	3.60	3.06
Indonesia	0.50	0.42
Japan	0.30	0.24
Korea, Rep.	0.80	0.66
Lao PDR	0.80	0.69
Malaysia	1.63	1.37
Philippines	0.70	0.56
Singapore	3.62	2.71
Taiwan, China	1.27	1.10
Thailand	1.25	1.02
Vietnam	1.42	1.28
United States	0.27	0.21
East Asia & Pacific	0.60	0.50
European Union	0.83	0.62
Latin America & Caribbean	0.45	0.38
Middle East & North Africa	0.78	0.62
North America	0.30	0.24
South Asia	0.42	0.31
Sub-Saharan Africa	0.59	0.48
OECD members	0.52	0.40
High income	0.58	0.45
Middle income	0.52	0.43
Low income	0.50	0.39
World	0.56	0.44

Note: Data are averages for the period 2000-2022. Source: Author's calculations based on data from the World Bank's World Development Indicators 2024. Data for Taiwan are obtained from the Central Bank of the Republic of China (Taiwan) and the Asian Development Bank's Key Indicators 2023.

Table 2: Major trade partners of East Asian countries

	China		Hong Kong		Indonesia		Japan		Korea		Malaysia	
Ranking	Export market	Share	Export market	Share	Export market	Share	Export market	Share	Export market	Share	Export market	Share
1	USA	0.19	China	0.50	Japan	0.16	USA	0.21	China	0.22	Singapore	0.15
2	Hong Kong	0.14	USA	0.12	China	0.11	China	0.16	USA	0.14	USA	0.13
3	Japan	0.09	Japan	0.04	USA	0.11	Korea	0.07	Japan	0.07	China	0.11
4	Korea	0.05	India	0.02	Singapore	0.08	Taiwan	0.06	Hong Kong	0.06	Japan	0.10
5	Germany	0.04	Taiwan	0.02	India	0.05	Hong Kong	0.05	Vietnam	0.04	Hong Kong	0.05
6	Netherlands	0.03	Germany	0.02	Korea	0.06	Thailand	0.04	Taiwan	0.03	Thailand	0.05
7	Vietnam	0.02	UK	0.02	Malaysia	0.05	Singapore	0.03	Singapore	0.03	India	0.03
8	India	0.02	Singapore	0.02	Thailand	0.03	Germany	0.03	India	0.02	Korea	0.03
9	UK	0.02	Korea	0.02	Taiwan	0.03	Malaysia	0.02	Germany	0.02	Australia	0.03
10	Singapore	0.02	Netherlands	0.02	Philippines	0.02	Australia	0.02	Mexico	0.02	Indonesia	0.03

	Philippines		Singapore		Taiwan		Thailand		Vietnam	
Ranking	Export market	Share	Export market	Share	Export market	Share	Export market	Share	Export market	Share
1	USA	0.17	Malaysia	0.12	China	0.32	USA	0.14	USA	0.19
2	Japan	0.17	China	0.10	USA	0.13	China	0.10	China	0.11
3	China	0.10	Hong Kong	0.11	Hong Kong	0.09	Japan	0.11	Japan	0.11
4	Hong Kong	0.10	Indonesia	0.09	Japan	0.07	Hong Kong	0.05	Korea	0.04
5	Singapore	0.07	USA	0.09	Singapore	0.06	Malaysia	0.05	Hong Kong	0.02
6	Netherlands	0.06	Japan	0.05	Korea	0.04	Singapore	0.05	Germany	0.03
7	Taiwan	0.04	Taiwan	0.04	Vietnam	0.02	Australia	0.04	Netherlands	0.02
8	Germany	0.04	Korea	0.04	Malaysia	0.02	Indonesia	0.03	Australia	0.04
9	Korea	0.04	Thailand	0.04	Germany	0.02	Vietnam	0.03	UK	0.03
10	Thailand	0.04	Australia	0.03	Mexico	0.02	Philippines	0.02	Malaysia	0.02

Table 2 (continued)

	China		Hong Kong		Indonesia		Japan		Korea		Malaysia	
Ranking	Import market	Share	Import market	Share	Import market	Share	Import market	Share	Import market	Share	Import market	Share
1	Japan	0.12	China	0.45	China	0.16	China	0.22	China	0.17	China	0.15
2	Korea	0.10	Japan	0.08	Singapore	0.13	USA	0.12	Japan	0.14	Singapore	0.12
3	Taiwan	0.10	Taiwan	0.07	Japan	0.11	Australia	0.06	USA	0.11	Japan	0.12
4	USA	0.08	Singapore	0.06	USA	0.06	Saudi Arabia	0.05	Saudi Arabia	0.06	USA	0.11
5	Germany	0.05	USA	0.05	Malaysia	0.05	Korea	0.04	Australia	0.04	Taiwan	0.05
6	Australia	0.04	Korea	0.05	Korea	0.05	UAE	0.04	Germany	0.04	Thailand	0.05
7	Malaysia	0.03	Malaysia	0.03	Thailand	0.05	Taiwan	0.04	Taiwan	0.03	Korea	0.05
8	Brazil	0.03	Thailand	0.02	Australia	0.04	Indonesia	0.04	Qatar	0.03	Indonesia	0.04
9	Russia	0.02	Switzerland	0.02	Saudi Arabia	0.03	Germany	0.03	UAE	0.03	Germany	0.04
10	Saudi Arabia	0.02	India	0.02	India	0.02	Malaysia	0.03	Indonesia	0.03	Australia	0.02

	Philippines		Singapore		Taiwan		Thailand		Vietnam	
Ranking	Import market	Share	Import market	Share	Import market	Share	Import market	Share		
1	China	0.12	Malaysia	0.13	Japan	0.20	Japan	0.18	China	0.23
2	Japan	0.13	China	0.11	China	0.14	China	0.15	Korea	0.14
3	USA	0.12	USA	0.12	USA	0.13	USA	0.07	Japan	0.10
4	Korea	0.07	Taiwan	0.07	Korea	0.06	Malaysia	0.06	Taiwan	0.09
5	Singapore	0.07	Japan	0.08	Singapore	0.06	UAE	0.04	Thailand	0.05
6	Taiwan	0.06	Korea	0.05	Hong Kong	0.04	Korea	0.04	USA	0.04
7	Thailand	0.05	Indonesia	NaN	Germany	0.03	Taiwan	0.04	Singapore	0.07
8	Indonesia	0.04	Saudi Arabia	0.03	Saudi Arabia	0.03	Singapore	0.04	Malaysia	0.03
9	Malaysia	0.04	Thailand	0.03	Australia	0.03	Indonesia	0.03	Indonesia	0.02
10	Saudi Arabia	0.03	Germany	0.03	Malaysia	0.03	Saudi Arabia	0.03	India	0.02

Note: Data are averages for the period 2000-2022. Source: Author's calculations based on data from the IMF's Direction of Trade Statistics (DOTS).

Table 3: Shares of intra-regional trade in total trade of various regions in the world

Region	1980	1990	2000	2010	2020	2022
East Asia	0.35	0.43	0.50	0.50	0.50	0.45
EU28	0.63	0.68	0.63	0.61	0.61	0.60
NAFTA	0.35	0.36	0.45	0.39	0.37	0.38
South America	0.13	0.15	0.23	0.20	0.16	0.17
Middle East	NA	NA	0.04	0.07	0.09	0.06
Africa	NA	NA	0.01	0.02	0.02	0.01

Note: Share of intra-regional trade is the ratio of intra-regional trade to the sum of intra- and extra-regional trade. Source: Author's calculations based on data from the RIETI-TID Trade Industry Database 2022, Research Institute of Economy, Trade, and Industry, Japan.

Table 4: Shares by type of goods in intra-regional and extra-regional trade in East Asia

	Primary goods		Intermediate goods		Final goods	
From \ To	East Asia	Rest of the world	East Asia	Rest of the world	East Asia	Rest of the world
East Asia	0.04	0.02	0.64	0.39	0.32	0.59
Rest of the world	0.34	0.15	0.43	0.46	0.23	0.39

Note: Data are averages for the period 2000-2022. Share for each year t is calculated as $share^{k}_{ij,t} = X^{k}_{ij,t}/X^{all}_{ij,t}$, with $X =$ export volume, $i =$ exporting country, $j =$ importing country, $k =$ type of goods (either primary, intermediate, or final goods), $all =$ all types of goods (the sum over k). Source: Author's calculations based on data from the RIETI-TID Trade Industry Database 2022, Research Institute of Economy, Trade, and Industry, Japan.

Table 5: Shares by type of goods in trade between East Asian countries and their major trade partners

Intermediate goods

From \ To	CHN	HKG	IDN	JPN	KOR	MYS	PHL	SGP	TWN	THA	VNM	EA	Non-EA	USA	World
CHN	—	0.46	0.55	0.34	0.58	0.62	0.67	0.58	0.62	0.58	0.67	0.48	0.33	0.26	0.39
HKG	0.57	—	0.72	0.41	0.75	0.63	0.73	0.60	0.61	0.80	0.74	0.65	0.46	0.33	0.54
IDN	0.55	0.35	—	0.51	0.53	0.60	0.35	0.55	0.56	0.49	0.68	0.53	0.42	0.25	0.48
JPN	0.67	0.69	0.72	—	0.71	0.71	0.78	0.72	0.69	0.75	0.69	0.69	0.44	0.43	0.57
KOR	0.78	0.84	0.82	0.72	—	0.79	0.83	0.84	0.84	0.76	0.77	0.79	0.51	0.48	0.66
MYS	0.79	0.80	0.64	0.71	0.78	—	0.71	0.73	0.82	0.62	0.74	0.75	0.55	0.52	0.67
PHL	0.66	0.78	0.58	0.55	0.59	0.79	—	0.83	0.76	0.73	0.74	0.69	0.52	0.48	0.63
SGP	0.79	0.84	0.86	0.59	0.78	0.84	0.78	—	0.80	0.73	0.82	0.81	0.63	0.53	0.73
TWN	0.78	0.85	0.78	0.70	0.84	0.84	0.90	0.90	—	0.74	0.84	0.80	0.57	0.51	0.72
THA	0.58	0.60	0.63	0.43	0.52	0.60	0.50	0.69	0.60	—	0.68	0.56	0.34	0.28	0.45
VNM	0.33	0.50	0.37	0.31	0.27	0.36	0.39	0.27	0.43	0.47	—	0.36	0.12	0.11	0.21
EA	0.71	0.61	0.69	0.47	0.65	0.71	0.72	0.70	0.69	0.66	0.73	0.64	0.39	0.34	0.51
Non-EA	0.38	0.56	0.50	0.35	0.41	0.63	0.52	0.60	0.49	0.47	0.54	0.43	0.46	0.41	0.46
USA	0.46	0.56	0.48	0.46	0.50	0.75	0.74	0.72	0.54	0.59	0.49	0.53	0.55	—	0.55
World	0.52	0.60	0.62	0.40	0.51	0.68	0.65	0.66	0.60	0.58	0.68	0.54	0.46	0.39	0.48

Table 5 (continued)

Final goods

From \ To	CHN	HKG	IDN	JPN	KOR	MYS	PHL	SGP	TWN	THA	VNM	EA	Non-EA	USA	World
CHN	—	0.53	0.37	0.64	0.36	0.36	0.29	0.41	0.33	0.41	0.31	0.49	0.66	0.73	0.60
HKG	0.22	—	0.24	0.49	0.20	0.35	0.27	0.39	0.31	0.18	0.19	0.26	0.51	0.67	0.41
IDN	0.10	0.38	—	0.15	0.10	0.17	0.33	0.25	0.09	0.24	0.24	0.17	0.40	0.62	0.26
JPN	0.31	0.30	0.27	—	0.26	0.28	0.22	0.27	0.30	0.25	0.29	0.29	0.56	0.57	0.42
KOR	0.21	0.15	0.17	0.26	—	0.21	0.15	0.16	0.16	0.24	0.22	0.21	0.49	0.52	0.34
MYS	0.11	0.19	0.18	0.24	0.13	—	0.19	0.22	0.15	0.22	0.21	0.18	0.38	0.47	0.26
PHL	0.24	0.19	0.35	0.38	0.30	0.15	—	0.15	0.19	0.21	0.21	0.24	0.46	0.51	0.32
SGP	0.21	0.15	0.13	0.37	0.21	0.15	0.19	—	0.19	0.25	0.17	0.18	0.36	0.47	0.25
TWN	0.21	0.15	0.21	0.29	0.15	0.16	0.10	0.10	—	0.26	0.15	0.19	0.42	0.48	0.27
THA	0.32	0.38	0.33	0.51	0.33	0.29	0.48	0.29	0.35	—	0.29	0.37	0.63	0.69	0.50
VNM	0.28	0.48	0.33	0.52	0.58	0.29	0.55	0.35	0.47	0.35	—	0.41	0.77	0.82	0.62
EA	0.24	0.38	0.25	0.47	0.28	0.25	0.24	0.26	0.27	0.29	0.25	0.31	0.58	0.65	0.46
Non-EA	0.22	0.40	0.20	0.27	0.20	0.22	0.21	0.23	0.23	0.19	0.29	0.23	0.39	0.41	0.36
USA	0.34	0.41	0.27	0.40	0.34	0.20	0.16	0.26	0.32	0.28	0.31	0.33	0.38	—	0.37
World	0.23	0.38	0.23	0.36	0.24	0.24	0.23	0.25	0.25	0.25	0.26	0.28	0.43	0.49	0.39

Note: Abbreviations: CHN = China; HKG = Hong Kong; IDN = Indonesia; JPN = Japan; KOR = Korea; MYS = Malaysia; PHL = the Philippines; SGP = Singapore; TWN = Taiwan; THA = Thailand; VNM = Vietnam; EA = East Asia. See Table 4 for more details on the data source and the definition of the share for each type of goods.

3. Empirical framework and data

To analyze the effects of external and domestic macroeconomic shocks on an East Asian economy, I use a vector autoregression with block exogeneity (hereafter VARX). As well known in the VAR literature, a VARX is suitable for analyzing the effects of shocks on a small open economy (SOE).[4] The details of this method are described below.

Consider a VAR model comprising two blocks: one containing variables of relatively large countries (block 1) and the other containing variables of a SOE (block 2). Given the small size of the SOE compared to the larger economies, we can reasonably assume that the variables in block 2 do not affect those in block 1. In other words, the variables in block 1 are considered exogenous to those in block 2. With this assumption, we can write the structural form of the VARX model as follows.

$$\begin{bmatrix} A_{11} & 0 \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} B_{11}(L) & 0 \\ B_{21}(L) & B_{22}(L) \end{bmatrix} \begin{bmatrix} y_{1t-1} \\ y_{2t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{bmatrix} \quad (1)$$

Here, t denotes time, and y_{1t} and y_{2t} are column vectors of the variables in blocks 1 and 2, respectively. A_{ij} are coefficient matrices and $B_{ij}(L)$ are polynomials composed of matrices of coefficients in the lag operator. ϵ_{1t} and ϵ_{2t} are column vectors of shocks in blocks 1 and 2, respectively, and satisfy $(\epsilon'_{1t}, \epsilon'_{2t})' \sim (0, I)$, where I is an identity matrix.

It can be shown that in the structural VARX model given in (1), the impacts of ϵ_{1t} on y_{1t} and the impacts of ϵ_{2t} on y_{2t} are captured by the inverse matrices of A_{11} and A_{22}, respectively. We assume that A_{11} and A_{22} have a recursive structure, which is justified later. Based on this assumption, the matrix

$$A \equiv \begin{bmatrix} A_{11} & 0 \\ A_{21} & A_{22} \end{bmatrix}$$

and its inverse also exhibit a recursive structure. The latter can be identified as the Cholesky decomposition of the covariance matrix of the residuals $(u'_{1t}, u'_{2t})'$ in the following reduced form of the VARX in (1):

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} D_{11}(L) & 0 \\ D_{21}(L) & D_{22}(L) \end{bmatrix} \begin{bmatrix} y_{1t-1} \\ y_{2t-1} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix} \quad (2)$$

The reduced-form VAR in (2) can be estimated directly using ordinary least squares (OLS). From its estimation result and the recursive structure noted above, we can identify A (and thus A_{11} and A_{22}), $B_{ij}(L)$, and the structural shocks $(\epsilon_{1t}, \epsilon_{2t})'$ in the structural model (1). Once the structural VAR is identified, conventional analyses, such as impulse response functions (IRFs) and variance decomposition, can be conducted to examine the transmission of shocks to the SOE.

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4 See, e.g., Allegret, Couharde, and Guillaumin (2012), Maćkowiak (2007), Sato, Zhang, and McAleer (2011), and Vu and Nakata (2018).

Variables and shocks in the VARX

I include three variables in block 1: the real GDPs of the USA, China, and Japan. In other words, $y_{1t} = (gdp_{USA,t}, gdp_{CHN,t}, gdp_{JPN,t})'$. The rationale for including the outputs of these three countries in the VAR is straightforward from the analysis in the previous section: they are the largest trade partners for most East Asian countries, and our primary interest lies in examining how output shocks originating from them are transmitted to an East Asian country.

The justification for treating outputs of the USA, China, and Japan as exogenous to an East Asian SOE are twofold. First, the economic sizes of these three countries far exceed those of any East Asian country (except China and Japan). Evidence for this is presented in Table 6. For example, in 2000 Thailand' GDP was 1/61 of the USA's, 1/10 of China's, and 1/26 of Japan's. By 2020, these ratios had shifted to 1/45, 1/28, and 1/14, respectively. Similarly, the corresponding numbers for Taiwan were 1/43, 1/7, and 1/18 in 2000, and 1/31, 1/19, and 1/10 in 2020, respectively. Second, including outputs of the USA, China, and Japan in the exogenous block helps us preclude unrealistic results that can sometimes arise in conventional VAR models, such as a shock originating from a small country significantly affecting variables of a much larger country.[5]

In block 2 of the VARX, I include four variables: real exports, real imports, real GDP, and the real effective exchange rate (REER); thus, $y_{2t} = (exp_{i,t}, imp_{i,t}, gdp_{i,t}, reer_{i,t})'$, where i denotes an East Asian country. In addition to the fact that these are variables of intrinsic interest, the inclusion of them is motivated by theoretical considerations, specifically the export function and the import function in open economy macroeconomic theory. Furthermore, the inclusion of these variables, especially exports and imports of East Asian countries, enables investigation of the role of intra-regional trade in intermediate goods in the international transmission of shocks in East Asia. This aspect will be elaborated on in the following section.

Given the variables y_{1t} and y_{2t} and the recursive structure of the matrices A_{11} and A_{22} explained above, the structural shocks in the two blocks of the VARX can be labeled as follows: USA output shock, Chinese output shock, Japanese output shock, and country i's export shock, import shock, output shock, and REER shock. As quarterly data are employed in this paper (see below), the recursive structure assumed for the matrices A_{11} and A_{22} is plausible. Except for the REER, which is ordered last, all other variables represent quantities that, as is widely understood, adjust slowly. Therefore, within a quarter, they can be reasonably assumed not to respond to shocks originating from the variables ordered after them.

[5] Indeed, in an earlier stage of this study, I estimated a conventional VAR and obtained such results.

Table 6: GDP of East Asian countries relative to the USA

Country	2000	2010	2020	2023
United States	1.000	1.000	1.000	1.000
China	0.172	0.392	0.628	0.669
Hong Kong SAR, China	0.012	0.015	0.015	0.014
Japan	0.423	0.376	0.323	0.309
Korea, Rep.	0.058	0.077	0.082	0.080
Indonesia	0.034	0.048	0.063	0.065
Malaysia	NA	0.017	0.020	0.021
Philippines	0.010	0.013	0.018	0.019
Singapore	0.011	0.016	0.018	0.018
Thailand	0.017	0.022	0.022	0.022
Taiwan, China	0.023	0.030	0.033	0.033
Vietnam	0.006	0.010	0.015	0.015

Note: The GDP of the USA is normalized to one. GDP measured at constant 2010 US$ is used in the calculation.
Source: Author's calculations based on data from the World Bank's Global Economic Monitoring database.

Data and estimation of the VARX

I employ in this paper a quarterly dataset spanning from 2000Q1 to 2019Q4, covering the following 11 East Asian economies: China, Hong Kong, Indonesia, Japan, Korea, Malaysia, the Philippines, Singapore, Taiwan, Thailand, and Vietnam. Data are primarily obtained from the World Bank's Global Economic Monitoring (GEM) database, with some exceptions: GDP data for Malaysia in the early 2000s are sourced from the GVAR modeling website created by L. Vanessa Smith, and trade data for Vietnam are sourced from UNCTAD Statistics.

The data for all seven variables in the VARX are seasonally adjusted. For variables other than the REER, the data are measured in constant local currency prices and converted to 2010 US dollars. For exports and imports, I use merchandise (or goods) data because services data are not available. The REER is defined such that an increase implies a real appreciation of the home currency.

The reduced-form VARX is estimated with four lags and a constant term for each of the following nine economies: Hong Kong, Indonesia, Korea, Malaysia, the Philippines, Singapore, Taiwan, Thailand, and Vietnam. The data on all seven variables are transformed into the first differences of their logarithms and multiplied by 100 before being used in estimation. However, in the IRFs reported later, these variables are converted back to levels.

For Japan and China, considering the sizes of their economies as noted above, I treat them as large countries, similar to the USA, and estimate a conventional recursive VAR model containing six variables, i.e., $y_t = (gdp_{USA,t}, gdp_{CHN,t}, gdp_{JPN,t}, exp_{j,t}, imp_{j,t}, reer_{j,t})'$ where $j = CHN, JPN$. This model is also estimated with four lags and a constant term.[6] Note that this recursive VAR can be considered a special case of VARX, in which block 2 ceases to exist.

4. Empirical results and analysis

This section presents the effects of shocks on East Asian economies based on the IRFs and the variance decomposition results obtained from the estimated VAR models described in the previous section. The results are depicted in Figures 1 and 2 and Table 7. In Figures 1 and 2, a shock is quantified as a 1% increase at impact in the variable from which the shock originates.

Responses of outputs of the USA, China, and Japan to their output shocks

Figure 1 shows the IRFs of GDP for the USA, China, and Japan to their respective output shocks. These are the IRFs for block 1 of the VARX. A USA output shock, which increases its GDP at impact by 1%, raises GDP of China and Japan by approximately 0.4-0.5% at impact. The effects are statistically significant and persistent in all three countries. The increases of GDP after 3 years are 1.8%, 0.8%, and 1.6% in the USA, China, and Japan, respectively.

A Chinese output shock raises the GDP of China by 1% at impact, by definition, and further at longer horizons. This shock also increases GDP of Japan significantly and persistently. However, the effect of this shock on GDP of the USA is short-lived and statistically insignificant.

A Japanese output shock raises its GDP persistently. The shock significantly increases the USA' GDP at 2-4 quarter the horizons but reduces China's GDP after about a year. The latter result appears somewhat puzzling.

Responses of East Asian economies to external shocks

Now let us turn to the IRFs for the East Asian countries, which are shown in Figure 2. These are the IRFs for block 2 of the VARX.

In response to a USA output shock, which can be interpreted as an external demand shock to East Asia, exports and imports of most East Asian countries increase significantly at certain horizons. GDP also rises significantly in all countries except Korea and Indonesia. The increases in both exports and imports of each East Asian country are consistent with the region's trade structure discussed in Section 2. The underlying mechanism, clarified by Vu (2016), can be summarized as follows. The increase in

[6] For China, the sample starts from 2005Q1 because data on its exports and imports are only available from this period.

the GDP of the USA, one major trade partner of many East Asian countries, raises demand for exports of several East Asian countries. Since a significant portion of these exports comprises final goods produced from intermediate goods —which are, in turn, produced and traded within a network of many East Asian countries—the increase in demand for and thus production of the final goods results in increased production of and trade in intermediate goods by all East Asian countries participating in the network. The overall result, as observed, is an increase in exports and imports across all East Asian countries.

A Chinese output shock causes significant increases in exports (at certain horizons) in all East Asian countries, except Singapore and the Philippines. A similar effect of this shock on GDP of East Asian countries is also observed.

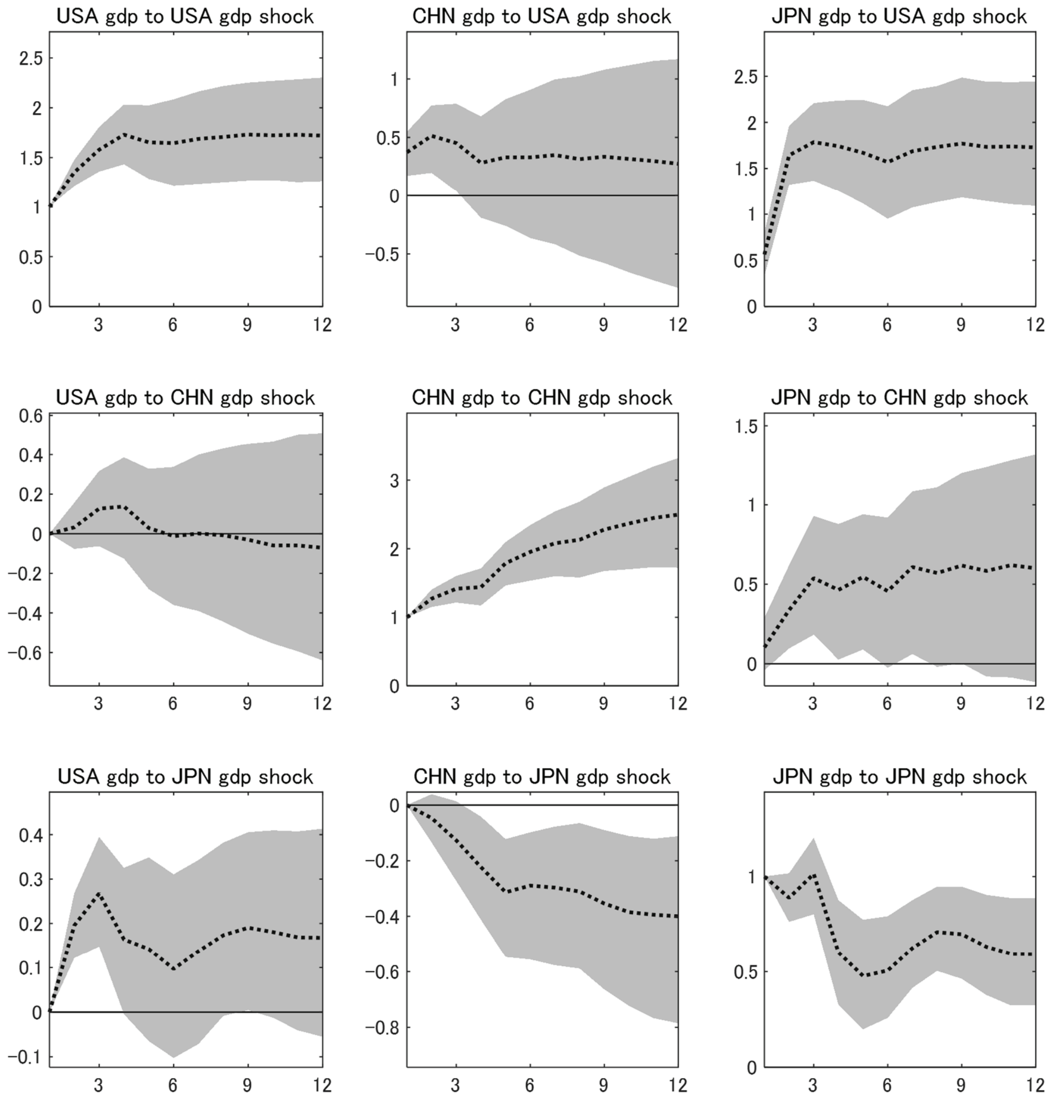
A Japanese output shock significantly, though only temporarily, raises exports and GDP in the Philippines and Thailand (countries other than Japan) while reducing Korea's exports. The result of either negative or insignificant effects of the Japanese output shock on exports and outputs of the other East Asian countries can be partly explained from the aforementioned result that this shock reduces GDP of China, the largest importer of intermediate goods in the region, which counteracts the positive network effects. The more pronounced effects of Chinese output shocks on East Asian countries compared to Japanese output shocks suggest a growing influence of the Chinese economy in East Asia and increasing integration of the region's economies with China. A similar finding is reported in Inoue, Kaya, and Oshige (2015).

Responses of East Asian economies to domestic shocks

We now consider the responses of East Asian economies to their internal shocks. A home output shock raises imports in all countries except Thailand. This result is consistent with the import function in open economy macroeconomic theory, including the textbook Mundell-Fleming model. An export shock raises both exports and imports in most countries. This co-movement of exports and imports in response to an export shock aligns with the trade dynamics of intermediate goods in East Asian countries. The export shock also significantly boosts GDP in all countries except Japan.

Although not shown in Figure 2, a REER shock, defined as a real appreciation of the home currency, significantly reduces exports and imports in China, Hong Kong, Japan, Singapore, and Taiwan, but increases these variables in Korea and the Philippines. These contrasting results are challenging to explain using traditional open economy macroeconomic theories such as the Mundell-Fleming model, but can be understood within the framework of a NOEM model with trade in intermediate goods.

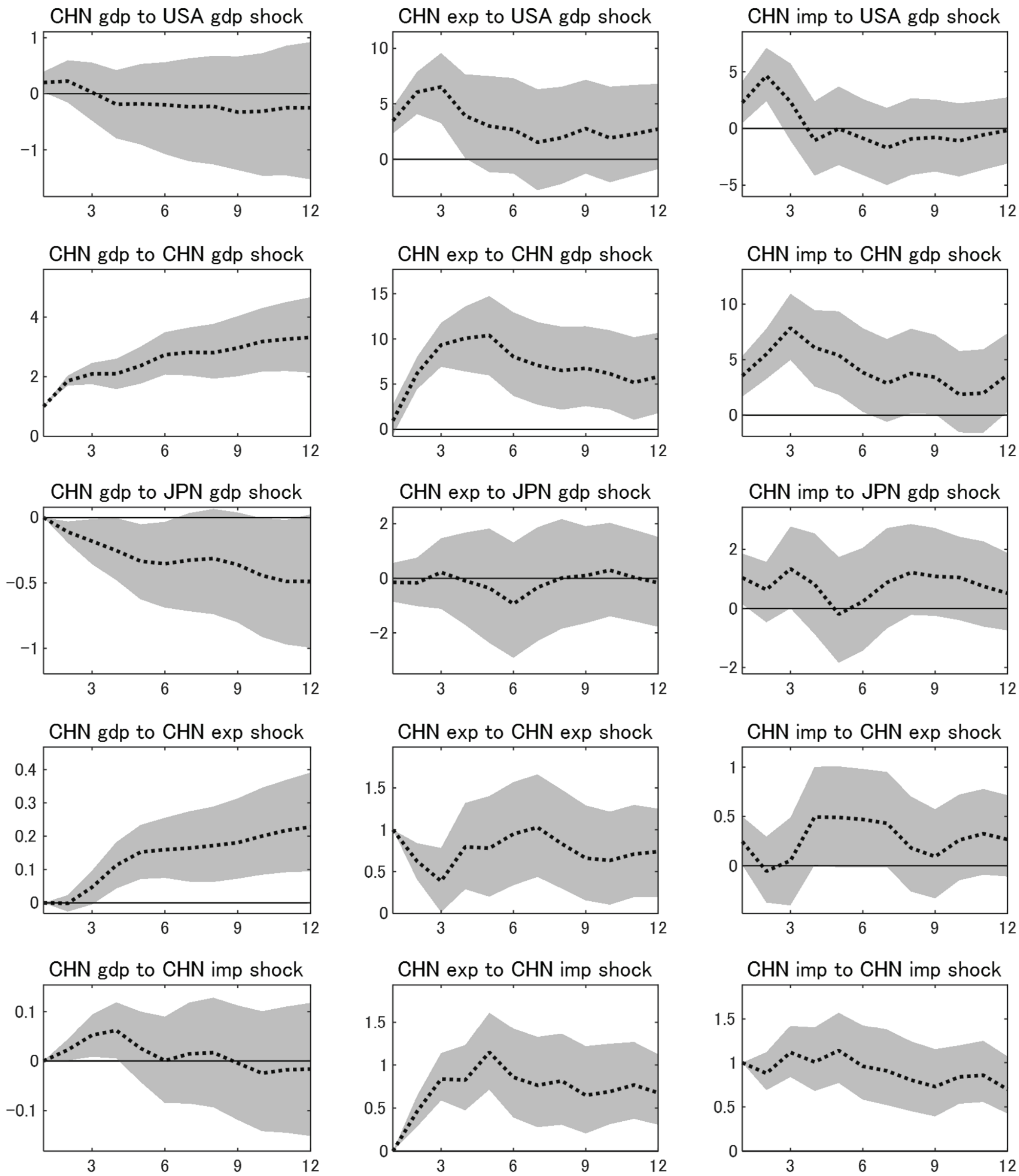
Figure 1: Responses of GDP of the USA, China, and Japan to output shocks originating from the USA, China, and Japan



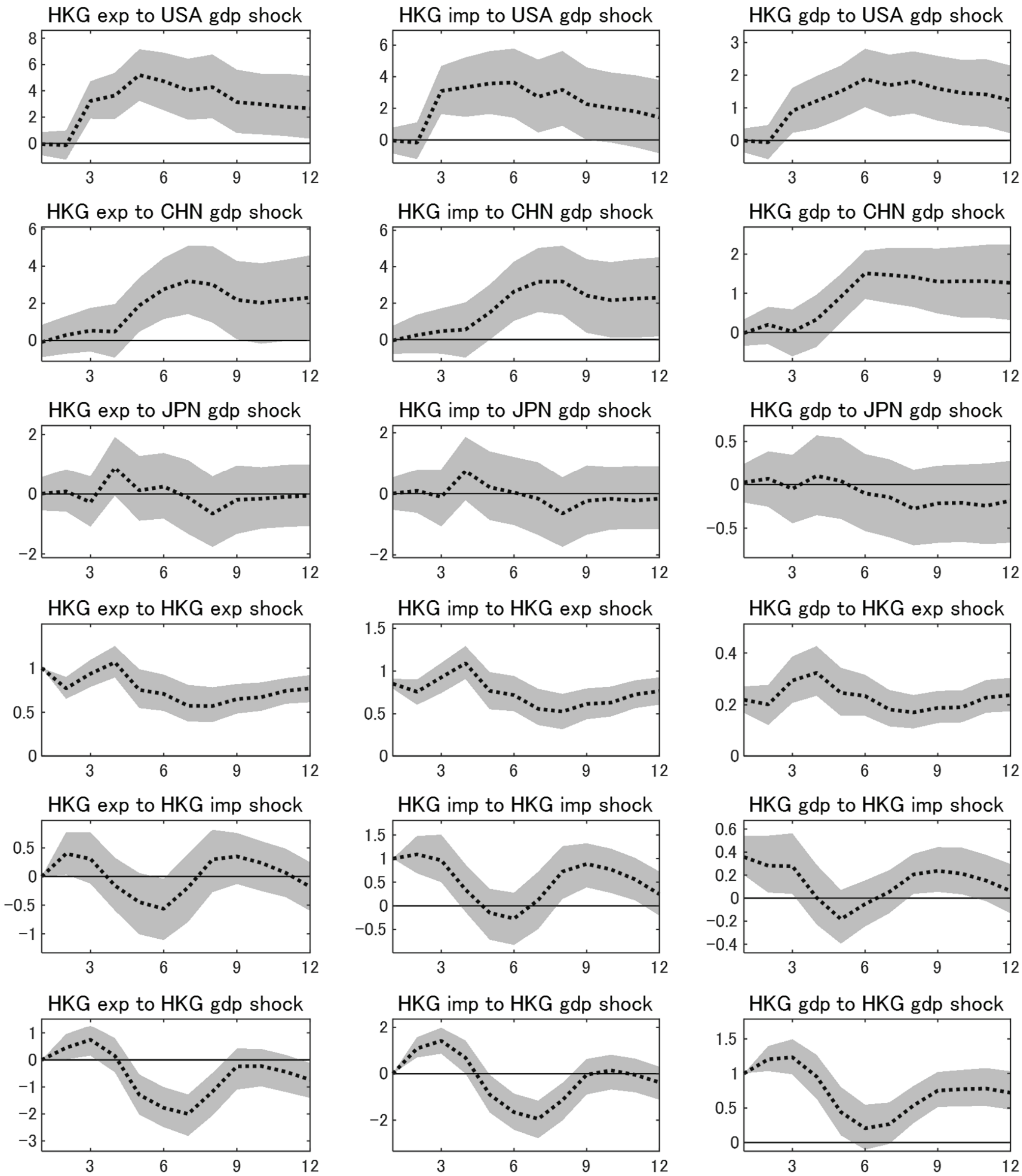
Note: A shock is defined as a 1% increase in the variable from which it originates. The horizontal axis displays quarters, with the shock occurring in the first quarter, and the vertical axis displays percentage changes. Shaded areas indicate the 68% error bands, and dotted lines represent the medians, which are calculated using a bootstrap method. Source: Author's calculations based on the VAR model and data described in Section 3.

Figure 2: Responses of East Asian economies to external and domestic shocks

China



Hong Kong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HKG gdp to USA gdp shock
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HKG exp to JPN gdp shock
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HKG exp to HKG exp shock
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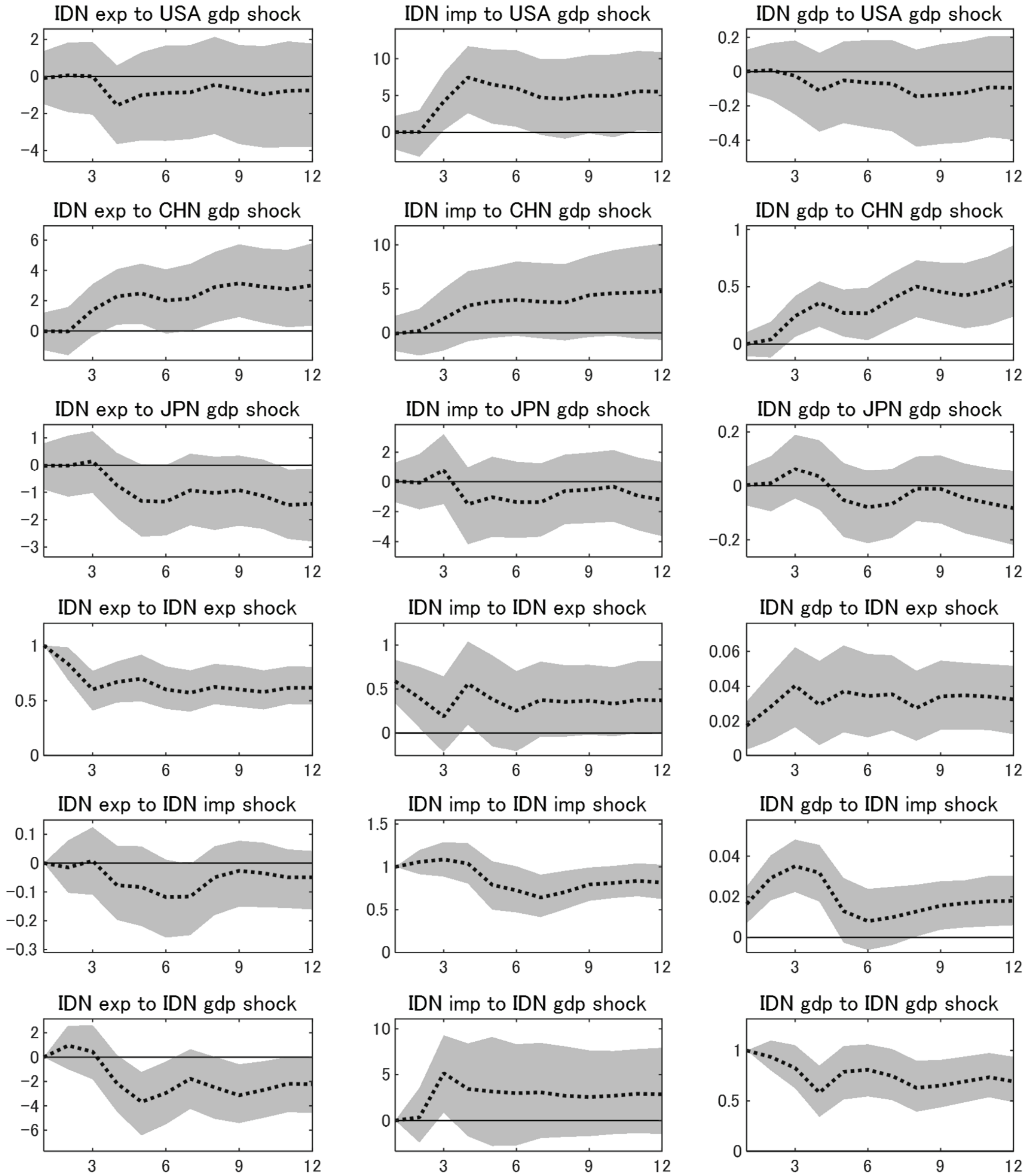
3
6
9
12

Indonesia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IDN exp to JPN gdp shock
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IDN gdp to JPN gdp shock
IDN exp to IDN exp shock
IDN imp to IDN exp shock
IDN gdp to IDN exp shock
IDN exp to IDN imp shock
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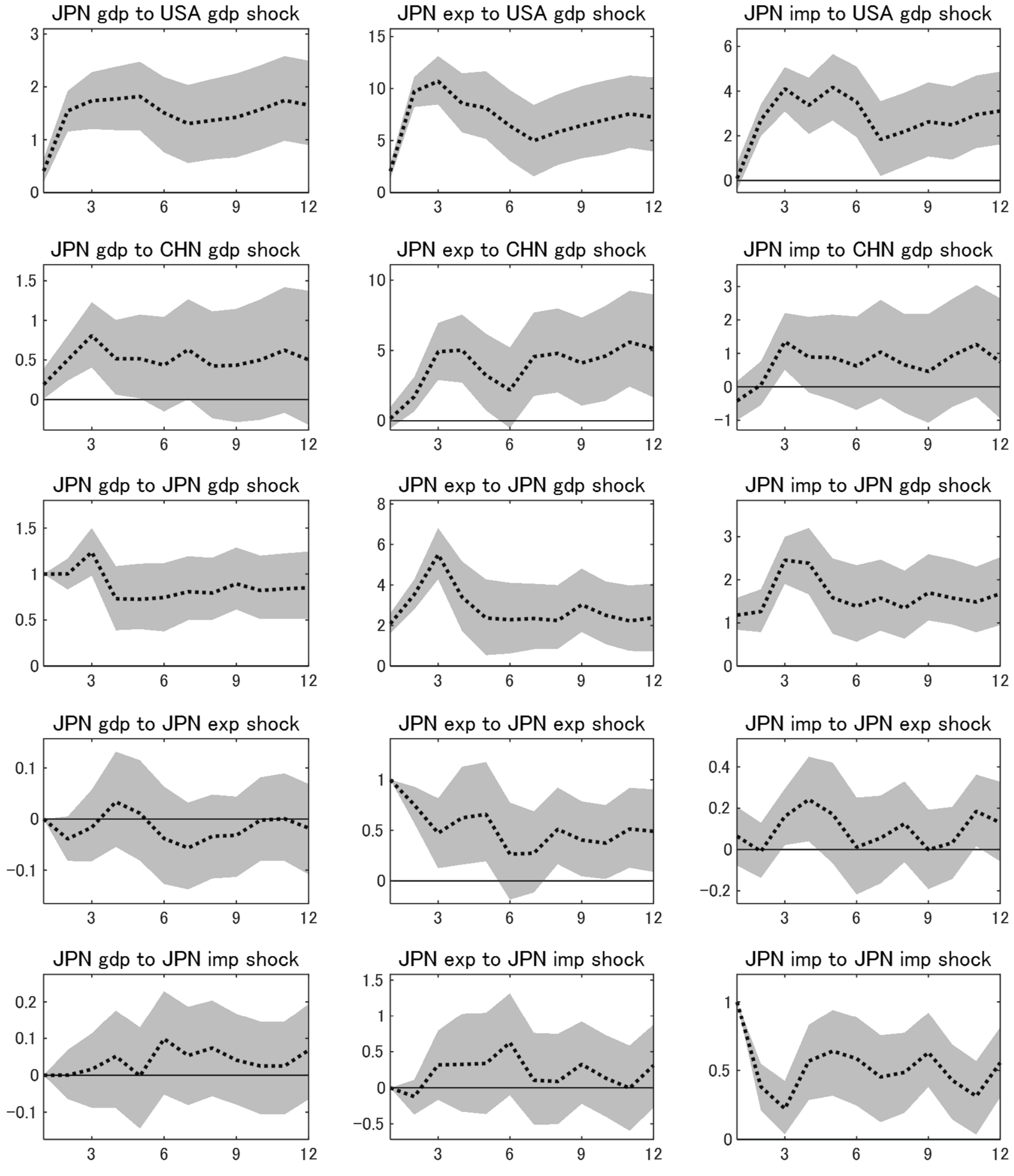
Japan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JPN exp to USA gdp shock
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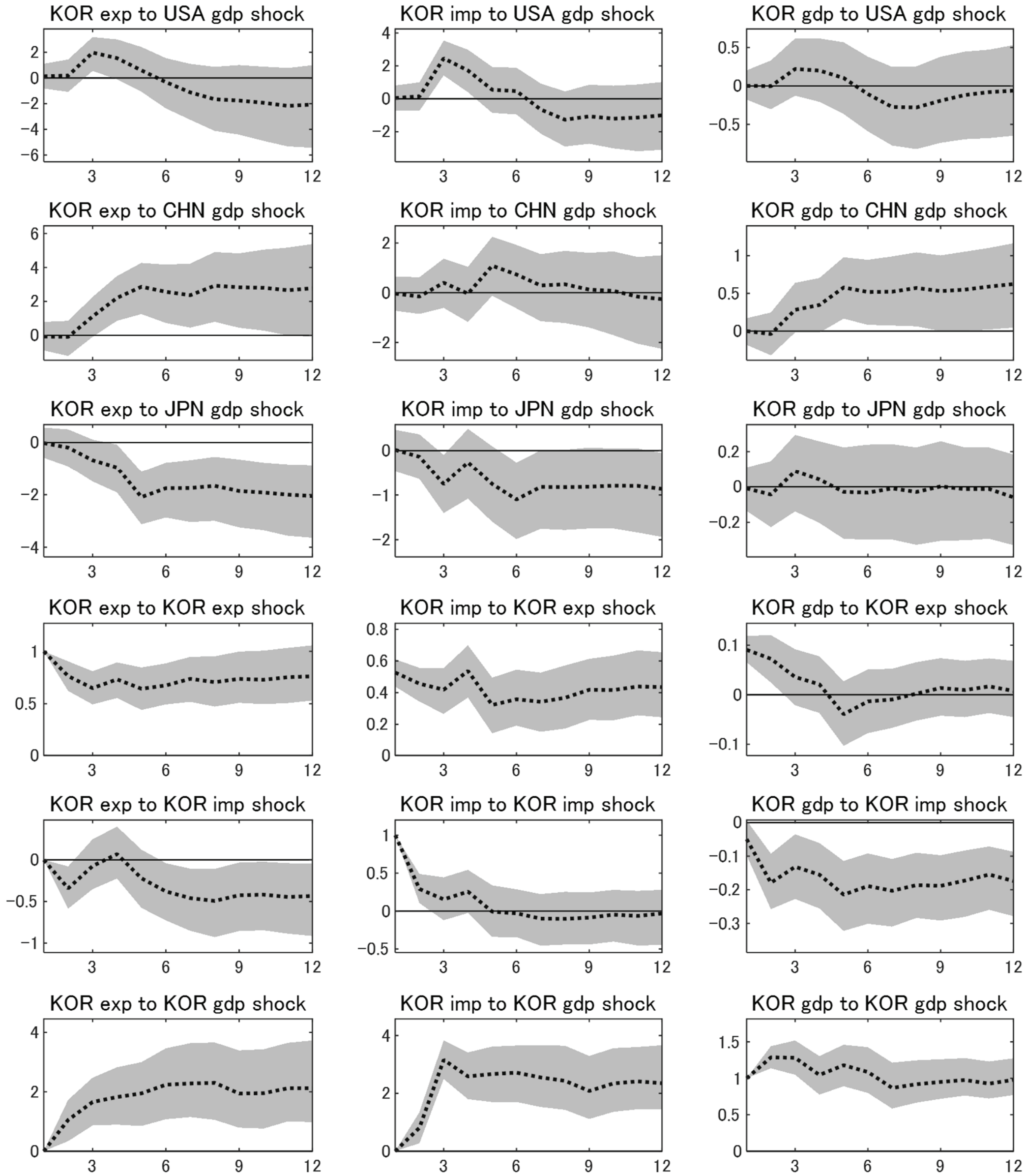
Korea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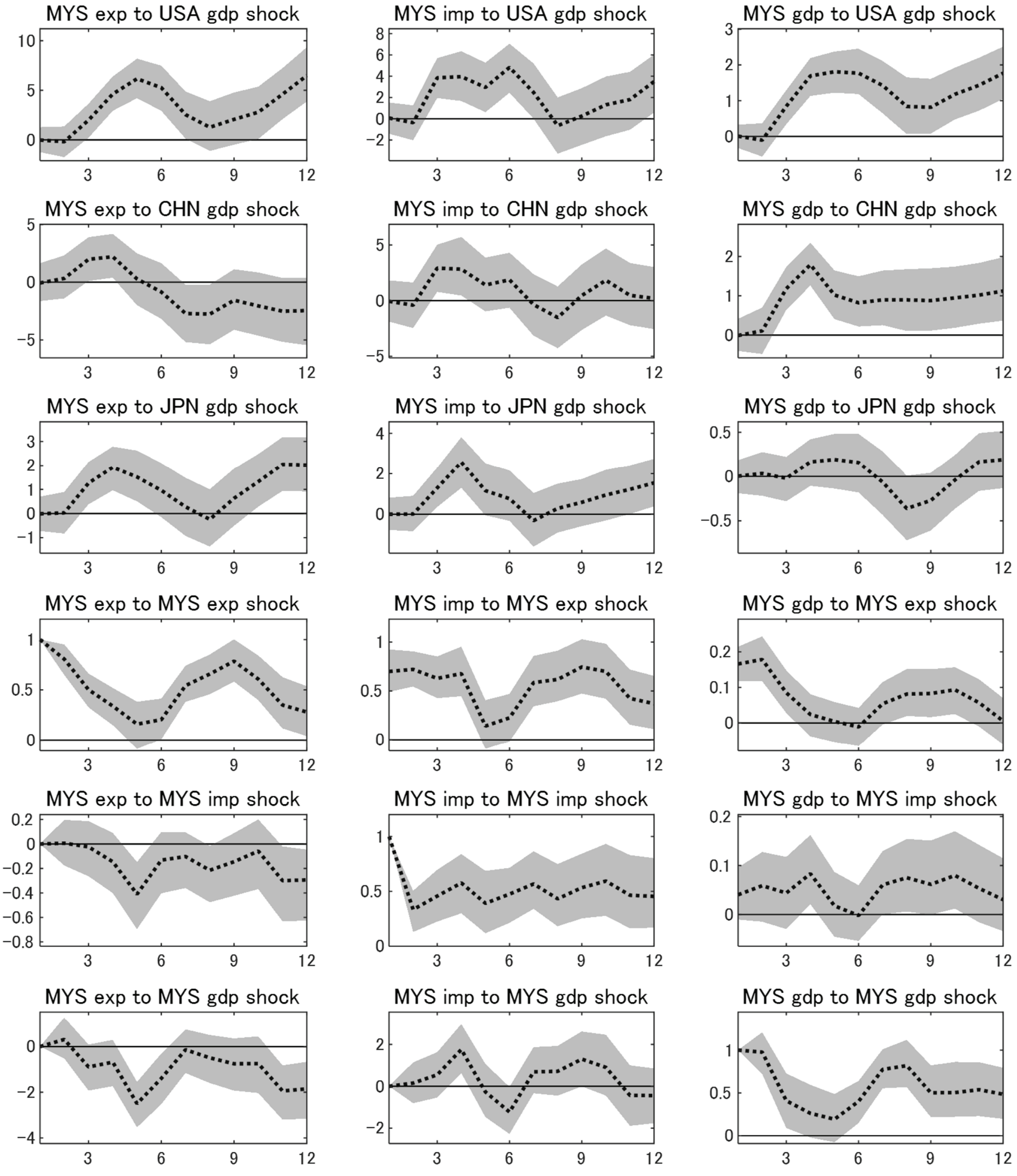
Malaysia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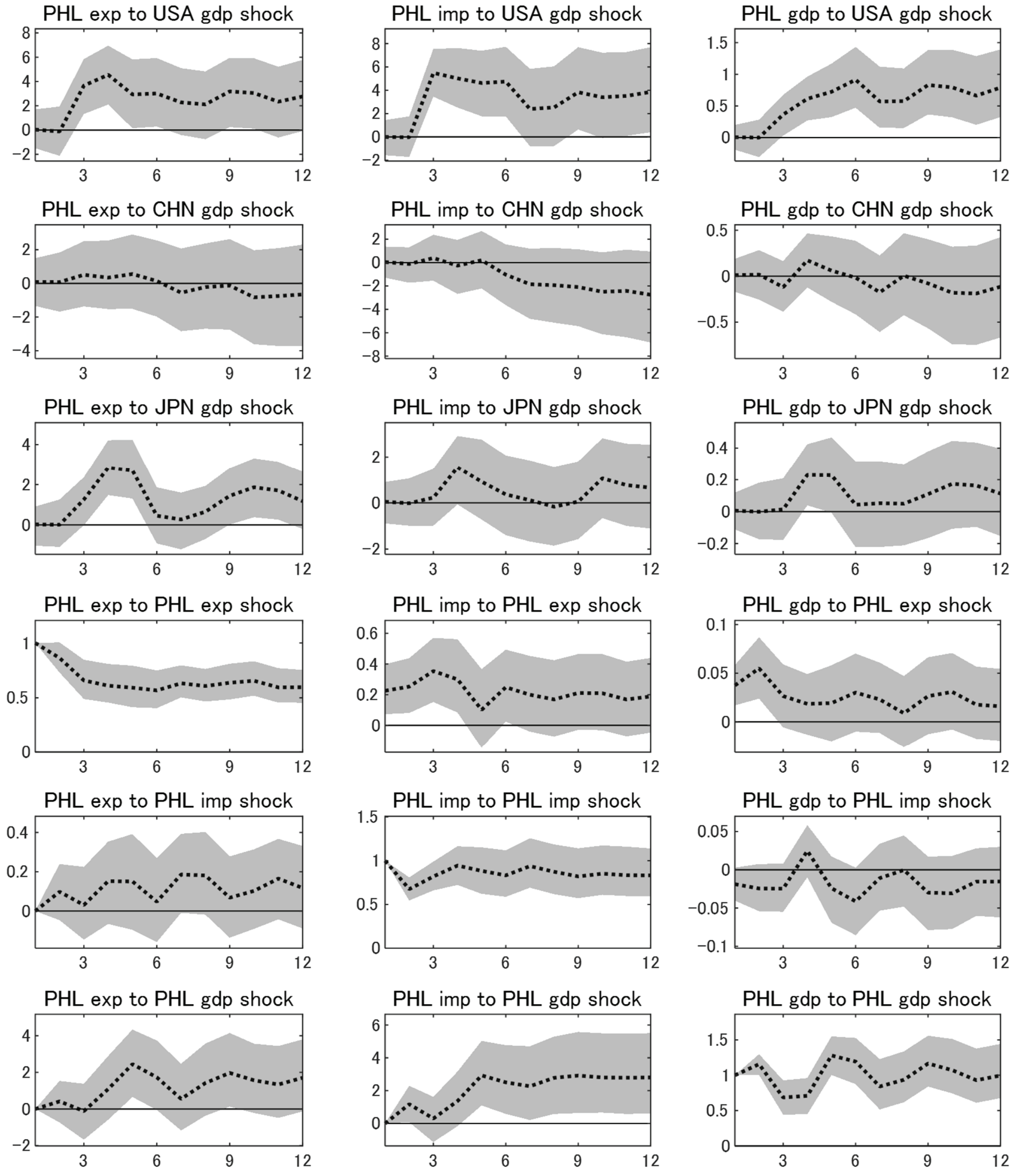
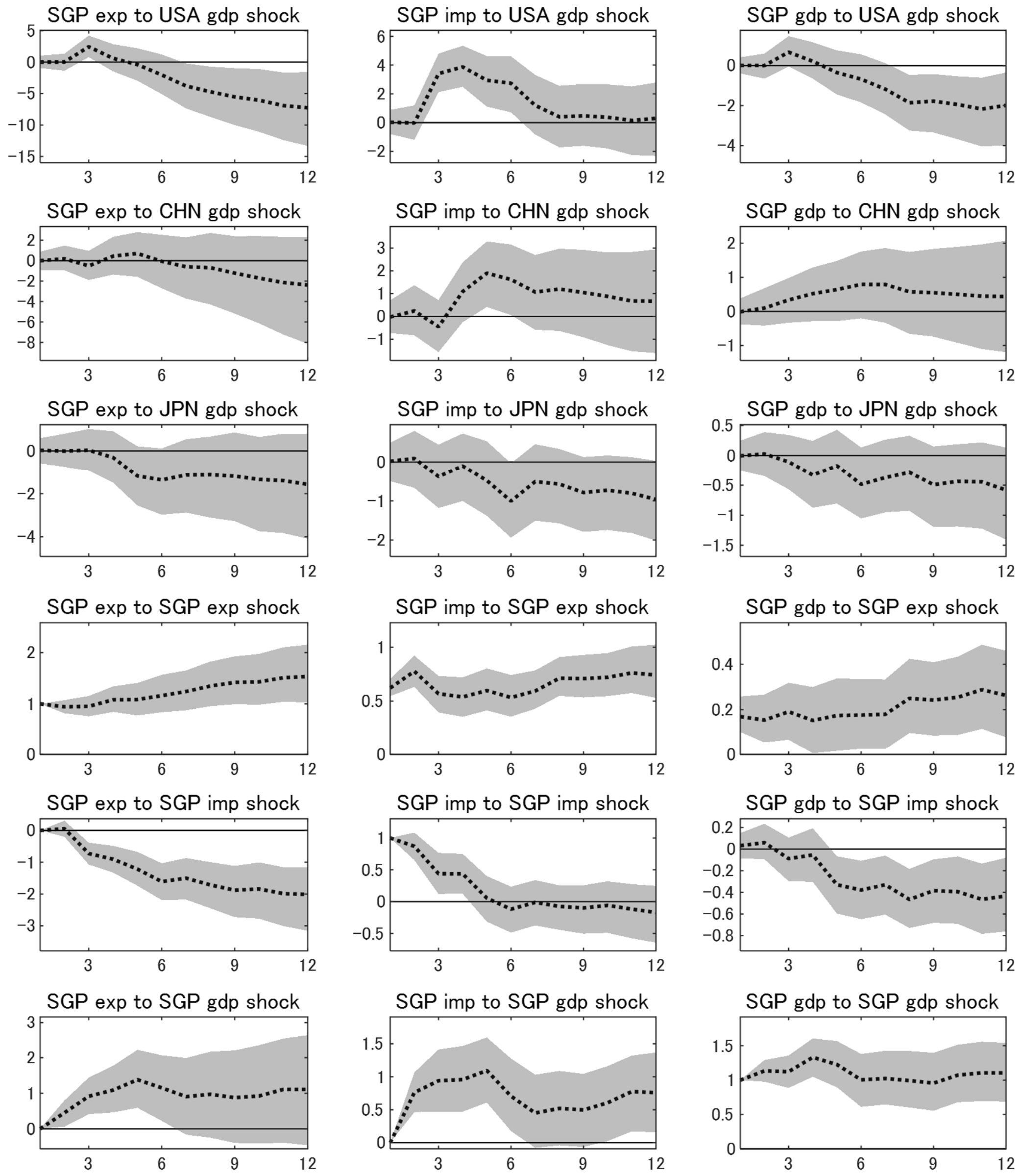
Philippines



Singapore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SGP imp to USA gdp shock
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SGP exp to SGP exp shock
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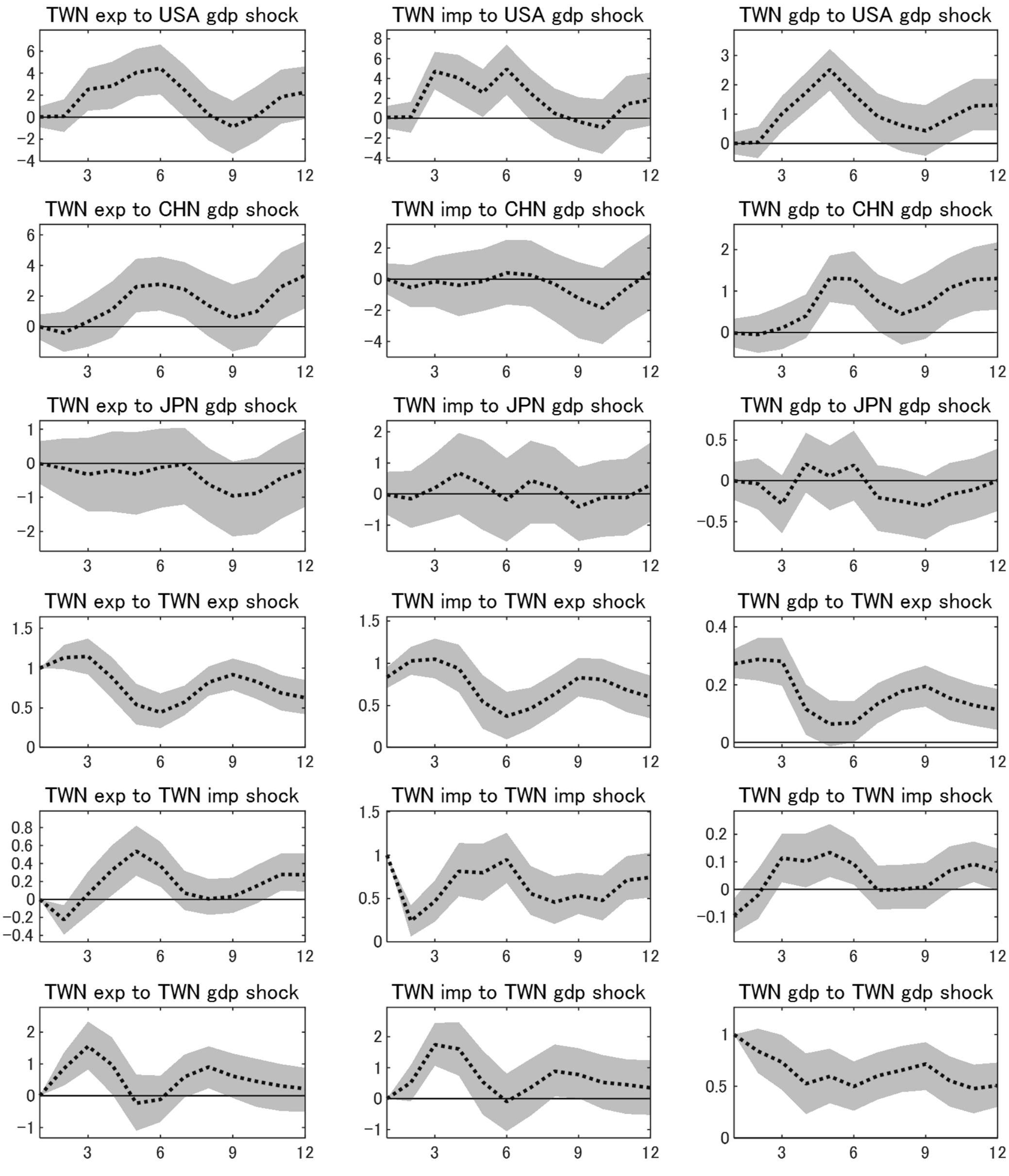
SGP gdp to SGP gdp shock

Taiwan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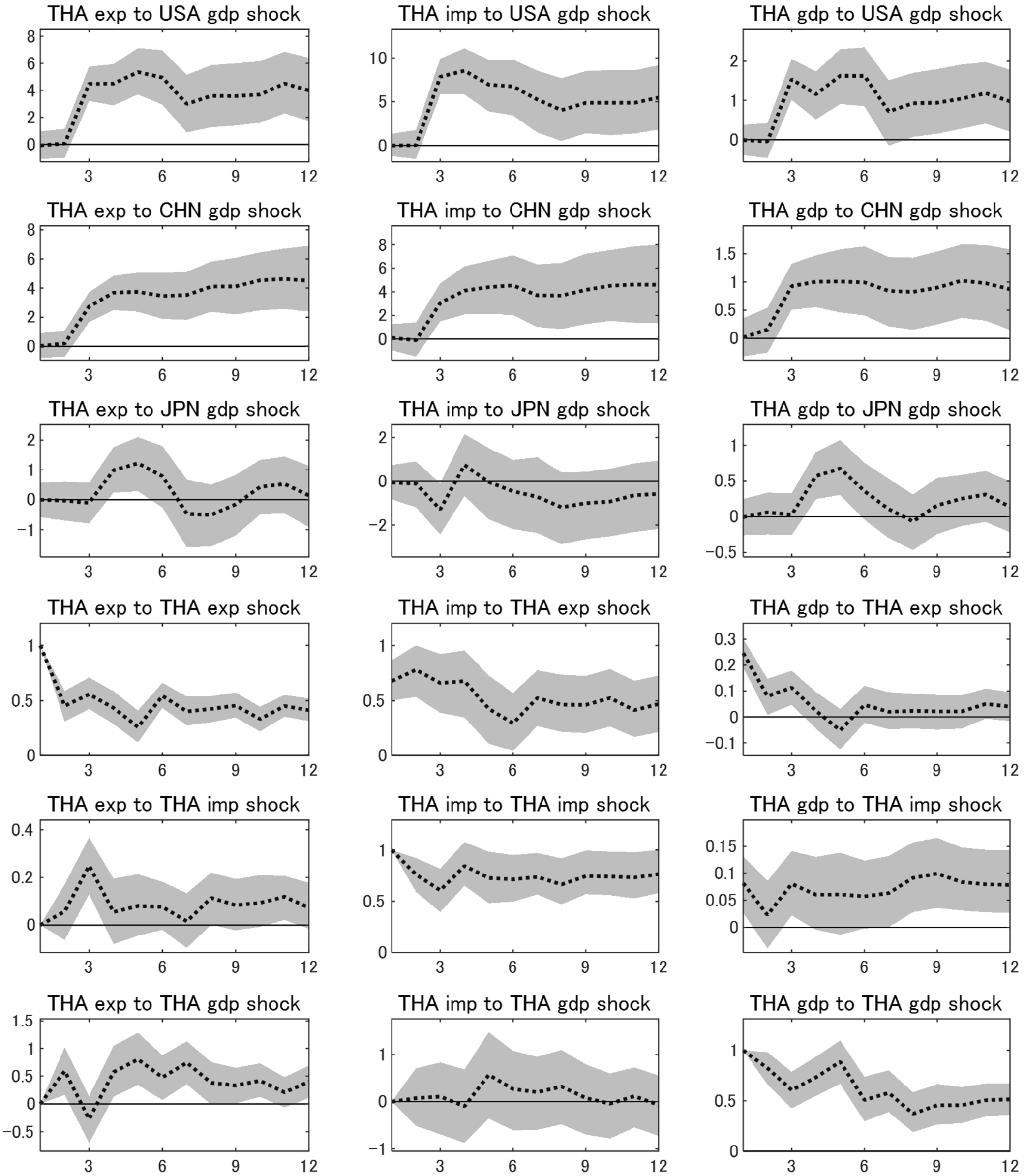
Thailand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THA exp to CHN gdp shock
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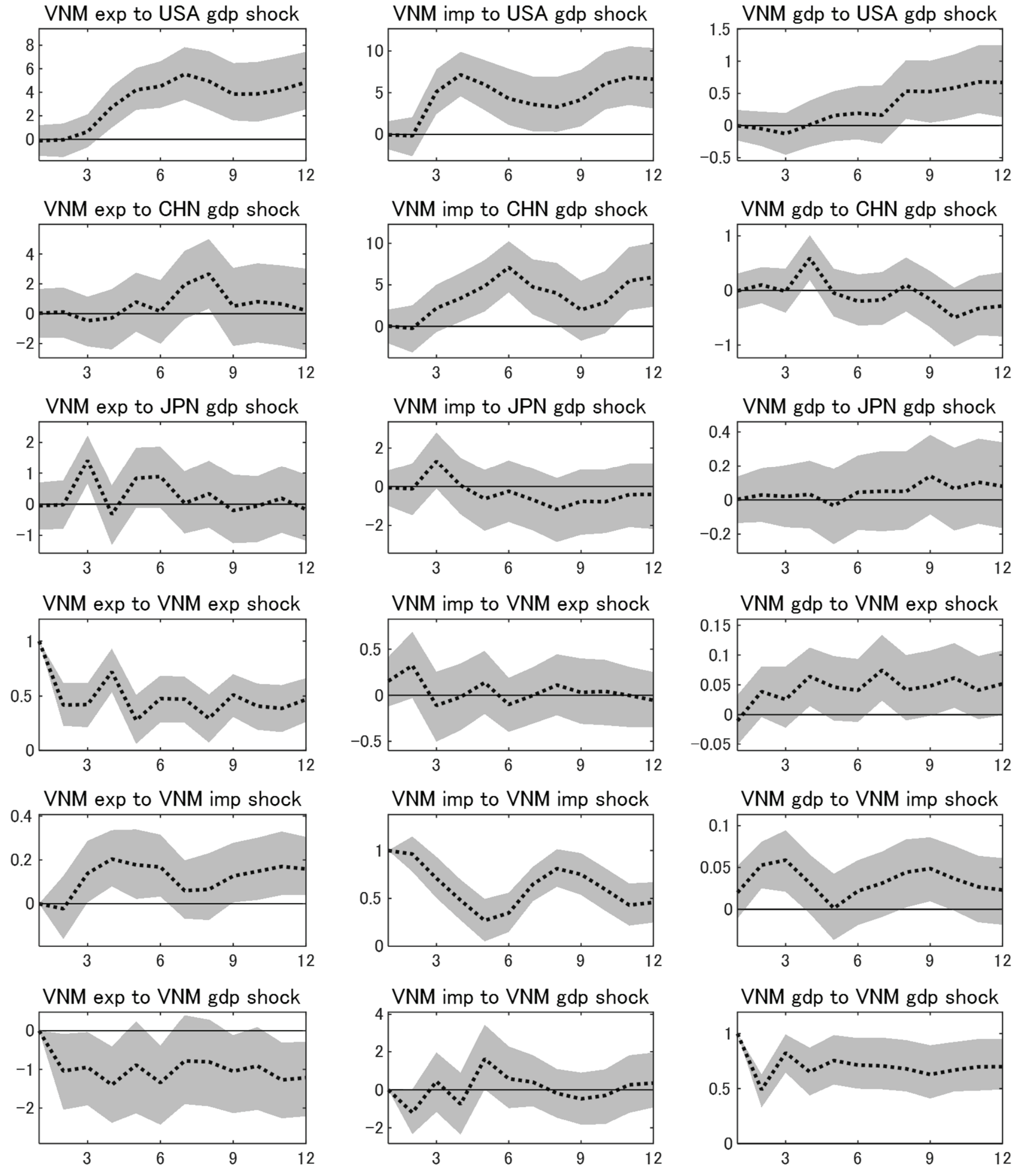
THA gdp to CHN gdp shock
THA exp to JPN gdp shock
THA imp to JPN gdp shock
THA gdp to JPN gdp shock
THA exp to THA exp shock
THA imp to THA exp shock
THA gdp to THA exp shock
THA exp to THA imp shock
THA imp to THA imp shock
THA gdp to THA imp shock
THA exp to THA gdp shock
THA imp to THA gdp shock
THA gdp to THA gdp shock

Vietnam



Note: Notation: *exp* is real exports; *imp* is real imports; *reer* is the real effective exchange rate (an increase in which indicates a real appreciation of the home currency). A shock is defined as a 1% increase in the variable from which the shock originates. The horizontal axis displays quarters, with the shock occurring in the first quarter, and the vertical axis displays percentage changes. Shaded areas indicate the 68% error bands, and dotted lines represent the medians, which are calculated using a bootstrap method. Source: Author's calculations based on the VAR model and data described in Section 3.

Variance decomposition results

Table 7 displays the variance decomposition for the four variables—GDP, exports, imports, and the REER—for each East Asian country in our study. Overall, at short horizons (e.g., 1 quarter), the majority of variation in each variable is attributable to shocks to itself. This is especially true for GDP and the REER. However, at longer horizons (e.g., 12 quarters), other shocks may also play a role. We also observe that, export shocks and external output shocks account for a significant proportion of the variance of imports in most East Asian countries. This result can be interpreted as being closely related to the East Asian trade structure, where intermediate goods are extensively traded intra-regionally.

Trade structure and macroeconomic interdependence in East Asia: More systematic evidence

Thus far, I have examined the VAR results for each country to explore how intra-regional trade in intermediate goods is related to macroeconomic interdependence between East Asian countries. In this subsection, I will utilize the cross-country information from the variance decomposition results in a more systematic way to further investigate this issue.

I posit the following two conjectures. First, as intermediate goods are imported to produce exported goods (which also aligns with the IRF results discussed above, where a positive export shock raises both exports and imports in many East Asian countries), a higher share of intermediate goods in the imports of an East Asian country would lead to a higher contribution of export shocks to the variance of imports for that country. Second, given that a positive USA output shock raises both exports of final goods to the USA and exports of intermediate goods to East Asia, resulting in higher total exports and output for an East Asian country, a higher share of intermediate goods in exports to East Asia would lead to a higher contribution of USA output shocks to the variance of GDP for that country.

Figure 3 provides evidence supporting these conjectures. Panel (a) plots the contribution of the export shock to the variance of imports against the share of intermediate goods in total imports for each East Asian country. Panel (b) plots the contribution of the USA output shock to the variance of GDP against the share of intermediate goods in total exports to East Asia. In these panels, the data displayed in Tables 5 and 7 for East Asian countries are used. The slopes of the regression lines are estimated at 0.268 and 0.507, respectively, indicating positive correlations between the vertical-axis variables and the horizontal-axis ones and aligning with our conjectures.[7] The results indicate that East Asian countries with imports more concentrated in intermediate goods are more susceptible to export shocks in terms of their imports. Additionally, East Asian countries whose regional exports predominantly consist of intermediate goods are more significantly influenced by U.S. output shocks in terms of their GDP.

[7] The corresponding p-values for the two regressions are 0.11 and 0.08, respectively.

Table 7: Variance decomposition for variables of East Asian countries

		China				Japan			
Shock	Horizon	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER
USA	1 quarter	0.24	0.07	0.05	0.08	0.12	0.00	0.07	0.11
output	4 quarters	0.20	0.22	0.07	0.15	0.47	0.23	0.30	0.14
shock	12 quarters	0.19	0.20	0.06	0.12	0.40	0.25	0.29	0.16
CHN	1 quarter	0.01	0.13	0.95	0.08	0.00	0.02	0.02	0.04
output	4 quarters	0.24	0.15	0.72	0.16	0.10	0.07	0.07	0.11
shock	12 quarters	0.23	0.17	0.60	0.23	0.16	0.08	0.08	0.14
JPN	1 quarter	0.00	0.05	0.00	0.02	0.25	0.18	0.91	0.00
output	4 quarters	0.01	0.06	0.04	0.02	0.20	0.14	0.51	0.09
shock	12 quarters	0.03	0.08	0.05	0.04	0.18	0.14	0.45	0.08
Export	1 quarter	0.74	0.03	0.00	0.01	0.63	0.01	0.00	0.00
shock	4 quarters	0.38	0.11	0.12	0.06	0.17	0.02	0.02	0.03
	12 quarters	0.34	0.11	0.13	0.06	0.16	0.05	0.03	0.08
Import	1 quarter	0.00	0.72	0.00	0.07	0.00	0.79	0.00	0.09
shock	4 quarters	0.15	0.43	0.04	0.18	0.02	0.47	0.00	0.11
	12 quarters	0.19	0.37	0.09	0.18	0.05	0.39	0.04	0.15
REER	1 quarter	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.76
shock	4 quarters	0.02	0.03	0.01	0.44	0.05	0.07	0.10	0.52
	12 quarters	0.04	0.06	0.07	0.38	0.05	0.09	0.11	0.39

Table 7 (continued)

		Hong Kong				Indonesia				Korea			
Shock	Horizon	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER
USA	1 quarter	0.06	0.10	0.10	0.03	0.04	0.00	0.02	0.00	0.00	0.01	0.20	0.22
output	4 quarters	0.23	0.27	0.20	0.10	0.06	0.08	0.02	0.08	0.13	0.25	0.22	0.21
shock	12 quarters	0.21	0.22	0.16	0.07	0.06	0.08	0.03	0.08	0.15	0.25	0.22	0.23
CHN	1 quarter	0.04	0.11	0.34	0.04	0.00	0.01	0.06	0.01	0.03	0.00	0.12	0.23
output	4 quarters	0.03	0.08	0.26	0.03	0.03	0.01	0.09	0.03	0.09	0.07	0.16	0.21
shock	12 quarters	0.03	0.06	0.22	0.08	0.04	0.02	0.15	0.04	0.10	0.06	0.14	0.20
JPN	1 quarter	0.05	0.03	0.01	0.00	0.00	0.03	0.02	0.01	0.00	0.01	0.00	0.03
output	4 quarters	0.12	0.07	0.03	0.06	0.02	0.06	0.09	0.04	0.05	0.04	0.01	0.04
shock	12 quarters	0.12	0.07	0.05	0.06	0.02	0.07	0.09	0.06	0.06	0.04	0.02	0.04
Export shock	1 quarter	0.85	0.64	0.10	0.00	0.96	0.14	0.02	0.01	0.96	0.46	0.11	0.02
	4 quarters	0.56	0.42	0.13	0.07	0.82	0.16	0.06	0.06	0.63	0.23	0.10	0.02
	12 quarters	0.43	0.32	0.12	0.06	0.78	0.16	0.05	0.07	0.54	0.24	0.15	0.04
Import shock	1 quarter	0.00	0.12	0.01	0.00	0.00	0.83	0.05	0.12	0.00	0.51	0.00	0.00
	4 quarters	0.01	0.08	0.02	0.05	0.01	0.61	0.10	0.10	0.07	0.33	0.11	0.12
	12 quarters	0.02	0.08	0.04	0.05	0.02	0.60	0.16	0.12	0.09	0.30	0.11	0.15
Home	1 quarter	0.00	0.00	0.44	0.01	0.00	0.00	0.83	0.00	0.00	0.00	0.57	0.05
output	4 quarters	0.01	0.06	0.33	0.07	0.03	0.03	0.63	0.10	0.02	0.09	0.38	0.05
shock	12 quarters	0.12	0.19	0.36	0.24	0.04	0.03	0.51	0.09	0.02	0.08	0.32	0.05
REER shock	1 quarter	0.00	0.00	0.00	0.91	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.45
	4 quarters	0.04	0.03	0.04	0.63	0.02	0.04	0.01	0.58	0.01	0.01	0.01	0.35
	12 quarters	0.07	0.05	0.05	0.44	0.02	0.04	0.02	0.53	0.03	0.03	0.03	0.29

Table 7 (continued)

		Malaysia				Philippines				Singapore			
Shock	Horizon	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER
USA	1 quarter	0.40	0.26	0.48	0.00	0.15	0.00	0.10	0.01	0.00	0.00	0.12	0.02
output	4 quarters	0.33	0.32	0.42	0.10	0.19	0.19	0.15	0.05	0.10	0.27	0.18	0.08
shock	12 quarters	0.35	0.29	0.37	0.14	0.17	0.18	0.17	0.05	0.15	0.28	0.20	0.08
CHN	1 quarter	0.05	0.08	0.00	0.00	0.00	0.00	0.00	0.02	0.10	0.02	0.07	0.00
output	4 quarters	0.10	0.07	0.18	0.04	0.01	0.01	0.04	0.03	0.10	0.05	0.07	0.03
shock	12 quarters	0.09	0.09	0.15	0.07	0.02	0.04	0.05	0.06	0.08	0.05	0.08	0.11
JPN	1 quarter	0.04	0.01	0.07	0.01	0.10	0.12	0.13	0.02	0.05	0.04	0.01	0.02
output	4 quarters	0.11	0.15	0.04	0.04	0.12	0.12	0.10	0.07	0.05	0.03	0.03	0.02
shock	12 quarters	0.14	0.19	0.08	0.11	0.21	0.13	0.09	0.08	0.04	0.05	0.05	0.05
Export shock	1 quarter	0.52	0.18	0.03	0.04	0.74	0.01	0.00	0.01	0.85	0.52	0.09	0.04
	4 quarters	0.41	0.10	0.03	0.05	0.64	0.02	0.01	0.08	0.55	0.31	0.07	0.04
	12 quarters	0.25	0.09	0.04	0.12	0.49	0.05	0.02	0.08	0.45	0.27	0.07	0.07
Import shock	1 quarter	0.00	0.47	0.01	0.03	0.00	0.87	0.06	0.01	0.00	0.41	0.01	0.08
	4 quarters	0.01	0.33	0.01	0.09	0.02	0.64	0.14	0.05	0.13	0.27	0.04	0.09
	12 quarters	0.05	0.23	0.04	0.07	0.05	0.55	0.20	0.05	0.17	0.26	0.14	0.09
Home	1 quarter	0.00	0.00	0.41	0.15	0.00	0.00	0.71	0.00	0.00	0.00	0.70	0.00
output	4 quarters	0.04	0.02	0.29	0.22	0.02	0.02	0.52	0.02	0.03	0.06	0.56	0.10
shock	12 quarters	0.09	0.10	0.27	0.18	0.05	0.03	0.45	0.02	0.03	0.06	0.41	0.09
REER shock	1 quarter	0.00	0.00	0.00	0.78	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.84
	4 quarters	0.00	0.01	0.03	0.45	0.01	0.01	0.04	0.70	0.05	0.01	0.04	0.64
	12 quarters	0.04	0.02	0.05	0.31	0.02	0.01	0.02	0.66	0.07	0.03	0.05	0.52

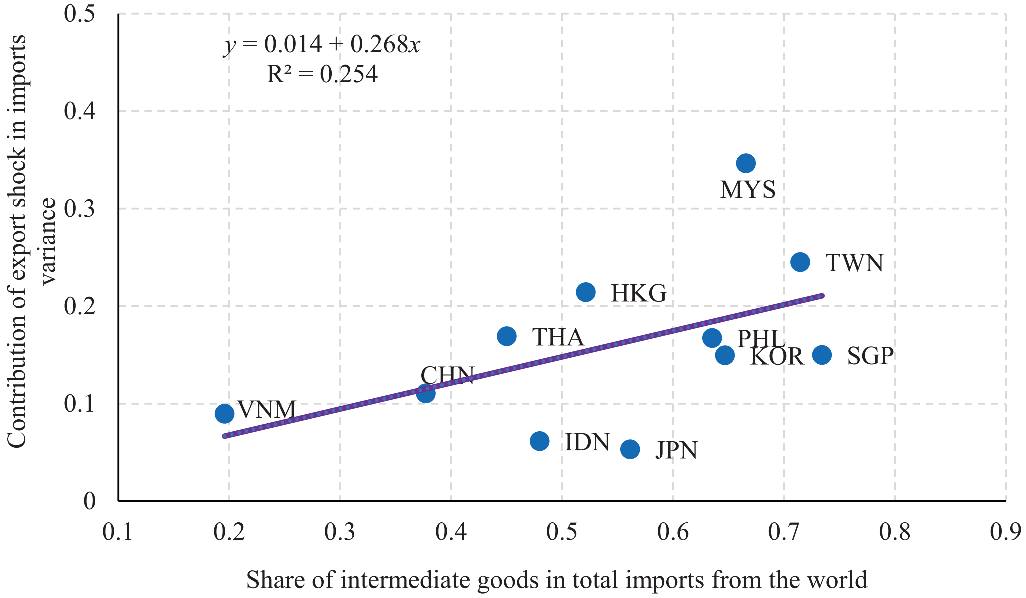
Table 7 (continued)

		Taiwan				Thailand				Vietnam			
Shock	Horizon	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER	Exp.	Imp.	GDP	REER
USA output shock	1 quarter	0.18	0.09	0.16	0.04	0.10	0.07	0.03	0.10	0.02	0.13	0.01	0.00
	4 quarters	0.22	0.27	0.21	0.08	0.20	0.31	0.13	0.10	0.09	0.27	0.02	0.02
	12 quarters	0.25	0.28	0.26	0.11	0.17	0.30	0.14	0.08	0.09	0.24	0.09	0.11
CHN output shock	1 quarter	0.11	0.05	0.31	0.00	0.02	0.01	0.01	0.03	0.01	0.00	0.00	0.22
	4 quarters	0.15	0.05	0.21	0.05	0.09	0.06	0.04	0.03	0.04	0.06	0.14	0.19
	12 quarters	0.16	0.07	0.21	0.11	0.08	0.06	0.04	0.04	0.11	0.11	0.14	0.19
JPN output shock	1 quarter	0.05	0.02	0.01	0.03	0.01	0.01	0.06	0.04	0.01	0.05	0.00	0.00
	4 quarters	0.03	0.03	0.06	0.04	0.03	0.10	0.09	0.04	0.13	0.16	0.02	0.16
	12 quarters	0.03	0.03	0.07	0.04	0.13	0.10	0.13	0.10	0.13	0.11	0.04	0.13
Export shock	1 quarter	0.66	0.33	0.16	0.09	0.87	0.27	0.37	0.00	0.97	0.00	0.00	0.00
	4 quarters	0.40	0.16	0.15	0.08	0.54	0.14	0.35	0.01	0.66	0.06	0.05	0.07
	12 quarters	0.31	0.15	0.12	0.08	0.49	0.16	0.31	0.03	0.60	0.07	0.09	0.07
Import shock	1 quarter	0.00	0.51	0.03	0.01	0.00	0.64	0.04	0.01	0.00	0.82	0.02	0.02
	4 quarters	0.10	0.43	0.07	0.02	0.07	0.35	0.06	0.05	0.02	0.39	0.05	0.11
	12 quarters	0.11	0.37	0.08	0.04	0.06	0.33	0.05	0.06	0.02	0.34	0.07	0.11
Home output shock	1 quarter	0.00	0.00	0.34	0.01	0.00	0.00	0.49	0.01	0.00	0.00	0.96	0.01
	4 quarters	0.06	0.03	0.22	0.09	0.05	0.00	0.33	0.18	0.03	0.04	0.69	0.03
	12 quarters	0.09	0.06	0.17	0.09	0.06	0.01	0.30	0.16	0.03	0.07	0.54	0.04
REER shock	1 quarter	0.00	0.00	0.00	0.82	0.00	0.00	0.00	0.81	0.00	0.00	0.00	0.75
	4 quarters	0.04	0.03	0.07	0.64	0.01	0.04	0.00	0.59	0.03	0.02	0.02	0.42
	12 quarters	0.06	0.06	0.07	0.53	0.02	0.04	0.03	0.52	0.03	0.06	0.03	0.34

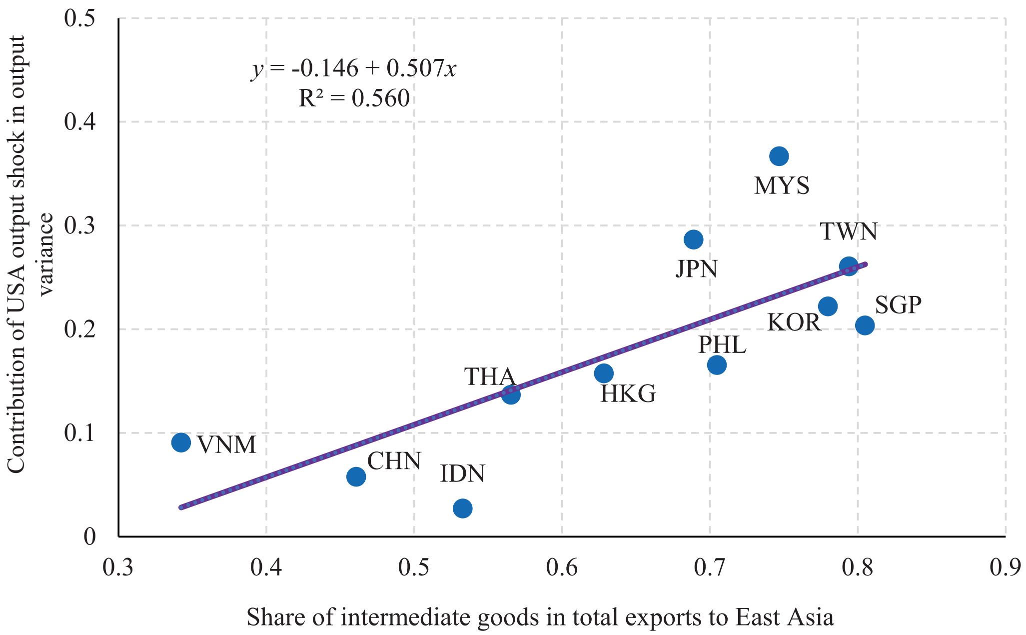
Source: Author's calculations based on the estimated VAR model and data described in Section 3.

Figure 3: Relationship between the share of intermediate goods in trade and the contribution of shocks to the variance of macroeconomic variables in East Asia

(a)



(b)



Source: Variance decomposition data are from Table 7 with the horizon of 12 quarters. Data on the share of intermediate goods in trade are from Table 5.

5. Concluding remarks

In this paper, I documented stylized facts underlying East Asia's trade structure and empirically analyzed it from an international macroeconomic perspective. Among the various facts I established using detailed data on East Asian countries, the most notable one is the significant role of intermediate goods in intra-regional trade in East Asia. By contrast, trade of the region with the rest of the world is characterized by a much larger share of final goods. I then explored how this trade structure influences macroeconomic interdependence in East Asia. To address this question, I used a structural VAR model with block exogeneity to empirically investigate the effects of various external and internal shocks on 11 East Asian countries and analyzed how these effects are connected to the trade structure in the region.

The primary conclusion of the paper is that the transmission of shocks to East Asian economies is closely related to the region's trade structure, aligning with the theoretical insights from Vu (2016). More specifically, the key findings are as follows: First, exports, imports, and GDP of East Asian countries respond positively to USA output shocks, with countries with a higher concentration of intermediate goods in exports showing greater sensitivity of GDP to such external output shocks. Second, positive export shocks increase both exports and imports of East Asian economies, with countries with a larger share of intermediate goods in their imports exhibiting greater sensitivity of imports to export shocks. Third, a comparison between the effects of output shocks from China and Japan, the two major trade partners of most East Asian countries outside the USA, reveals that in recent years the effects of Chinese output shocks have become more influential for East Asia. This result supports the view that the Chinese output shocks have exerted a greater effect on East Asia. This underscores the growing integration of East Asia with the Chinese economy and the expanding of the latter in the region.

Further research could provide a deeper understanding of the issues studied here. One potential direction is to utilize more disaggregated trade data, such as industry-specific and partner-specific data. Since East Asian countries specialize in different industries, each of which have its own structure of vertical intra-industry trade and varying reliance on intermediate goods, differences in their trade patterns at disaggregated levels could shape how shocks propagate across sectors and countries.

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The impact of oil price fluctuations on Asian stock market correlation

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Abstract

This study analyzes how oil price shocks affected stock price correlations in the stock markets of five major ASEAN countries: Indonesia, Malaysia, the Philippines, Singapore, and Thailand. Using structural VAR and historical decomposition, we calculate counterfactual (pure) returns under the assumption that the markets are not affected by oil market shocks. We compare the rolling correlations between those markets with the correlations of their actual returns. Our results confirm that oil price shocks affect correlations between countries; however, the effects are strongly time-varying.

Keywords: ASEAN, Stock market, oil price, VAR.
JEL Classification Codes: G15, Q43.

1. Introduction

As the economies of East Asian countries continue to grow, interest in the region's stock markets is also rising. Many previous studies have pointed out that the correlations among stock markets in East Asia are gradually increasing.

Takahashi (2010) pointed out two underlying factors of the increasing international interconnectedness of financial markets. One is the growing international interdependence of the real economies, increasing the susceptibility of each country's economy to global factors, while the second is the mounting activity in global portfolio investment.

East Asian countries, especially ASEAN countries, are small open economies that are known to be strongly influenced by global factors. In particular, energy price fluctuations are often noted as an important factor in global economic fluctuations. The two oil shocks in the 1970s, the sudden surge in oil prices in the 2000s, and the further increase in energy prices following Russia's invasion of Ukraine in 2022 have been major disruptive factors in the world economy.

Fluctuations in energy prices affect the stock markets of ASEAN countries through their impact on corporate earnings; however, these impacts are thought to vary by country and region. The most obvious reason for this heterogeneity is the difference between oil-exporting and -importing countries. However, ASEAN countries adopt diverse exchange rate and monetary policy regimes, and these differences also affect the channels through which global shocks spread to domestic economies. For example, Vu and Nakata (2018) analyzed how oil price shocks impact the macroeconomic factors (output, prices, interest rates, exchange rates, etc.) of ASEAN countries. They found that shocks to production and prices were more significant in oil-importing countries like Thailand and the Philippines. Moreover, the effect on interest and exchange rates depends on the exchange rate and monetary policy regimes.

In other words, fluctuations in energy prices act as global economic shocks and have a common impact on stock markets in all countries. However, because this impact depends on each country's economic structure and policy regime, how it affects the correlations between international stock markets is unclear.[1]

Therefore, this study analyzes how oil price shocks affect stock price correlations in the stock markets of five major ASEAN countries: Indonesia, Malaysia, the Philippines, Singapore, and Thailand.[2]

2. Recent trends in stock markets of the five ASEAN countries

Figure 1 illustrates the stock price index trends for the five ASEAN countries. The stock prices of all ASEAN countries at the final date (2020 m4) are higher than they were at the initial date (1987 m1), but the extent of the increase varies significantly from country to country. In addition, stock prices have not increased consistently but have significantly risen and fallen, especially around the Asian currency (1997-1998) and global financial crises (2008-2009).

Next, we examine the correlations between real stock returns in ASEAN countries. Figure 2 shows the trend of the rolling correlation coefficients between the real stock returns of the five ASEAN countries (10 pairs) over 50-month rolling windows. The correlation coefficients also fluctuate significantly depending on the period, and the strength of the correlation differs greatly depending on the pair.

Figure 3 plots the average correlation coefficients of 10 pairs for each rolling window to capture the overall trend of correlations between markets.

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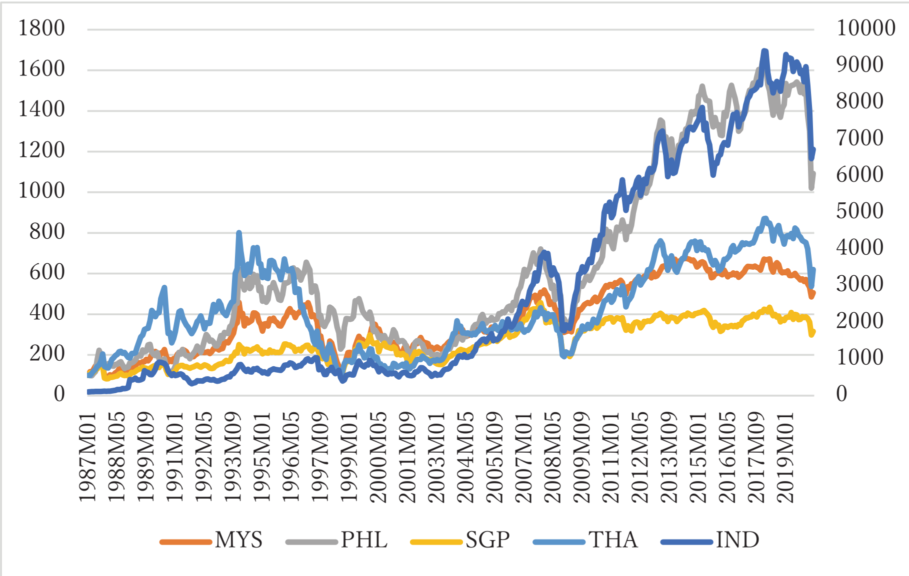
[1] Conversely, the correlation between international stock markets reflects differences in economic structures and policy regimes.

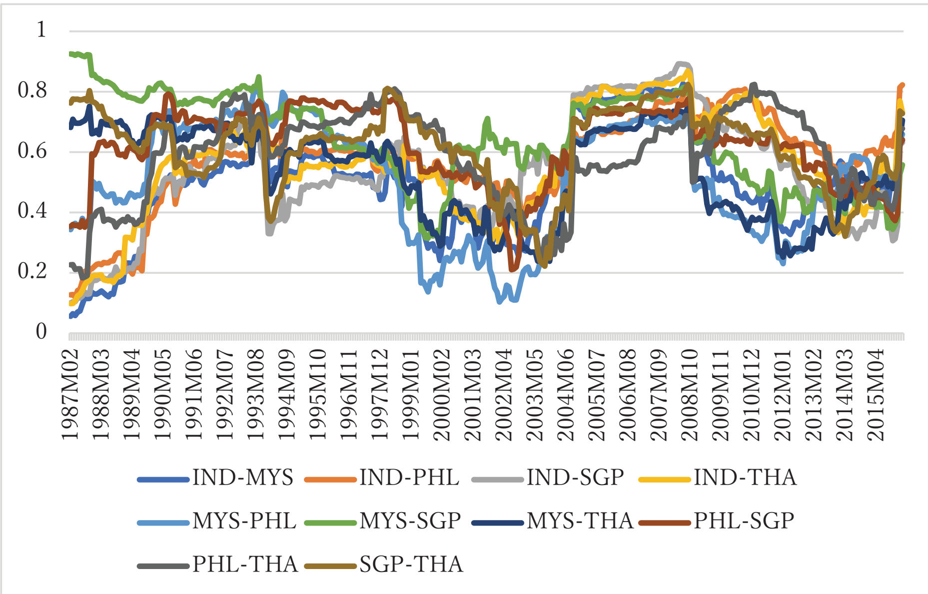
[2] In recent years, the major ASEAN countries, ASEAN - 5, have often been referred to as Indonesia, Malaysia, the Philippines, Thailand, and Vietnam, but in this study, we chose the above five countries because we are able to obtain long-term stock price data.

Figure 1: Stock price trends in the five ASEAN countries



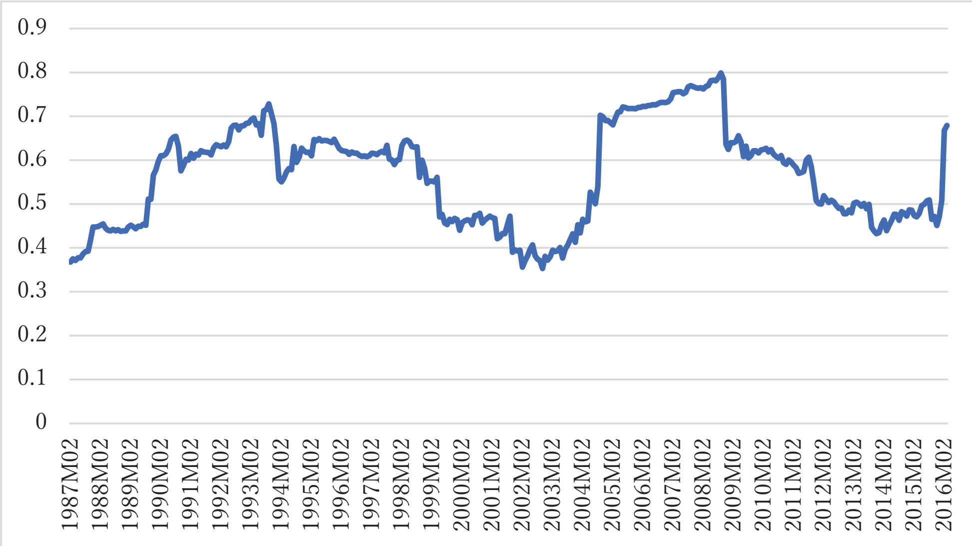
Note: IND: Indonesia, MYS: Malaysia, PHL: Singapore, SGP: Singapore, THA: Thailand. All data have been adjusted to 100 as of February 1987. Indonesia is the only country with a large growth rate, so it is shown on the right axis.
Data source: CEIC database

Figure 2: Rolling correlations of real stock returns in the five ASEAN countries



Note: IND: Indonesia, MYS: Malaysia, PHL: Singapore, SGP: Singapore, THA: Thailand. The horizontal axis indicates the first date of the 50-month rolling windows.
Data sources: Stock price indexes were obtained from the CEIC database, and real stock returns were calculated using logarithmic first differences. Consumer price indexes (CPIs) for each country were obtained from the International Financial Statistics (IFS), and inflation rates were calculated using logarithmic first differences. Real stock returns were calculated by subtracting the latter from the former.

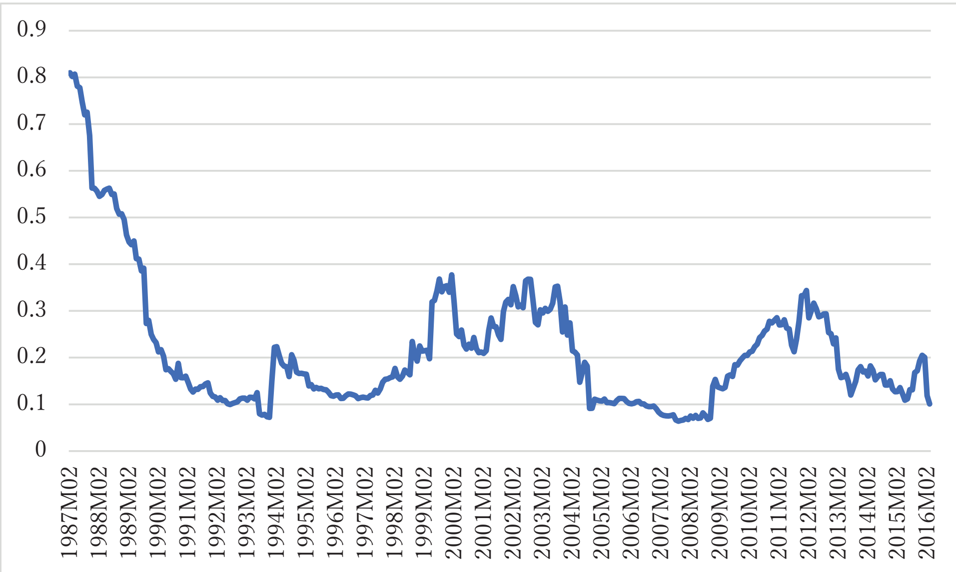
Figure 3: Average rolling correlations for five ASEAN countries



Note: The horizontal axis indicates the first date of the rolling window.

Figure 3 shows that the correlation coefficients between markets are robust from 1990 to 1997 and 2004 to 2012. In addition, Figure 4 plots the standard deviation of the correlation coefficients of 10 pairs for each rolling window to capture the trend of the variation in the correlation coefficients between market pairs.

Figure 4: Standard deviation of rolling correlations for five ASEAN countries



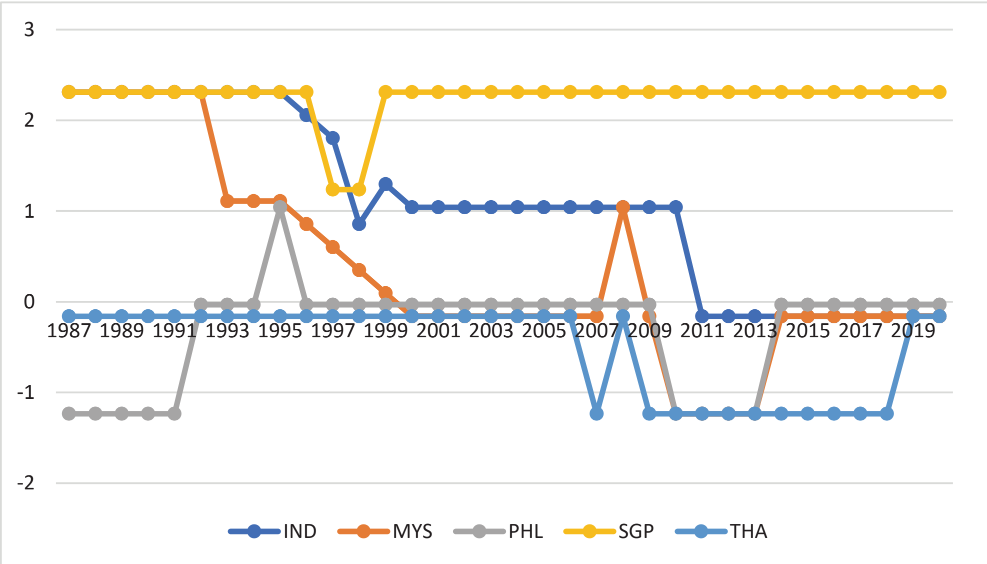
Note: The horizontal axis indicates the first date of the rolling window.

Figure 4 shows that the standard deviation of the correlation coefficients between market pairs was substantial at the beginning but dropped rapidly. Also, comparing Figure 3 with Figure 4, the average and standard deviation of the correlation coefficients are roughly inversely correlated.

The fluctuations in the international correlations of real stock returns may be caused by changes in financial market regulations. In the case of ASEAN countries, one way to confirm whether such a relationship exists is to look at an index of financial market liberalization. Figure 5 plots the Chinn-Ito Index,[3] which is often referred to as an index of financial market liberalization. The higher the index, the fewer the financial market regulations.

Figure 5 reveals that multiple countries strengthened their regulations during the Asian currency and global financial (hereafter GFC) crises. This result is consistent with the decline in correlation coefficients during these periods. However, with a few exceptions, correlation coefficients do not tend to rise when regulations are relaxed. Therefore, this result suggests that the fluctuations in the correlation coefficients of real stock returns seen in Figure 3 are caused by something other than changes in the region's financial market regulations.

Figure 5: Trends in the index of financial market liberalization (Chinn -Ito index)



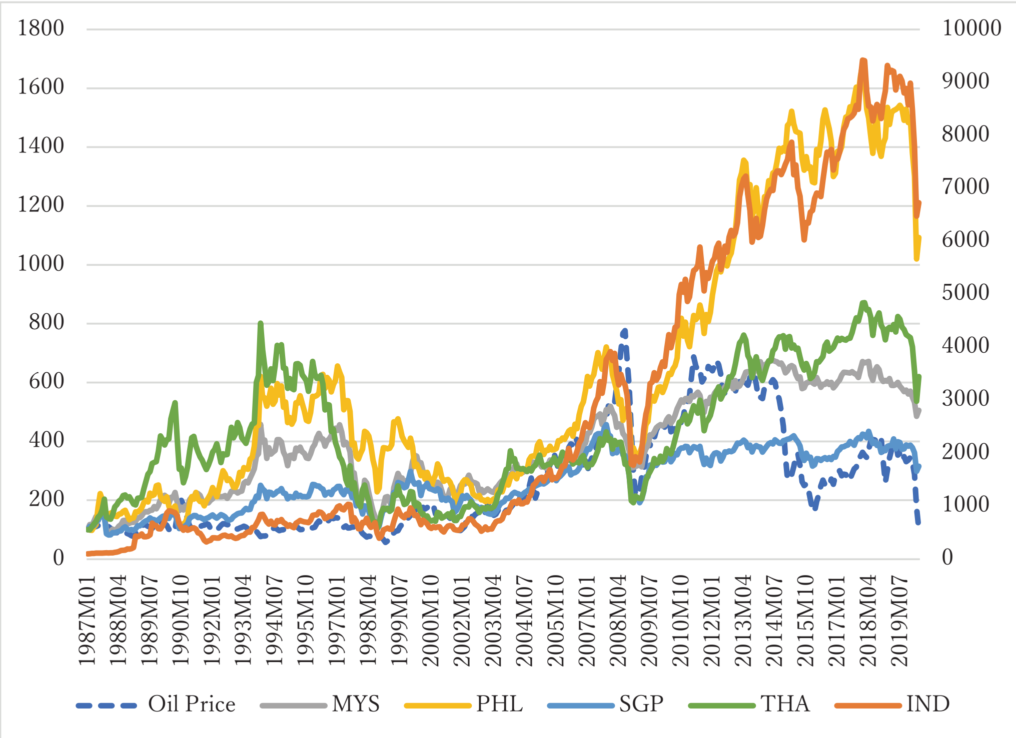
Note: The Chinn- Ito Index is calculated using various factors that measure the degree of financial market liberalization, such as restrictions on current account and financial balance transactions and parallel exchange rates. For more information, please refer to the explanation on the data source website.
Data source: The Chinn-Ito Index website (https://web.pdx.edu/~ito/Chinn-Ito_website.htm)

[3] Vu and Inoue (2024) provide a detailed explanation of the Chin-Ito index.

Finally, to examine this study's subject, that is, the relationship between oil price fluctuations and stock prices in ASEAN countries, Figure 6 plots both the stock price indexes of the five ASEAN countries and crude oil price. The plot reveals that the crude oil price and stock prices of ASEAN countries moved in very similar ways from the Asian currency crisis to the GFC.

In this section, we examined the correlations between the five ASEAN stock markets, the dispersion of the correlation coefficients, and the relationship between regulations and oil prices. In Section 7, we use vector autoregression analysis (VAR) to quantitatively evaluate the extent to which oil market shocks have affected stock price correlations.

Figure 6: Trends in stock prices and oil prices in the five ASEAN countries



Note: All data have been adjusted so that February 1987 equals 100. Indonesia is the only country with a large growth rate, so it is shown on the right axis.

Data sources: Stock price indexes for each country were obtained from the CEIC database. The oil price is the US Crude Oil price index obtained from the International Energy Information Agency website, using the Oil Imported Acquisition Cost by Refiner (see Section 5 for details of this data).

3. Previous research

Previous research directly related to this study's topic can be broadly divided into two strands: 1) research that analyzes the interdependence of stock markets in ASEAN countries and 2) research that analyzes how oil price fluctuations impact stock markets in ASEAN countries.[4]

Much prior research has explored the interdependence of stock markets in ASEAN countries, driven by both policy and empirical interest. In an early study, Imamura and Asako (2000) analyzed weekly data from eight Asian countries using lag augmented VAR. They found that stock price correlations increased after the Asian currency crisis. Karim and Karim (2012) used the autoregressive distributed lag (ARDL) bounds test to examine whether stock markets in five ASEAN countries (Indonesia, Malaysia, the Philippines, Thailand, and Singapore) were integrated. They found that these markets became more integrated after the Asian currency crisis and especially after the GFC.

Many recent studies have focused on the relationship between the ASEAN countries and China, which is rapidly expanding its economic influence over them. Glick and Hutchinson (2013) examined the linkage between China and other Asian asset markets and found that while the linkage between long-term interest rates was weak, the linkage between stock price returns was much more substantial. In particular, they found that the linkage between stock returns increased during the GFC and has remained the same since then.

Guimarães-Filho and Hong (2016) used the Diebold and Yilmaz method[5] to estimate the connectedness of stock returns and volatility between Asian emerging countries, developed countries, and other emerging markets, and examined the relationship within Asia and beyond.[6] Guimarães-Filho and Hong (2016) showed that the connectedness of returns and volatility rose worldwide after the GFC but has declined gradually since around 2013. In addition, Asian emerging markets shifted from receivers of shocks to drivers of shocks after the GFC. At the same time, China's net connectedness rose sharply during the 2015 China shock.

Fujiwara and Takahashi (2012) examined the linkage between financial and goods markets by estimating and comparing the spillover indexes of financial markets (bond markets, stock markets) and real sectors (production indexes) in Asian and developed countries. They found that while the US market drives stock market fluctuations in both Asian and developed countries, China is the primary source of economic volatility in the real sectors. They call this phenomenon “macro-finance dissonance.”

Regarding the correlations between stock prices in ASEAN countries and oil price, Robiyato (2018) estimated the time-varying correlation coefficients between oil price and daily stock returns for five ASEAN countries (Indonesia, Malaysia, the Philippines, Thailand, and Singapore) using dynamic

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[4] An extensive amount research uses similar analyses for developed and East Asian countries such as Japan, China, and South Korea, so we omit these topics.

[5] Vu and Inoue (2024) used this method to create data on international stock market correlations and provide a detailed explanation.

[6] Connectedness is an index proposed by Diebold and Yilmaz (2015) that measures the strength of the connections between countries and markets based on variance decomposition of VAR forecast errors. Connectedness is an index of the connections between countries, calculated by subtracting the impact of other countries on a focal country from the influence of the focal country on other countries. When connectedness is positive, it can be considered a driver of change; when negative, it can be considered a receiver of change. For details, see Diebold and Yilmaz (2015).

conditional correlation GARCH. The results showed that the correlation coefficients fluctuated significantly over time in all cases and that, except for the Philippines, especially large correlation fluctuations occurred around the GFC. In addition, the correlations tended to be larger in oil-producing than non-oil-producing countries. Thorbecke (2018) also analyzed by sector how crude oil price affected stock prices in East Asian and Southeast Asian countries. He found that increases in crude oil price had a positive impact on the mining, metals, and oil and natural gas sectors. In contrast, their impact on the aviation, public services, and electricity sectors was negative

Compared to these previous studies, this study contributes by analyzing how oil price fluctuations impact the interdependence of ASEAN countries' stock markets. To the best of our knowledge, no similar analysis has been conducted in regions other than ASEAN.

4. Empirical framework

In this study, we take the following steps to analyze how oil price fluctuations affect international stock price correlations.[7]

1) Calculate the rolling correlation coefficients of real stock returns between ASEAN countries.
2) Estimate the effects of various oil price shocks on real stock returns.
3) Calculate the series of real stock returns as if oil price shocks did not occur.
4) Calculate the rolling correlation coefficients of the counterfactual real stock returns obtained in step 3 (hereafter referred to as "pure returns") and compare them with the original series obtained in step 1 to analyze how oil price shocks impacted the correlation structure of real stock returns.

The empirical methods used in steps 2 and 3 require a detailed explanation. First, in step 2, we use a VAR model to decompose oil price fluctuations into structural shocks based on their causes. As Kilian (2009) and Kilian and Park (2009) revealed, various factors cause the world market price of oil to fluctuate, including the supply side, demand side, and market speculation. Still, the impact these factors have on macroeconomic variables and asset prices differs in each country.

For example, an increase in the oil price can be caused by either a decrease in the oil supply (a leftward shift of the supply curve) or an increase in oil demand (a rightward shift of the demand curve). However, the implications for the whole economy are very different. An exogenous oil supply decrease reduces the economic growth of oil-importing countries, as was evident during the oil shocks in the 1970s and in the recent Russian invasion of Ukraine. Nevertheless, an increase in oil demand, which is often accompanied by faster world economic growth, may increase each country's economic growth

[7] In step 3, we calculate the real stock return in a counterfactual situation where the oil price shock is zero. In step 4, we evaluate the impact of the oil price shock by comparing the counterfactual situation with reality.

despite the rise in oil prices.

This study employs Kilian and Park's (2009) method to estimate the impact oil price fluctuations have on real stock returns by different factors. We estimate a four-variable reduced VAR model, as shown in equation (1), to analyze the response of each country's stock returns to oil price fluctuations.

$$\boldsymbol{y_t} = \boldsymbol{A_0} + \boldsymbol{A_1}\boldsymbol{y_{t-1}} + \cdots + \boldsymbol{A_p}\boldsymbol{y_{t-p}} + \boldsymbol{e_t} \quad (1)$$

In equation (1), $\boldsymbol{y_t}$ is a 4 ×1 column vector of endogenous variables, including crude oil production, proxy variables for global economic activity,[8] the crude oil price, and real stock returns. $\boldsymbol{A_i}(\boldsymbol{i} = \boldsymbol{1}, \cdots, \boldsymbol{p})$ is a 4×4 coefficient matrix, and $\boldsymbol{e_t}$ is a vector of error terms.

The error terms of the reduced VAR cannot be regarded as economically interpretable (structural) shocks. We identify structural shocks by placing constraints on the relationship between the observed error terms and shocks as shown in equation (2),

$$\boldsymbol{e_t} \equiv \begin{bmatrix} e_{1t}^{global\ oil\ production} \\ e_{2t}^{real\ economic\ activity} \\ e_{3t}^{oil\ price} \\ e_{4t}^{stock\ returns} \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_{1t}^{oil\ supply\ shock} \\ \varepsilon_{2t}^{aggregate\ demand\ shock} \\ \varepsilon_{3t}^{oil-specific\ demand\ shock} \\ \varepsilon_{4t}^{pure\ shock} \end{bmatrix}, E[\boldsymbol{\varepsilon_t}\boldsymbol{\varepsilon_t'}] = \boldsymbol{I} \quad (2)$$

As mentioned, the left-hand side of equation (2) is the error term vector of the four-variable VAR ($\boldsymbol{e_t}$). The first term on the right-hand side is the coefficient matrix, and the second is the vector of structural shocks ($\boldsymbol{\varepsilon_t}$) identified in equation (2). Following previous research, the elements of this vector are labeled as follows:

$\varepsilon_{1t}^{oil\ supply\ shock}$	Supply shock
$\varepsilon_{2t}^{aggregate\ demand\ shock}$	Aggregate demand shock
$\varepsilon_{3t}^{oil-specific\ demand\ shock}$	Oil market-specific demand shock
$\varepsilon_{4t}^{pure\ shock}$	Pure shock (Other shocks to real stock returns)

All shocks are uncorrelated with others that occur at the same time. The coefficient matrix is restricted to have elements above the diagonal equal to zero (lower triangular matrix),[9] which means that the following four assumptions are made about the relationships among the four variables of the

[8] The proxy for global economic activity used by Kilian and Park (2009) is an index constructed by Lutz Kilian from ocean freight rate data and is a deviation from the trend. For details of the construction method, see Kilian (2009).
[9] This method of identifying shocks is called Cholesky decomposition.

VAR.[10]

(i) At each point in time (monthly), crude oil production is not affected by other variables at that same time.
(ii) At each point in time (monthly), global economic activity is affected by the amount of crude oil production at that time but is not affected by other variables at that same time.
(iii) At each point in time (monthly), oil price may be affected by the amount of crude oil production and economic activity at the same time but are not affected by real stock returns at the same time.
(iv) At each point in time (monthly), real stock returns may be affected by other variables at the same time.

Based on these assumptions, the oil market-specific demand shock ($\varepsilon_{3t}^{oil-specific\ demand\ shock}$) can capture oil price fluctuations that are driven by factors other than contemporaneous supply and aggregate demand shocks. Previous studies often consider this shock a precautionary demand shock caused by uncertainty about the global oil market's future or a speculative demand shock caused by speculative demand in the market. However, Vu and Nakata (2019) pointed out that this shock may initially affect only the oil industry or a few related industries (so that there is no visible impact on aggregate demand at that same time) but may have a ripple effect on other industries over time.

In addition, pure shock ($\varepsilon_{4t}^{pure\ shock}$) includes all shocks to real stock returns other than oil price shocks. Therefore, this shock is likely to include a variety of shocks, including country-specific real and financial shocks and shocks associated with changes in US monetary policy.

Next, in step 3 of our analysis, we follow Iwaisako and Nakata (2019) to calculate the series of (counterfactual) real stock returns, assuming that these oil price shocks were zero. Iwaisako and Nakata (2019) used historical decomposition to evaluate the impact of oil price fluctuations on exchange rate fluctuations in five advanced countries. Historical decomposition is a method of decomposing the realized value of each variable into the parts contributed by the various structural shocks that occurred at that time or in the past. Our method makes it possible to calculate the series of variables that are realized when only each specific structural shock occurs (other structural shocks are zero). Using this method, we obtain a series of real stock returns that remove the effects of oil price shocks (supply, aggregate demand, and oil market-specific demand shocks).

5. Data

This study analyzes monthly data from January 1987 to April 2020 but excludes the Asian currency

[10] These assumptions are based on Kilian and Park (2009).

crisis period (May 1997 to December 1998), during which financial markets in ASEAN countries were in severe turmoil. The period is divided into before (January 1987 to April 1997) and after (January 1999 to April 2020) the Asian currency crisis.

The world oil production growth rate is the log difference of the world oil production obtained from the Global Oil Production Database based on the International EIA. The proxy for global economic activity is downloaded from Lutz Kilian's website. We collect data on the oil prices from the EIA website and use the logarithm of oil import acquisition cost by the refiner as the oil price. As the name suggests, this variable is the imported crude oil acquisition price of US oil refiners; we chose this due to its long-term continuity. We calculated real stock returns for the five ASEAN countries by obtaining stock price index data for each country from the CEIC database. We subtracted the inflation rate, which is the log difference of the CPI obtained from the IFS, from the nominal stock returns, which is the log difference of the stock price index.

6. Structural shocks in the oil market and stock prices

We estimate a four-variable VAR for the first (January 1987 to April 1997) and second half periods (January 1999 to April 2020) and estimate the cumulative impulse response. The lag order (p) in the VAR model was set to $p = 12$.

Table 1 shows the signs of the cumulative impulse responses of real stock returns when oil price shocks (supply, aggregate demand, and oil market-specific demand shocks) are applied. A (+) sign indicates that the cumulative impact of each oil price shock was positive, a (–) sign indicates that it was negative, and (・) indicates that the sign changed direction more than twice. Additionally, (*) indicates that the cumulative impulse response is significantly positive or negative in some of the 12 periods.

Table 1: Signs of cumulative impulse responses of real stock returns to oil price shocks

(a) 1987m2-1997m4

	Supply shock	Demand shock	Oil specific demand shock
Indonesia	+*	+	+
Malaysia	・	・	−
Philippines	+→−	+	−
Singapore	+→−	+	−*
Thailand	・	−→+	−*

(b) 1999m1-2020m4

	Supply shock	Demand shock	Oil specific demand shock
Indonesia	·	+*	+*→−*
Malaysia	·	+*	+→−*
Philippines	+→−	+*	+*→−
Singapore	+→−	+→−	+*→−
Thailand	·	+→−	+*→−

Note: The cumulative impulse response is calculated for 12 periods from the occurrence of the shock. We consider the cumulative impulse response as significantly positive if the lower confidence interval limit (95%) is greater than 0 anywhere in the 12 periods. We consider the cumulative impulse response as significantly negative if the upper limit of the confidence interval is less than 0.

Table 1 (a) shows that in the first half of the period, few cases exist where the impulse responses are significantly positive or negative. Supply shocks (shocks that increase the world oil production growth rate) have a significantly positive effect only in Indonesia. In addition, aggregate demand shocks have no significant impact in any country, and oil market-specific demand shocks have a significantly negative impact in Singapore and Thailand.

In contrast, Table 1 (b) shows that in the latter half period, the cumulative impulse response's effect is significant in more cases, and the signs are common to most pairs. Aggregate demand shocks have a significantly positive impact in Indonesia, Malaysia, and the Philippines. Meanwhile, oil market-specific demand shocks have a significantly positive impact in all countries except Malaysia; however, in all cases, the effect becomes significantly negative in the latter period.

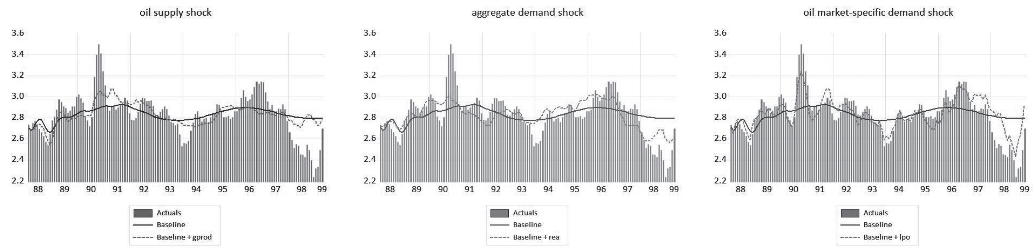
We estimate the three-variable (crude oil production, proxy for global economic activity, oil price) structural VAR[11] and perform historical decomposition to assess the extent to which oil price fluctuations can be explained by each structural shock (supply, aggregate demand, and oil market-specific demand shocks). Figure 7 shows the results of the historical decomposition of oil price fluctuations.

From Panels (a) and (b) in Figure 7, in the first half period, all three shocks contributed to oil price fluctuations. However, in the second half period, the contribution of demand shocks from 2004 to 2012 is immense, while the contribution of demand shocks specific to the oil market is sizeable before and after that period. These results reveal that even with the same oil price fluctuations, the factors behind the fluctuations vary greatly depending on the period.

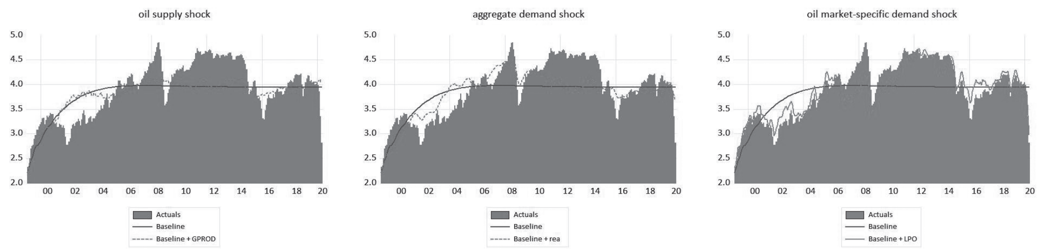
[11] The order of the variables is the same as in the four-variable VAR.

Figure 7: Historical decomposition of oil price fluctuations

Panel (a)



Panel (b)



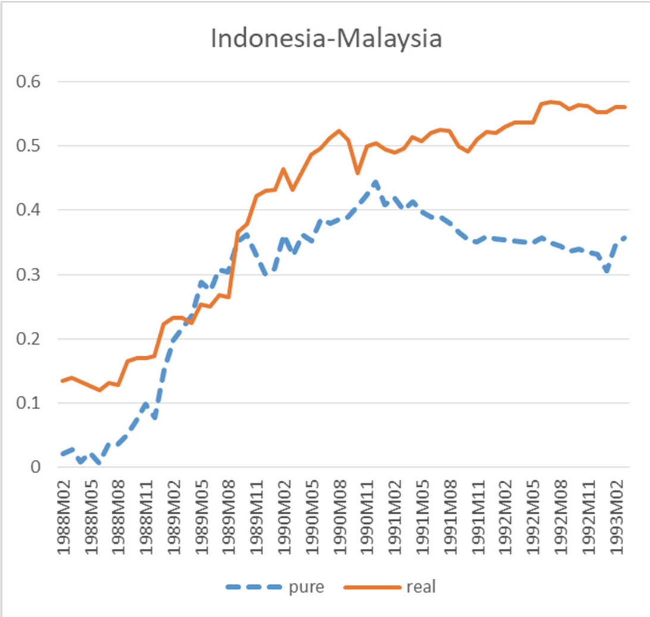
Note: GPROD: Supply shock, REA: Aggregate demand shock, LPO: Oil market-specific shock
The bar graph shows the actual price. The solid line indicates the baseline, and the dotted line represents the hypothetical price when only structural shocks are added to the baseline.

7. The impact of structural shocks on correlation structure

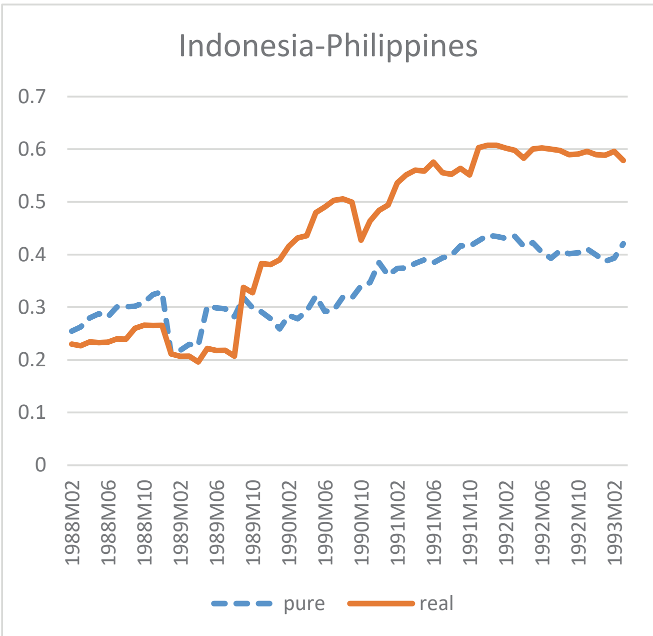
Next, based on the results of the four-variable VAR estimation, we calculate each country's pure stock return, removing the effects of the oil price shocks through historical decomposition. For these pure returns, we calculate the rolling correlations using a rolling window of 50 months. Figures 8 and 9 plot these rolling correlation coefficients and those of the real stock returns shown in Figure 2 by period.

Figure 8: Rolling correlations of real pure returns in the five ASEAN countries

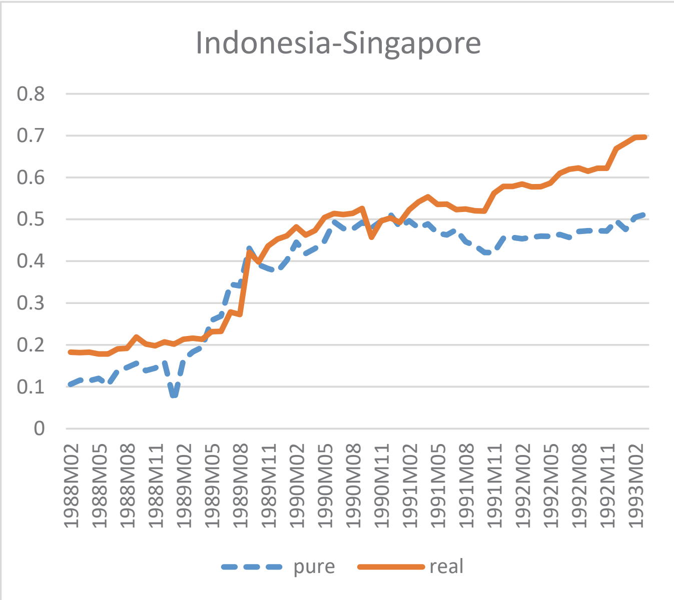
Panel (a)



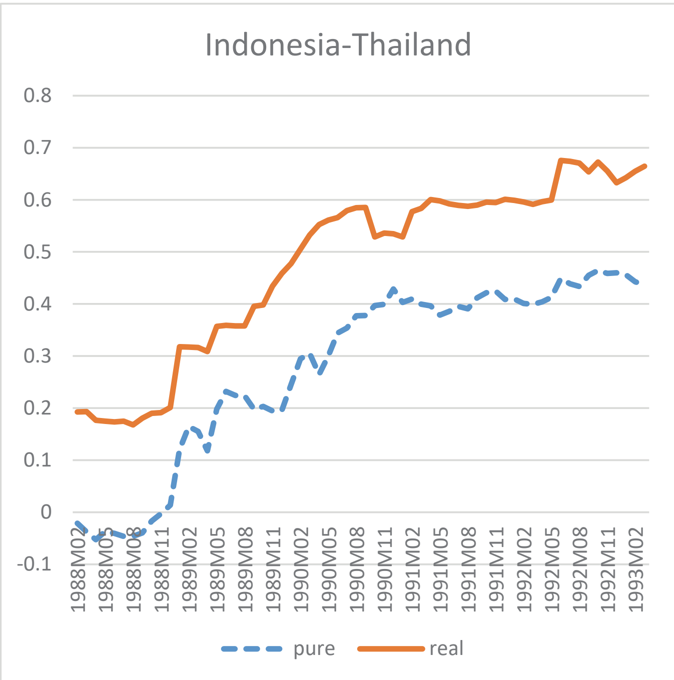
Panel (b)



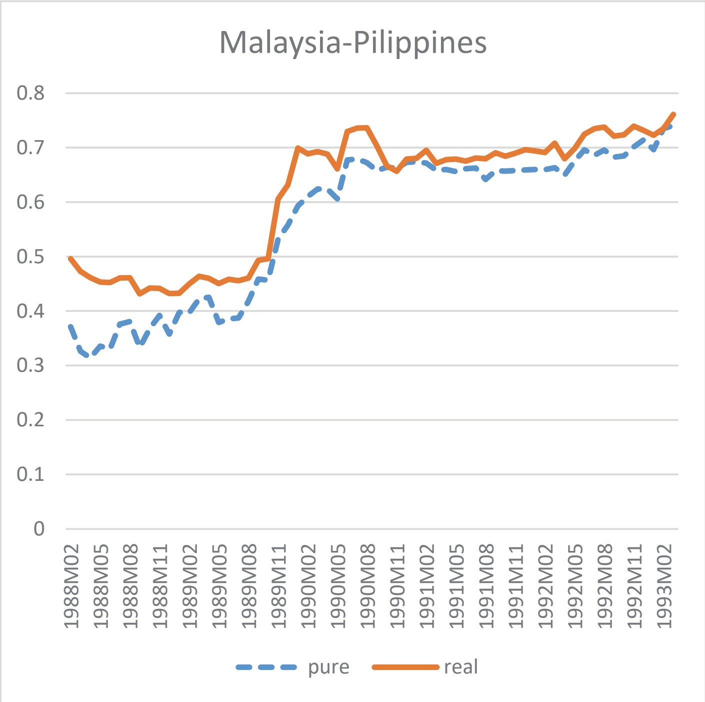
Panel (c)



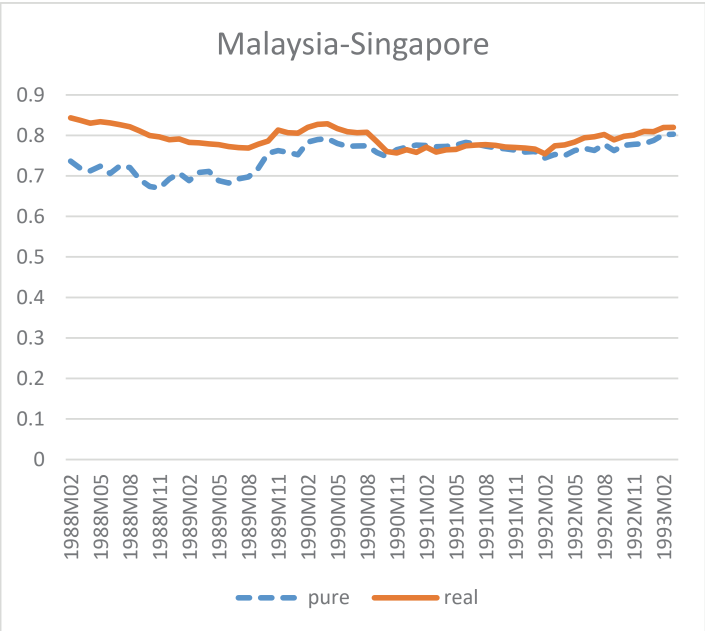
Panel (d)



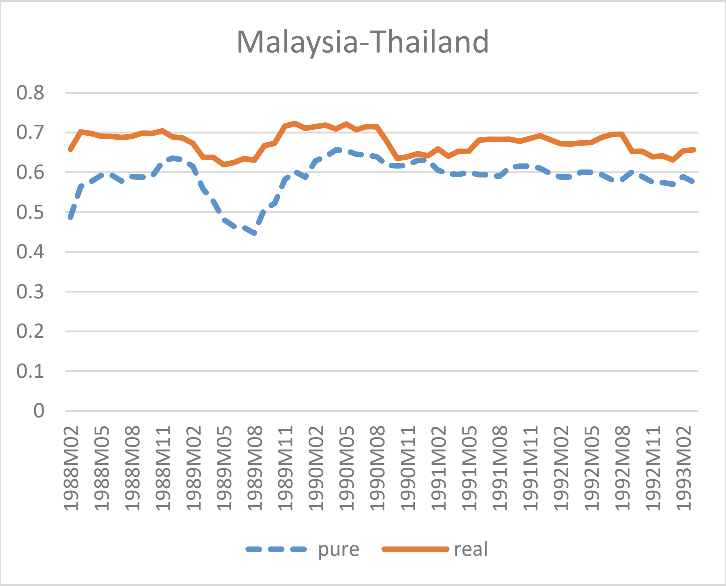
Panel (e)



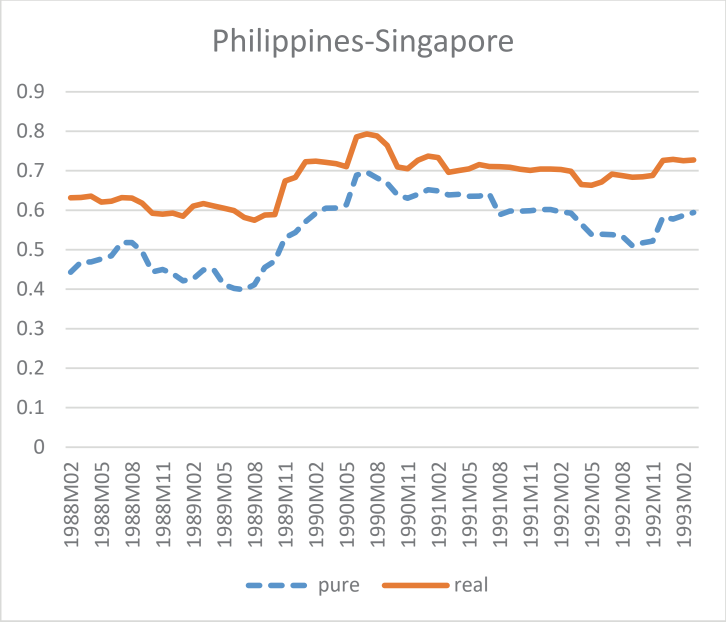
Panel (f)



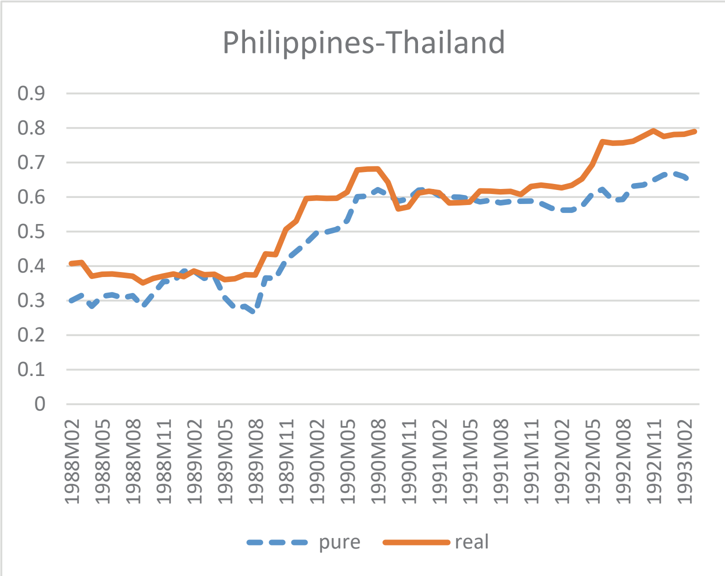
Panel (g)



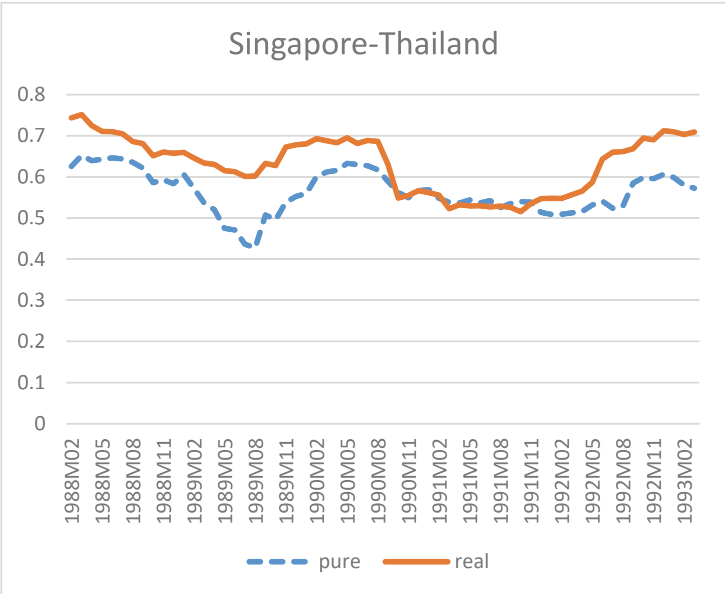
Panel (h)



Panel (i)



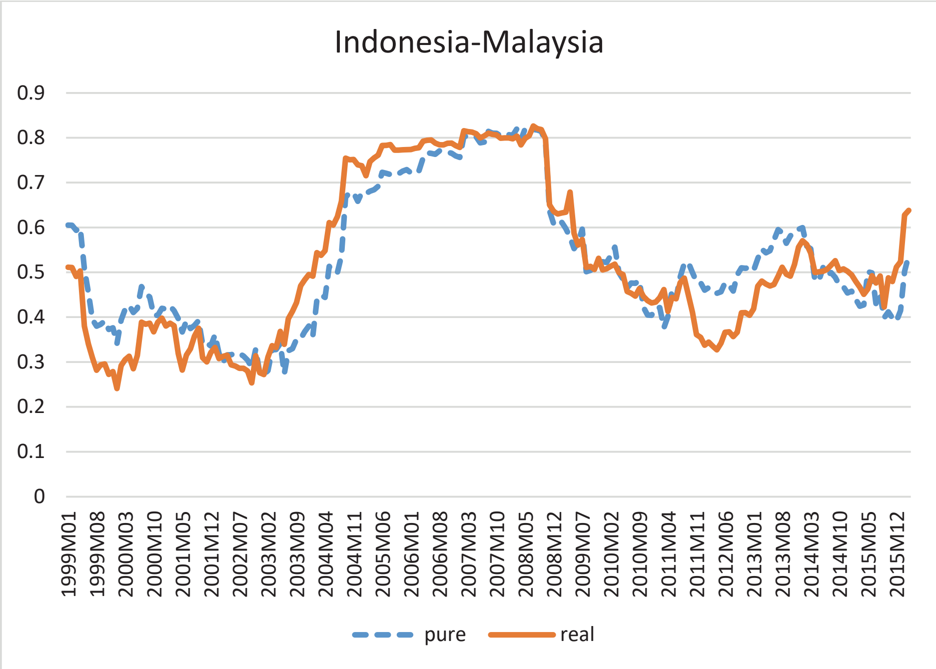
Panel (j)



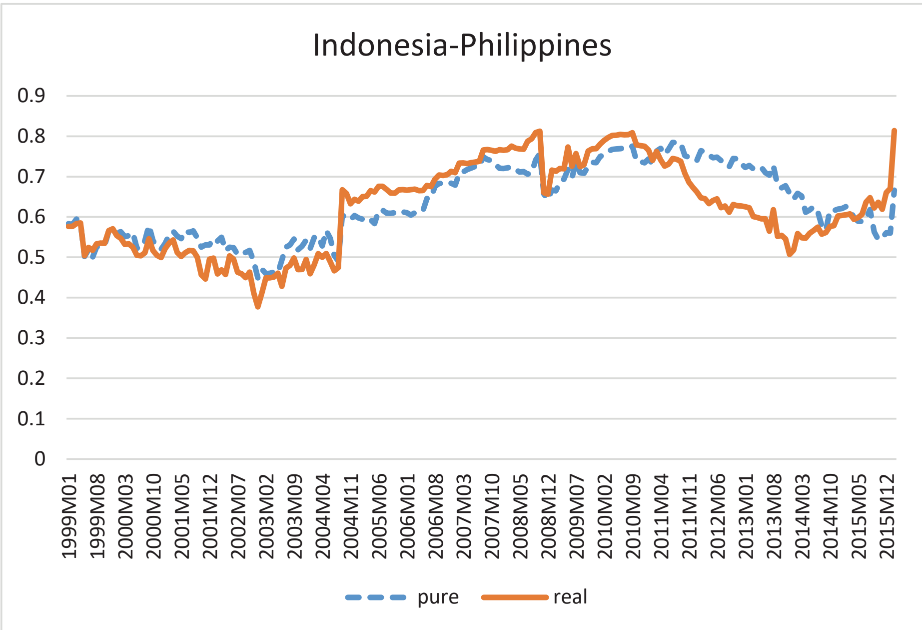
Note: The horizontal axis indicates the first date of the rolling window.
Data source: Pure returns are calculated from the series of real stock returns obtained by historical decomposition, which are affected only by pure shock.

Figure 9: Rolling correlations of real pure returns in the five ASEAN countries

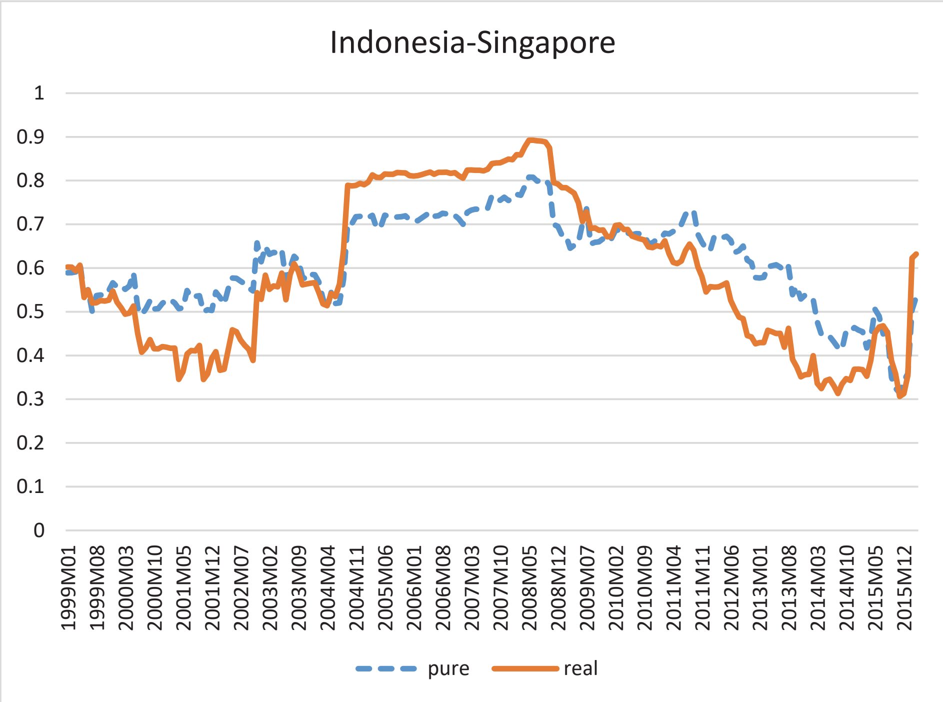
Panel (a)



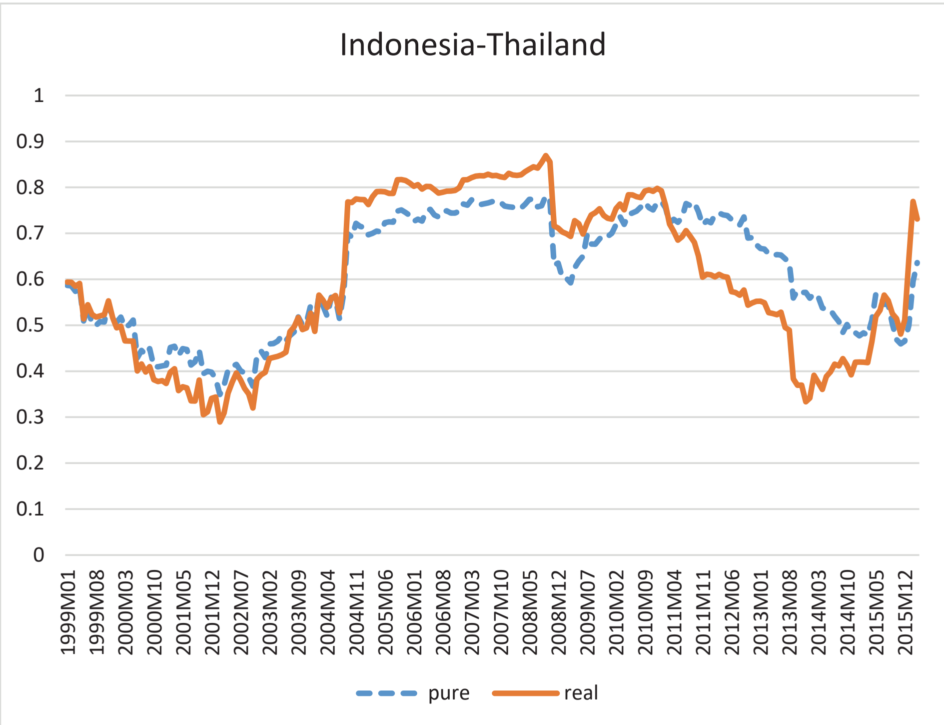
Panel (b)



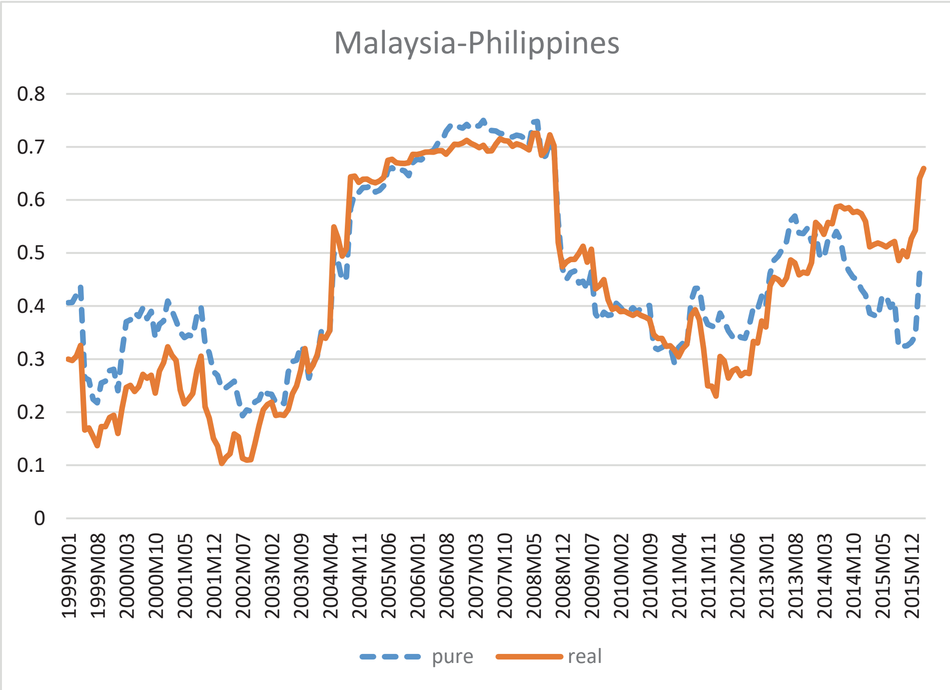
Panel (c)



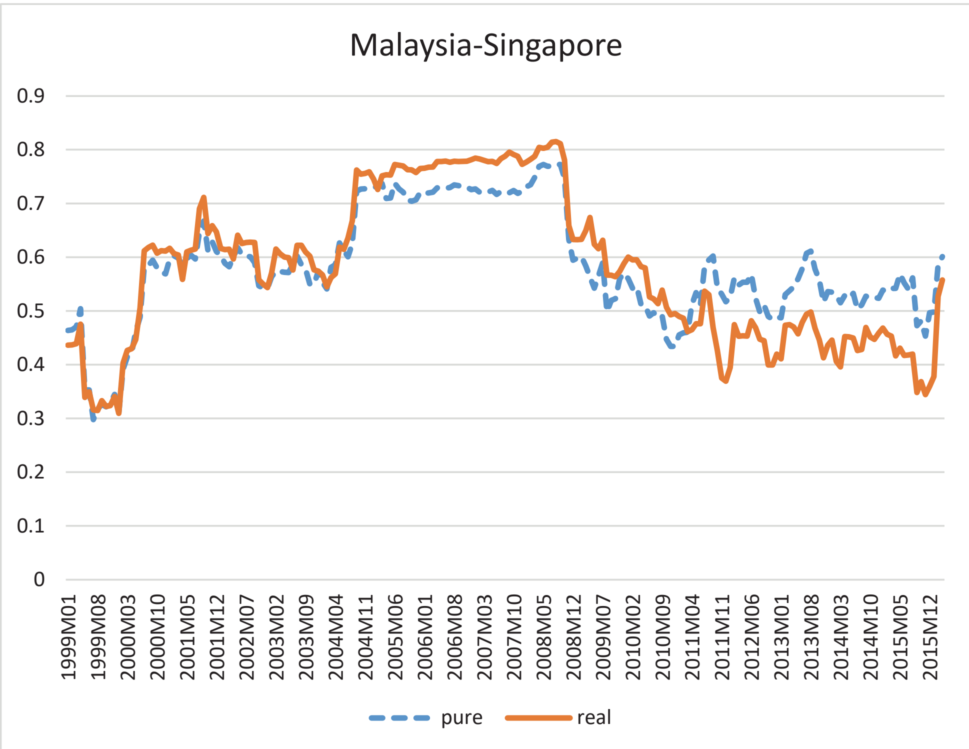
Panel (d)



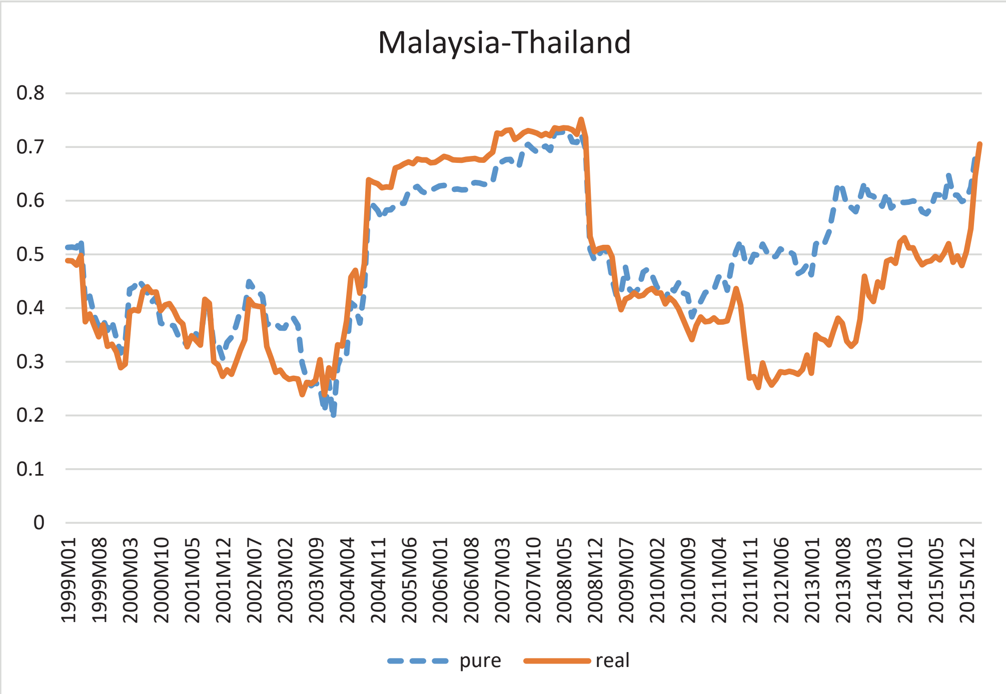
Panel (e)



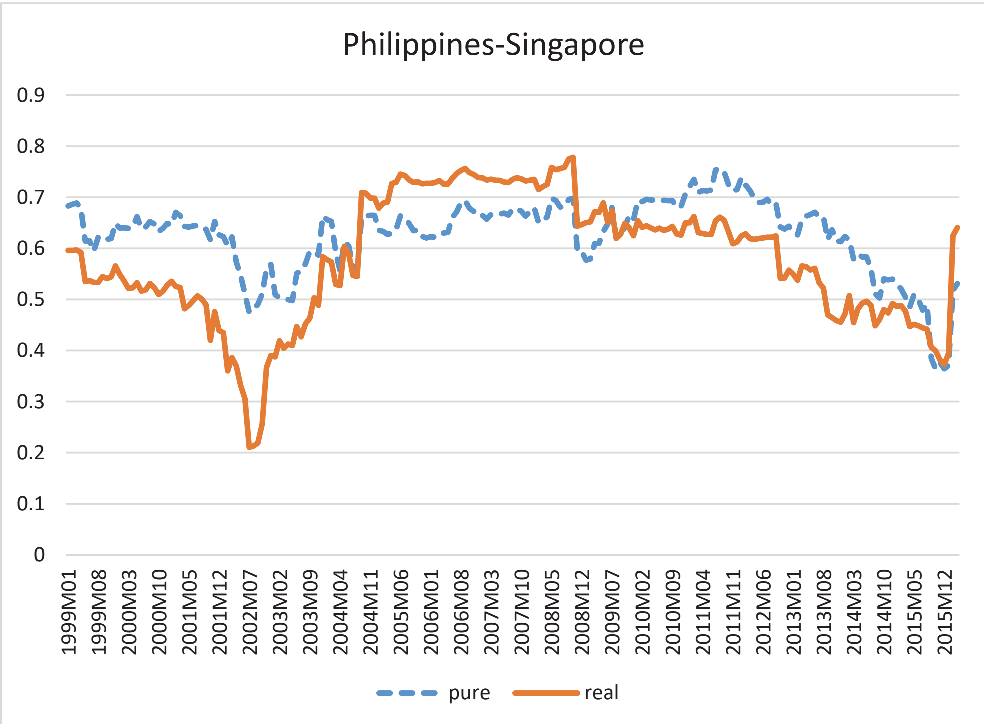
Panel (f)



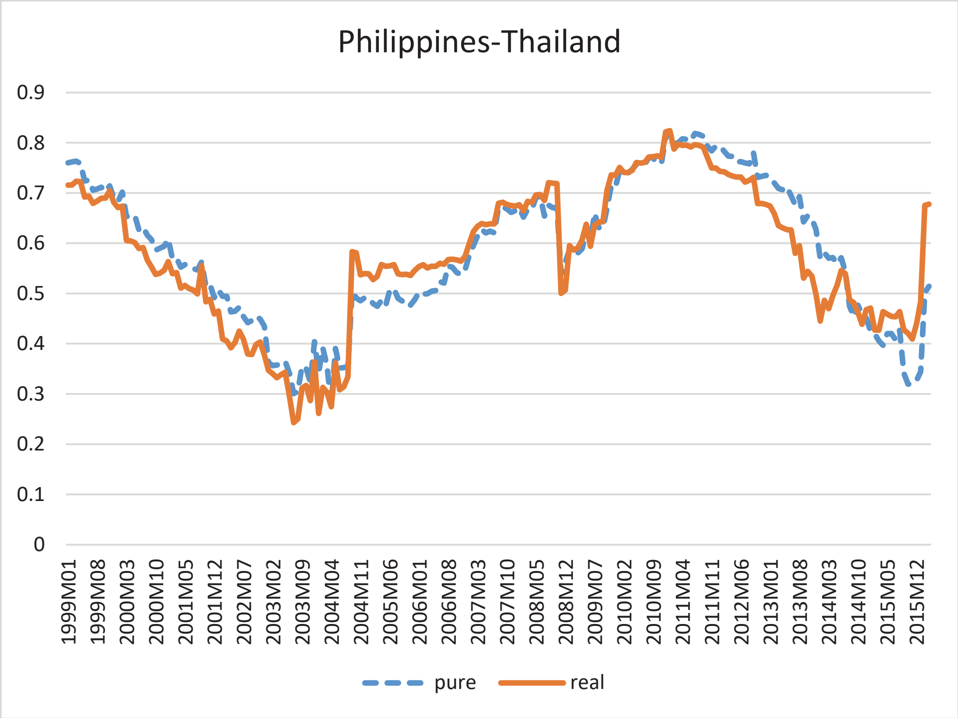
Panel (g)



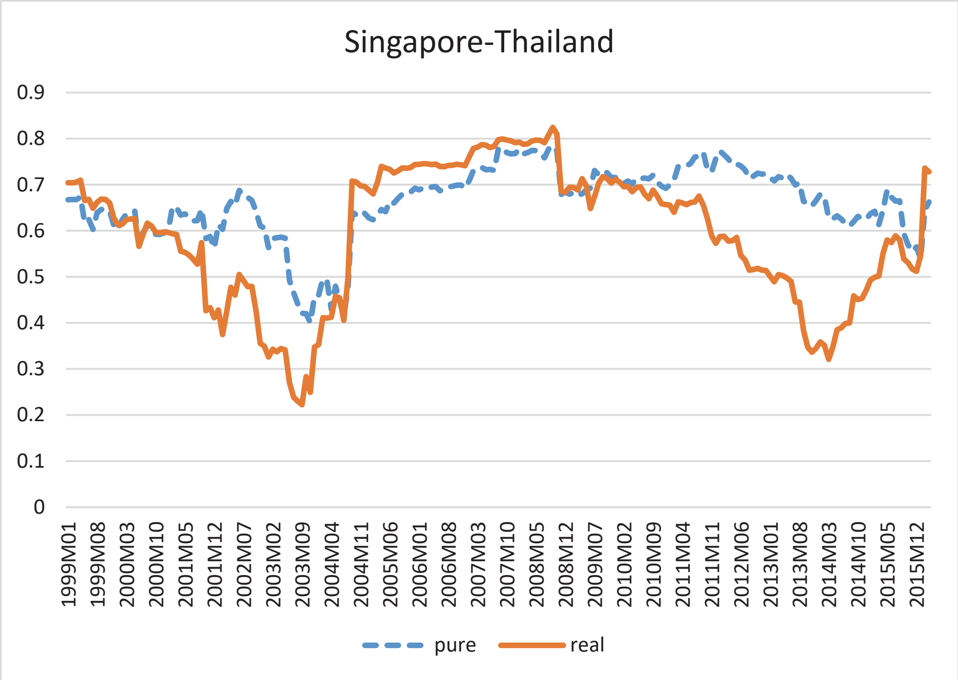
Panel (h)



Panel (i)



Panel (j)



Note: The horizontal axis indicates the first date of the rolling window.
Data source: Pure returns, which are affected only by pure shocks, are calculated from the series of real stock returns obtained by historical decomposition.

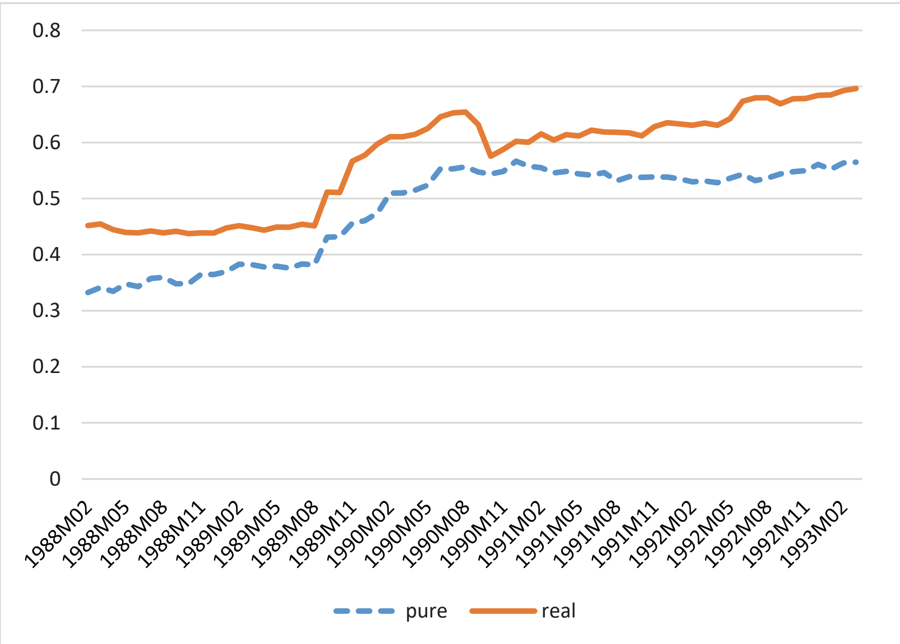
In the first half period (Figure 8), we can divide the pairs of the five ASEAN countries into those that show an upward correlation trend and those that remain stable with correlations of around 0.6 to 0.7. In most cases, real returns exceed pure returns, and the oil shock increases the correlations between stock markets. In particular, in the Indonesia-Malaysia, Indonesia-Philippines, and Indonesia-Thailand pairs, the oil shock increases the correlation by around 0.2. However, except for the Indonesia-Thailand pair, the effect of the oil shock fluctuates over time.

In the latter half period (Figure 9), the correlations of real returns for most pairs rose from around 2003 to 2008 and showed a declining trend thereafter. What is notable compared to the first period is that the direction of the oil shock's effect also fluctuates. While the oil shock increased correlations around the GFC, in many cases, it decreased correlations before and after that period. In other words, the oil shock amplified the correlations' fluctuations in the latter period.

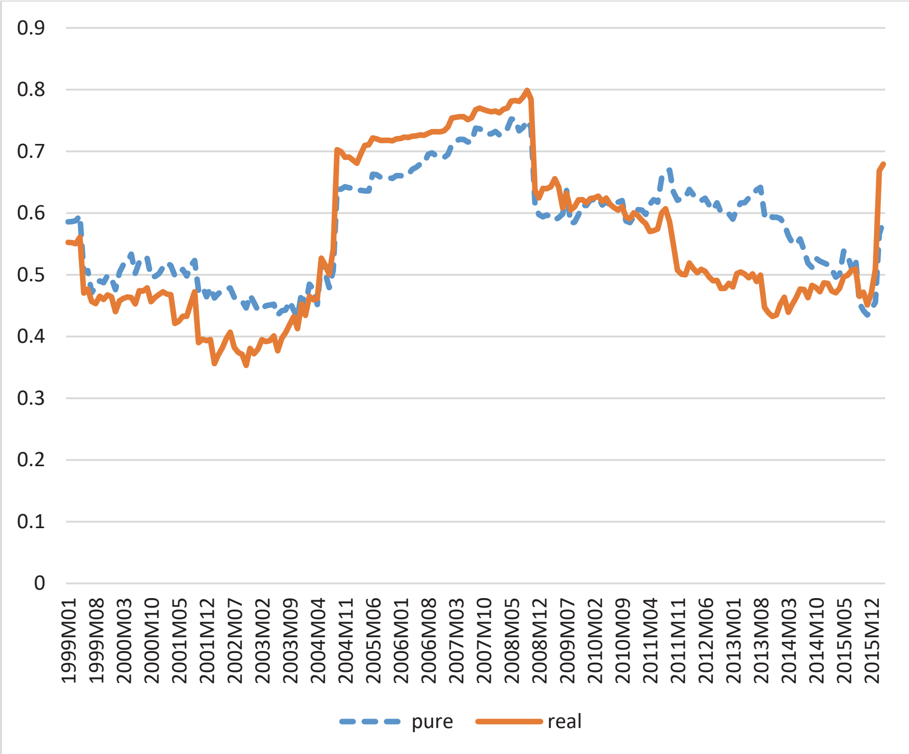
In Figure 10, we plot the average rolling correlation coefficients of pure returns for the 10 pairs shown in Figures 8 and 9 and the average correlation coefficients of real stock returns.

Figure 10: The average rolling correlation coefficients of pure returns

Panel (a)



Panel (b)



Note: The horizontal axis indicates the first date of the rolling window.
Data source: "Pure" is calculated by averaging the correlation coefficients of pure returns between 10 pairs of five ASEAN countries for each rolling window. "Real" is the same as the value in Figure 3.

In the first half period, the average value of the rolling correlations of real returns is consistently higher than that of pure returns. In contrast, in the second half period, the relationship between pure and real return correlations changes over time, resulting in amplified fluctuations in the correlation coefficients of real returns compared to those of pure returns.

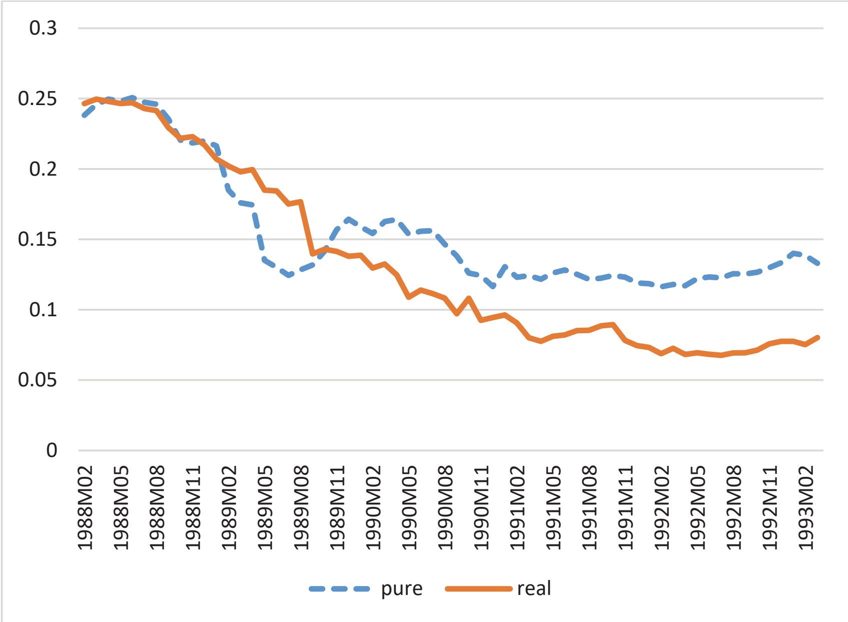
In Figure 11, the standard deviation of the rolling correlation coefficients for the 10 pairs shown in Figures 8 and 9 is plotted simultaneously with the standard deviation of the correlation coefficients of real returns shown in Figure 4.

Figure 11 reveals that in the first half period, the standard deviation of the correlation coefficient for pure returns is higher than that for real returns, while in the second half period, there is almost no difference between the two.

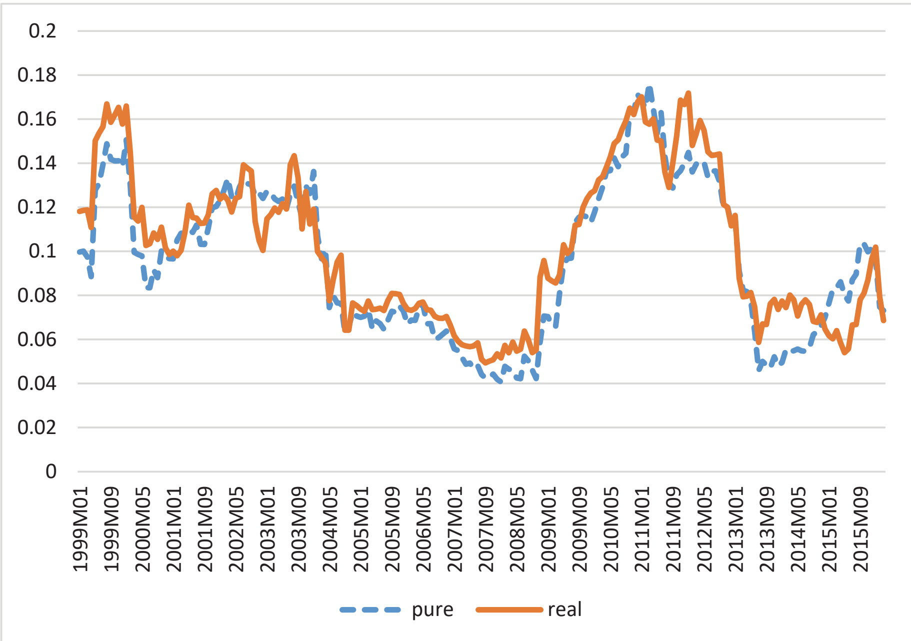
At the beginning of the first half period, disparities were present in the development of the five ASEAN countries' stock markets. The stock markets of Malaysia, Singapore, and Thailand were relatively large in terms of the ratio of market capitalization to GDP and number of listed companies (Kawai 1992). The correlations between real and pure returns among these markets were stable at a

Figure 11: Standard deviation of rolling correlations of pure returns

Panel (a)



Panel (b)



Note: The horizontal axis indicates the first date of the rolling window.
Data source: "Pure" is the standard deviation of the correlation coefficient of the pure return between 10 pairs of markets in the five ASEAN countries for each rolling window. "Real" is the same as the value in Figure 4.

relatively high level. In contrast, the correlations between Indonesia, which had a particularly underdeveloped stock market at the beginning, and other markets showed an upward trend but was consistently lower than other cases. In addition, the correlations of oil shocks between Indonesia and other countries tended to be higher than the correlations of pure returns. Thus, oil shocks increase correlations between markets (Figure 10, Panel (a)) but reduce the dispersion (standard deviation) of the correlations (Figure 11, Panel (a)).

In the latter half period, the correlations of pure shocks for many pairs increased around the GFC and has since declined. These results are consistent with those of previous studies, particularly Guimarāes-Filho and Hong (2016). As for the declining correlations in the 2010s, possible reasons include the declining degree of capital movement freedom in each country, as indicated by the Chinn-Ito index, and the emergence of political risks in Thailand, Malaysia, and other countries.

In contrast, the average correlation coefficient of real returns was lower than that of pure returns around 2000 and after 2011 but exceeded that of pure returns around the GFC, amplifying the correlation coefficient fluctuations (Figure 10, Panel (b)). However, the oil shock did not affect the dispersion between markets (Figure 11, Panel (b)).

As Figure 6 shows, the period when the correlations of real returns declined coincided with that when the relationships between ASEAN countries' stock prices and oil prices was not visible. Since we consider the world oil price exogenous to stock prices in ASEAN countries, the oil shock during this period may have had different impacts on each country's real returns in terms of direction and magnitude, lowering the correlations of real returns.

In this study's empirical framework, the impact of a single-unit oil shock (supply, aggregate demand, or demand shocks specific to the oil market) on each country's real return does not change. Still, as seen in Figure 7, the importance of structural shocks that move oil prices varies over time. Around 2000 and since 2011, oil prices have fluctuated almost entirely due to oil market-specific demand factors. Hence, the deviation between real and pure returns during this period is likely almost entirely due to differences in the responses of real returns to oil market-specific demand shocks.

To conduct such an analysis, the oil price shock must be broken down into its factors. This result demonstrates the superiority of this study's analytical method.

8. Conclusion

This study examines the correlation structure of real stock price returns in five major ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) using a VAR model to quantitatively evaluate how oil price fluctuations impact this correlation structure.

The results of this study reveal the following points. First, the correlation coefficients of real stock returns have repeatedly risen and fallen over the medium term, with no overall upward trend. Second, the results of the impulse response and historical decomposition of oil prices show that each structural shock's effect on real returns and the contribution of each structural shock to oil price fluctuations change over time. Third, the historical decomposition reveals that oil price shocks affect real return correlations between markets. Fourth, the impact of oil shocks on real returns differs between the first and second half periods, and, particularly in the second half period, the oil market-specific demand shock amplified the fluctuations in the correlations of real returns.

The asymmetric impacts of global factors on each country's macroeconomy and asset market are not limited to Asian stock markets. Iwaisako and Nakata (2019) revealed that oil price shocks have asymmetric effects on Japan and Australia's real effective exchange rates. Many previous studies have also focused on the differences in the reactions of macroeconomic variables and asset prices to oil price shocks between oil-exporting and -importing countries. This study's analysis also reveals that the responses to oil price shocks in Indonesia, an oil-producing country, and Thailand, an oil-importing country, differed significantly before the Asian currency crisis.[12]

However, issues must be considered before we can conclude that the asymmetric effects of oil price shocks are due to differences between oil-exporting and -importing countries. For example, the cumulative impulse response results show that the supply shock significantly and positively affected Indonesia's real stock return. This is a positive shock to the growth rate of world oil production, which has a negative impact on crude oil prices, so it is not consistent with the reaction of oil-producing countries that is usually assumed. Therefore, further analysis is needed to determine the factors that produce the asymmetric effect of oil price shocks, including the influence of exchange rate regimes and monetary policy regimes, as Vu and Nakata (2018) pointed out.

This study analyzed the time-varying correlations of real returns using rolling estimation. Still, it only considered changes in the relationship between the world oil market and each market's real returns over the long term around the timing of the Asian currency crisis. Previous research suggests that the interdependency of stock markets and impact of oil price fluctuations on the stock market are time varying, even in the short term. Therefore, as a future task, we plan to analyze shorter-term changes using time-varying parameter VAR and other methods.

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[12] However, Indonesia's balance of payments for crude oil and petroleum products has been in the red since 2003 (and since 2013, the balance of payments for crude oil alone has been in the red). Since the currency crisis, Indonesia has been considered an almost entirely oil-importing country. In recent years, Malaysia's balance of payments for crude oil and petroleum products has had periods of deficit and periods of surplus; thus, it cannot be considered either an oil-exporting or -importing country (although the balance of payments for crude oil alone has continued to be in the surplus).

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The Effects of COVID-19 on Firm Behavior – the Case of Japan

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Abstract

Following the onset of the coronavirus disease (COVID-19) pandemic, social distancing and government-mandated lockdowns became the norm. These measures have limited interactions among people, firms, and society, triggering an even larger decline in economic activity. In this study, we apply annual Japanese foreign affiliate data to quantify how COVID-19 has affected various aspects of firm behavior. The estimation results show that both the revenue and purchasing behavior of Japanese foreign affiliates have been affected by COVID-19. This negative impact occurred mainly through stringent regulations imposed by the host countries where affiliates are located. In general, these findings indicate that COVID-19 has negatively affected Japanese firms engaged in overseas activities. This leaves us with the question of when external shocks such as COVID-19 hinder firms' overseas activities and what role the government should play to achieve a balance between safety and economic revival.

Keywords: COVID-19, parent-affiliate data, lockdown, firm performance.
JEL Classification Codes: D22, D24, F21, F23.

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1. Introduction

Motivation and hypothesis

The shock from the coronavirus disease (COVID-19) pandemic quickly spilled over to the global economy, triggering a dramatic decline in economic activity driven by social distancing practices, government-mandated lockdowns, and other mobility restrictions. The media have frequently used the word “unprecedented in describing the consequences of the pandemic crisis.” An example of such commentary is that on the possibility of the world economy entering a period of de-globalization. Additionally, the first half of 2020 witnessed the largest decline in world trade and output since World War II (Antràs, 2020). The restrictions invoked under COVID-19 distorted economic activity by disorganizing work (supply side) and limiting people’s ability to consume (demand side), as well as through additional frictions in the functioning of transportation and distribution networks.

Moreover, as firms increasingly engage in overseas activities, the effects of the pandemic on various types of firms are important to assess. Accordingly, we hypothesize that firms engaging in multinational activities are more likely to be negatively affected by COVID-19 (either the disease itself or relevant lockdown policies). We examine how foreign affiliates’ activities have been affected by COVID-19. We further hypothesize that affiliates that rely more on the host country’s local markets for sales and production have been more negatively affected by COVID-19. We also investigate how COVID-19 has affected intra-firm trade and what types of restrictions in a host country have an impact.

What we do in this paper

We use annual Japanese foreign affiliate firm data to conduct a thorough evaluation of the impact of COVID-19 on the behavior of Japanese firms. These data are used to investigate how COVID-19 has caused chaos in multinational enterprises (MNEs). We conduct a reduced-form empirical analysis to investigate the mechanism by which multinational activities negatively affected firm performance during the COVID-19 pandemic. In this study, we find that lockdown measures may have negatively affected multinational activities during the COVID-19 pandemic. School closures, restrictions on gatherings, and work-from-home orders negatively affect affiliates’ local revenue and purchases. No other lockdown measures consistently demonstrated any significant effects. We find that lockdown measures can transmit this effect across borders and have a negative impact on other countries through foreign firms’ affiliates. This finding may have implications for the international coordination of disease control measures.

The policy implications of these findings are twofold. COVID-19 has had a negative impact on the sourcing and sales activities of Japanese firms’ foreign affiliates. When firms’ overseas activities are negatively affected by unexpected external shocks, such as the COVID-19 pandemic, local government officials should consider how to support these firms, especially those that are most vulnerable to such shocks. Meanwhile, different lockdown regulations in host countries have heterogeneous effects on the decision-making of Japanese foreign affiliates, which may spill over to their parent firms. Nevertheless, without further analysis, we cannot conclude whether these are temporary or long-term effects.

The remainder of this paper is structured as follows. Section 2 discusses the existing literature and how we position the current study. Section 3 introduces the data and methodology used in the analysis. Section 4 presents the estimation results and robustness checks. Finally, Section 5 concludes the paper.

2. Existing Literature

This study relates to two strands of research: the effect of pandemics and the impact of natural disasters on economic activity. The first includes literature focusing on pandemics and their economic impact. Research on how pandemics affect trade and economic development began before the COVID-19 outbreak. Huang (2021) used the 2003 severe acute respiratory syndrome (SARS) epidemic as a natural experiment to examine the resilience of Chinese manufacturing importers. That study found that firm imports fell by 7.9% on average when SARS hit the trade route. Furthermore, at its peak, the epidemic reduced total Chinese manufacturing output by approximately 0.7%. Previous research has also identified the detrimental effects of the 2014 Ebola outbreak in Africa, which led to a decrease in the provision of agricultural products and malnutrition in Africa (Alpha and Figuié, 2016). Since the beginning of the COVID-19 pandemic, various studies have been published on its effects on trade and the economy. For example, Hayakawa and Mukunoki (2020) discovered negative effects on durable and essential products and that workplace closures had significantly negative effects on trade. Chen et al. (2022) used high-frequency city-to-city truck flow data to estimate the economic costs of lockdown in China. Their model implied that a full lockdown in major cities reduced the real gross domestic product (GDP) by 4%. In this study, we investigate how different lockdown methods in one country can affect the overseas activities of MNEs differently and in what aspects.

This study also contributes to the literature on the impact of natural disasters on economic activity. For example, the 2011 Tōhoku earthquake in Japan caused severe disruptions to the affiliates of Japanese multinationals in the United States (Boehm, Flaaen, and Pandalai-Nayar, 2019). Carvalho et al. (2020) quantified the role of input–output linkages as a mechanism for the propagation and amplification of shocks. Their study found that the disruption caused by the disaster propagated upstream and downstream along supply chains and affected the direct and indirect suppliers and customers of disaster-stricken firms. However, in contrast to previous studies, we consider the input–output relations of MNEs across multiple countries.

3. Data, empirical approach, and robustness checks

3.1. Data

Firm-level Japanese foreign affiliates

Our data include extensive firm-level information on Japan's foreign affiliates from the Survey on Overseas Business and Activities prepared by the Research and Statistics Department of the Japanese Ministry of Economy, Trade and Industry (METI). This annual survey is conducted by METI using a questionnaire and covers all Japanese firms with at least one business enterprise in a foreign country. We focus mainly on the information provided by foreign affiliates, and our sample period covers 2018–2020. The survey includes both manufacturing and non-manufacturing sectors, but excludes firms in the finance, insurance, and real estate sectors. The survey questions cover a broad range of economic issues, including the establishment year, number of employees, assets, sales, and purchases by destination country, and some intellectual property indicators. Intra-firm trade information, such as exports to and imports from Japanese parent firms, is also included. While basic questions are constant across years, a subset of questions has some annual variations. In recent years, the trend has been to simplify surveys. However, the sector classifications used in the survey do not correspond to international standards (e.g., United Nations Industrial Development Organization or Organisation for Economic Co-operation and Development classifications) and changed slightly in 2002 and 2008. Therefore, we use the concordance table provided by Japan's Research Institute of Economy, Trade and Industry and aggregate it into 30 sectors.

First, we investigate affiliate revenues and purchases across parent firms. On average, 57% of the total revenue earned by an overseas affiliate in 2018 came from sales in the local market (Figure 3). Among local sales, on average, 51% of revenue was from sales to local Japanese firms, whereas 45% was from sales to local firms (Figure 4). Finally, on average, 49% of affiliates' sourcing comes from the local market (Figure 5). Among purchases from the local market, 65% are from local firms (Figure 6).

In this study, we are mainly interested in the performance of MNEs' overseas activities during the COVID-19 pandemic. For this purpose, we use Japan's foreign affiliate data from 2018 to the end of 2020, as the most recently available data are up to 2020. To address endogeneity concerns, we use firm-level control variables from 2018.

Country-level COVID-19 restrictions

We use indicators representing the damage caused by COVID-19 collected from the Oxford COVID-19 Government Response Tracker (Hale et al., 2021). Recent studies, such as Hayakawa and

Mukunoki (2021), also applied this dataset. The Oxford COVID-19 Government Response Tracker collects publicly available information on 21 government response indicators using a team of over 200 volunteers from the Oxford community and is updated continuously. We use eight of these policy indicators (C1–C8) that provide information on containment and closure policies because we assume that these indicators are those most likely to affect firms' decision-making.[1] For example, C2 Workplace closure includes 1 – recommended closure (or recommended work from home), 2 – required closure (or work from home) for some sectors or categories of workers, and 3 – required closure (or work from home) for all but essential workplaces (e.g., grocery stores, hospitals). Thus, a larger magnitude of the answer to question C2 corresponds to more severe restrictions related to COVID-19. This indicator is closely related to employees' working status and therefore assumed to affect firm behavior directly. Therefore, the more restrictive the index, the more negative the impact it may have on firms.

Other indicators include C1 School closure, C3 Cancel public events, C4 Restrictions on gatherings, C5 Close public transport, C6 Stay-at-home requirements, C7 Internal movements, and C8 International trips. All take categorical answers, as with C2 above. Compared to C2, these indicators have relatively indirect effects on firms. For example, during school closures, parents must stay at home to take care of their children, which reduces employees' working efficiency and negatively affects firms. For a more detailed description, please refer to Hale et al. (2021).

We merge affiliate-level data with country-level restriction data using three-digit ISO country codes across time. In addition to the sourcing and sales behaviors of Japanese foreign affiliates in local markets, we examine how heterogeneous COVID-19 restrictions affect within-firm interactions.

3.2. Empirical strategy

Effects of lockdown policies

Our empirical specifications explore the heterogeneous effects of COVID-19 and lockdown policies in each destination country. We use different indicators as proxies for the heterogeneous policies in each country. For example, using the stringency of workplace closures, as shown in Figure 2, workplace closures are less severe in Europe and Africa and more stringent in countries such as Russia, India, and Australia. We then include country-level stringency indicators as our variables of interest and examine how they affect the revenue of Japanese affiliates located in that country. As an alternative, we test the indicator of stay-at-home requirements, as shown in Figure 1. As robustness checks, we use international travel restrictions, public transport closures, and school closures in destination

[1] E1–E4 record economic policies such as income support to citizens or the provision of foreign aid. H1–H8 record health system policies such as the COVID-19 testing regime or emergency investments in healthcare. Three indicators (V1–V3) record vaccination policies. These measures are assumed to affect individuals more.

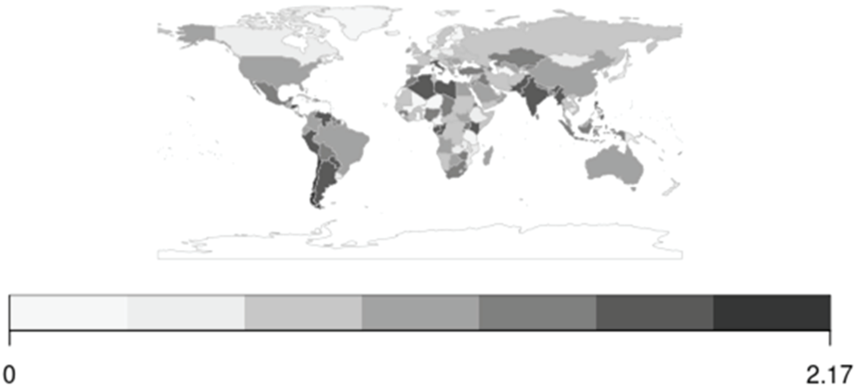
countries to account for the effects of COVID-19.

We examine the differential effects of the pandemic on MNEs and domestic firms by examining how their different responses before and after COVID-19. The baseline estimation takes the following continuous difference-in-differences form[2]:

$$Y_{fct} = \alpha_0 + Stringency_{ct} \times Post\_Covid_t + X_{fct} + FE_t + \varepsilon_{fct} \qquad (1)$$

Y_{fct} is the annual performance of foreign affiliate f located in country c at time t. In practice, we include the revenue or sourcing values of the affiliate and the intra-firm trade measures between the parent and affiliate firms. The stringency term is a country-level continuous variable proxied by the measurements introduced above. $Post\_Covid_t$ is a dummy variable that equals 1 if t = 2020 and 0 otherwise. X_f is a vector of firm-level covariates.

Figure 1: Stay-at-Home Restrictions in Destination Countries

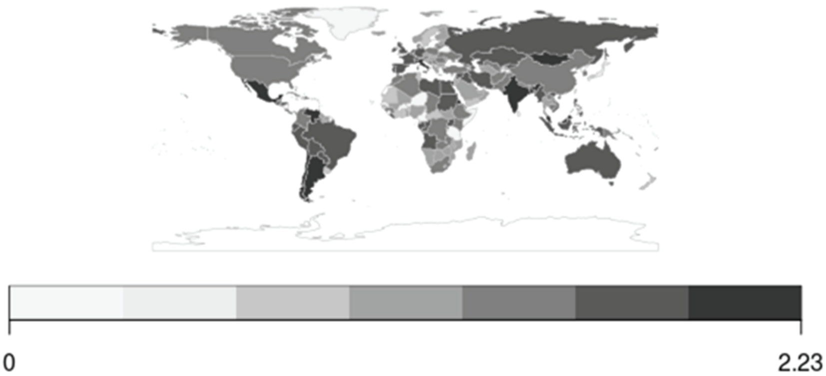


Note: COVID-19 = coronavirus disease. The unit of measurement is based on an ordinal scale: 0 – no measures; 1 – recommended closing (or recommended work from home) or all businesses open with alterations, resulting in significant differences compared to non-COVID-19 operations; 2 – required closing (or work from home) for some sectors or categories of workers; 3 – required closing (or work from home) for all-but-essential workplaces (e.g., grocery stores, doctors). The score for each country is the average of the scale over one year.

Sources: Oxford COVID-19 Government Response Tracker (Hale et al., 2021) and the authors' own calculations.

[2] Although we are aware that the difference-in-differences approach relies on the parallel trends assumption, which has also been noted by the referee, owing to data limitations, we are unable to show the evidence in the current draft.

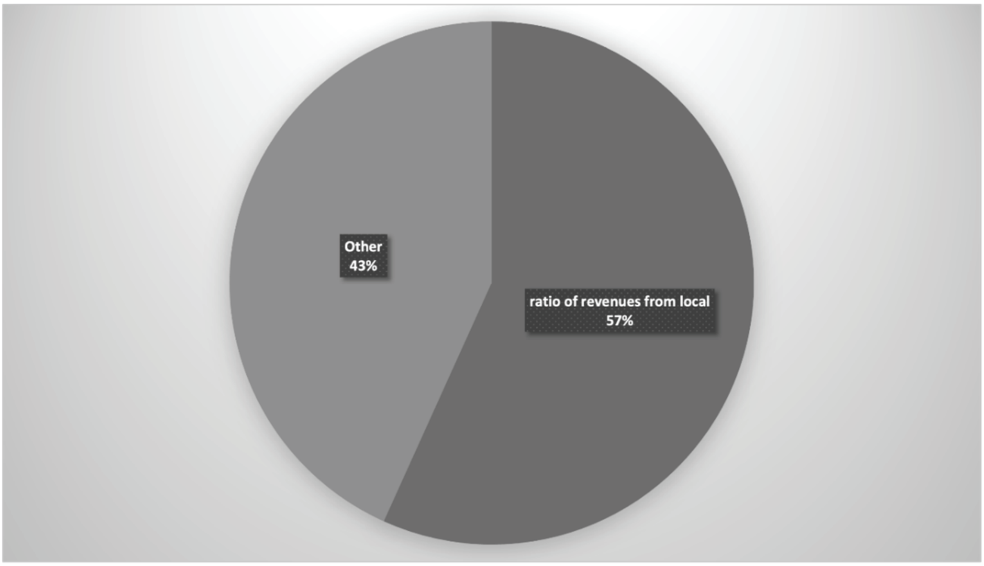
Figure 2: Workplace Closures in the Destination Country



Note: COVID-19 = coronavirus disease. The unit of measurement is based on an ordinal scale: 0 – no measures; 1 – recommended closing (or recommended work from home) or all businesses open with alterations, resulting in significant differences compared to non-COVID-19 operations; 2 – required closing (or work from home) for some sectors or categories of workers; 3 – required closing (or work from home) for all-but-essential workplaces (e.g., grocery stores, doctors). The score for each country is the average of the scale over one year.

Source: Oxford COVID-19 Government Response Tracker (Hale et al., 2021) and authors' calculations.

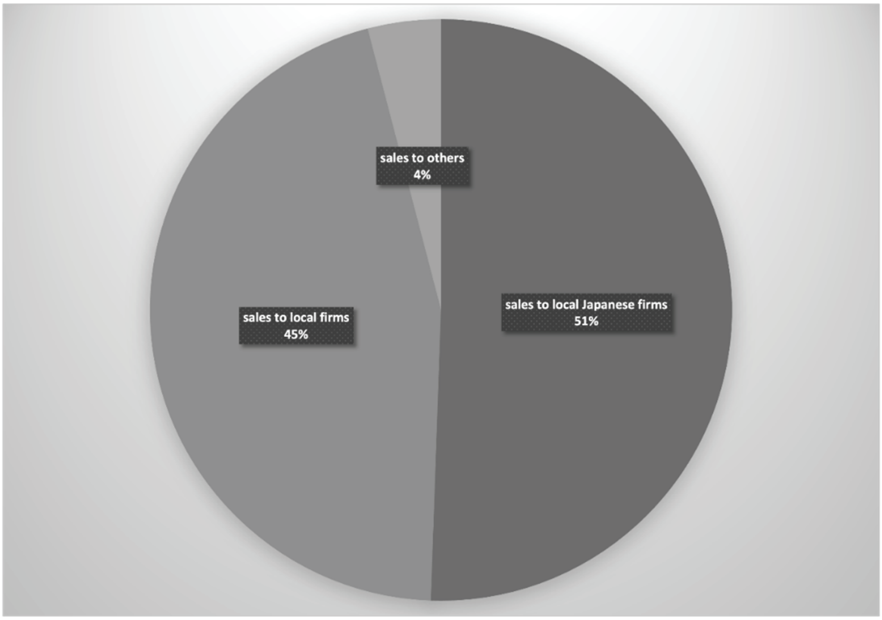
Figure 3: Revenue Sources Ratios – Local vs. Other



Note: "Revenues from local" is defined as the revenue owned by the affiliate firm from the local host country market where the affiliate is located.

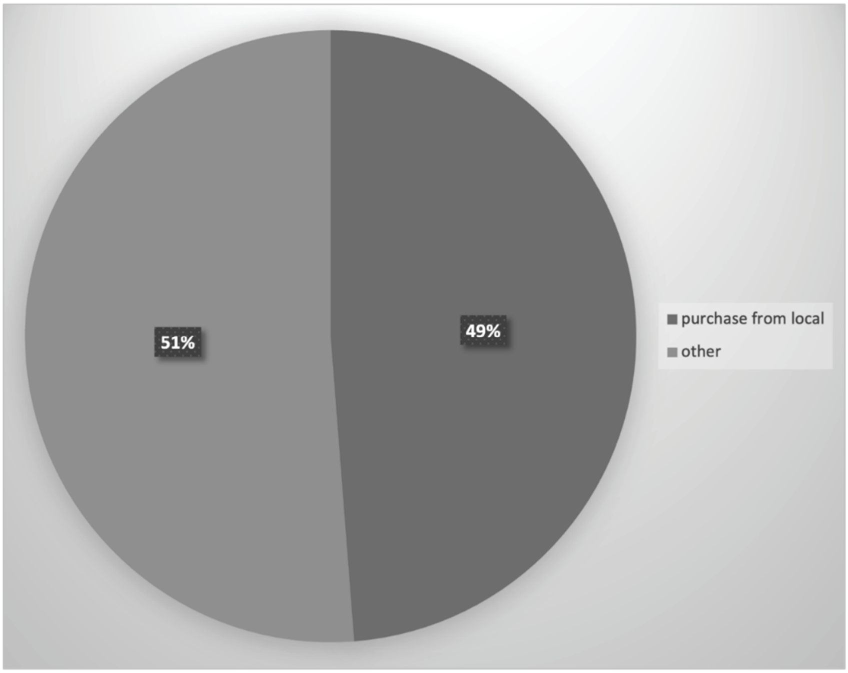
Sources: Survey on Overseas Business and Activities of the Ministry of Economy, Trade and Industry (METI) and the authors' own calculations.

Figure 4: Different Local Revenue Sources



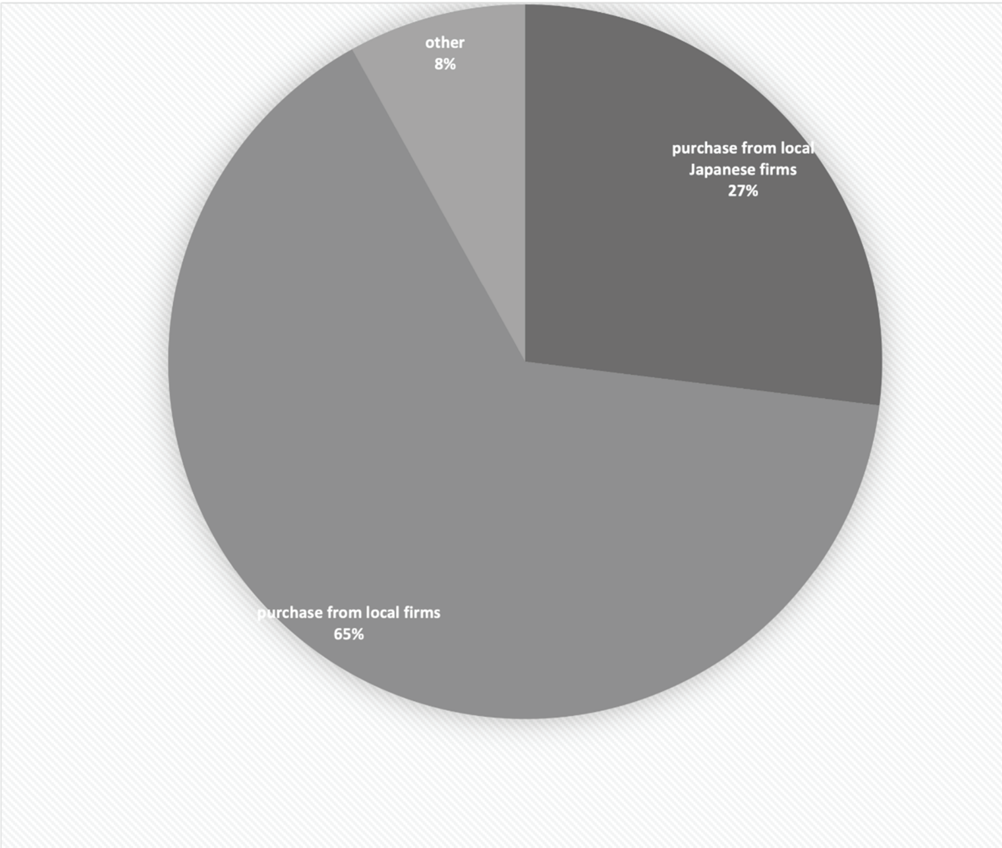
Source: Survey on Overseas Business and Activities of the Ministry of Economy, Trade and Industry (METI) and the authors' own calculations.

Figure 5: Different Purchase Sources



Source: Survey on Overseas Business and Activities of the Ministry of Economy, Trade and Industry (METI) and the authors' own calculations. "Purchase from Local" refers to purchases from local suppliers.

Figure 6: Sources of Purchases from Local Market



Source: Survey on Overseas Business and Activities of the Ministry of Economy, Trade and Industry (METI) and the authors' own calculations.

4. Estimation results

4.1. Baseline results

Table 2 summarizes the estimation results for Equation (1). When we focus on the affiliate's total local purchases and revenue, irrespective of whether we use the indicator for school closures, stay-at-home requirements, or restrictions on gatherings as the stringency proxy, the average treatment effect on the treated is always negative and significant. Furthermore, it remains significant regardless of whether we use samples from manufacturing industries only or from all industries. This shows that when we keep other conditions constant, more stringent COVID-19 regulations in the destination country will cause more damage to the Japanese affiliates located in that country. Of the eight stringency indicators, the three personal communication-related indicators are most likely to have a negative impact on firms' decision-making. This suggests that when employees are restricted from engaging in face-to-face interactions or distracted from work by taking care of their children (school closures may lead to parents spending more time with their children), it may negatively affect firm performance.

Another notable finding is how COVID-19 stringency indicators affect affiliates' overseas purchases and sales behavior. As shown in Table 3, restrictions negatively affect affiliates' purchases from Japan, the third country, and the Japanese parent firm. In contrast, restrictions on affiliates' revenue do not appear to have an impact with respect to the above three categories (revenue to Japan, the third country, and the Japanese parent firm). This indicates that COVID-19 regulations in destination countries have more severe effects on affiliates' cross-border sourcing patterns than on their sales abroad. A possible explanation might be that personnel working in firms' purchasing departments are more affected by COVID-19 restrictions than their counterparts working in sales-related departments. More detailed information is required to verify this phenomenon.

Combined with the above results, we can infer that Japanese MNEs' overseas affiliates have been negatively affected by COVID-19 in terms of both their local sales and sourcing activities, and that this impact is mainly through the channel of stringent regulations imposed by the destination countries where foreign affiliates are located. The affiliates' sourcing activities outside the destination countries were also affected; however, their sales patterns remained unchanged. These findings provide evidence that Japanese overseas affiliates are sensitive to external shocks, such as the COVID-19 pandemic, in their destination environment.

4.2. Robustness checks

In the baseline estimations, we use samples from manufacturing industries. However, it could be argued that firms in these industries have responded to COVID-19 differently than firms in other industries, such as service industries. Thus, we go a step further and perform two exercises. First, we expand our sample to include all industries. Second, we choose samples with both headquarters and foreign affiliates in manufacturing industries. The results (available upon request) are consistent with the baseline results. Compared to the baseline estimations using a limited sample, the signs do not change. The magnitude is larger in absolute terms when both the headquarters and foreign affiliates are in manufacturing. This implies that firms in manufacturing industries have been affected more by COVID-19 through the interaction between Japanese headquarters and their foreign affiliates.

Table 1: Results on Affiliate Revenue Sources

	Affiliate-level Revenues from Host Country Market							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.131***	-0.0429	-0.0507	-0.0689***	-0.0631	-0.0870**	-0.0279	0.0478
	(0.0294)	(0.0329)	(0.0425)	(0.0198)	(0.0396)	(0.0369)	(0.0404)	(0.0308)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.953	0.953	0.953	0.953	0.953	0.953	0.953	0.953
Obs	9,971	9,971	9,971	9,971	9,971	9,971	9,971	9,971
	Affiliate-level Revenues from Local Firms in the Host Country							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.116**	-0.00599	0.0122	-0.0281	-0.0120	-0.0562	-0.0279	0.0944
	(0.0587)	(0.0544)	(0.0667)	(0.0311)	(0.0702)	(0.0662)	(0.0679)	(0.0625)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.926	0.926	0.926	0.926	0.926	0.926	0.926	0.926
Obs	5,446	5,446	5,446	5,446	5,446	5,446	5,446	5,446
	Affiliate-level Revenues from Japanese Firms in the Host Country							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.160***	-0.0592	-0.114**	-0.114***	-0.0411	-0.106**	-0.0111	0.0720
	(0.0432)	(0.0383)	(0.0510)	(0.0277)	(0.0580)	(0.0497)	(0.0515)	(0.0448)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945
Obs	5,558	5,558	5,558	5,558	5,558	5,558	5,558	5,558

COVID-19 = coronavirus disease, Obs. = observations.

Notes: Standard errors are in parentheses. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.

Source: Authors' own calculations.

Table 2: Results on Affiliate Exports

	Affiliate-level Exports to Japan							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.0504	0.0405	-0.00500	0.00173	-0.0439	-0.0363	0.0348	0.0487
	(0.0476)	(0.0379)	(0.0479)	(0.0236)	(0.0538)	(0.0514)	(0.0526)	(0.0511)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.932	0.932	0.932	0.932	0.932	0.932	0.932	0.932
Obs	6,926	6,926	6,926	6,926	6,926	6,926	6,926	6,926
	Affiliate level Exports to Headquarter							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.0622	0.0256	-0.0172	-0.00687	-0.0455	-0.0736	0.0206	0.0653
	(0.0515)	(0.0411)	(0.0516)	(0.0257)	(0.0587)	(0.0553)	(0.0555)	(0.0598)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.931	0.931	0.931	0.931	0.931	0.931	0.931	0.931
Obs	6,200	6,200	6,200	6,200	6,200	6,200	6,200	6,200
	Affiliate-level Export to Other Countries							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.0404	-0.00260	-0.00953	-0.0442	-0.0296	-0.0319	0.00837	-0.0341
	(0.0527)	(0.0500)	(0.0605)	(0.0290)	(0.0618)	(0.0559)	(0.0590)	(0.0517)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.931	0.931	0.931	0.931	0.931	0.931	0.931	0.931
Obs	6,085	6,085	6,085	6,085	6,085	6,085	6,085	6,085

COVID-19 = coronavirus disease, Obs. = observations.

Notes: Standard errors are in parentheses. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.

Source: Authors' own calculations.

Table 3: Affiliate Purchases

	Affiliate-level Purchase from Host Country							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.129***	-0.0152	-0.0484	-0.0714***	-0.0108	-0.0900*	-0.0747*	0.123***
	(0.0408)	(0.0354)	(0.0468)	(0.0234)	(0.0550)	(0.0465)	(0.0433)	(0.0439)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943
Obs	8,275	8,275	8,275	8,275	8,275	8,275	8,275	8,275
	Affiliate-level Purchase from Local Firms in the Host Country							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.147***	-0.0254	-0.0632	-0.0719**	0.00971	-0.0896	-0.0591	0.195***
	(0.0558)	(0.0453)	(0.0611)	(0.0299)	(0.0756)	(0.0604)	(0.0563)	(0.0559)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.930	0.930	0.930	0.930	0.930	0.930	0.930	0.930
Obs	6,155	6,155	6,155	6,155	6,155	6,155	6,155	6,155
	Affiliate-level Purchase from Japanese Firms in the Host Country							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.0896	0.0789	0.00671	-0.0678	0.0619	0.00275	0.120	0.0567
	(0.0668)	(0.0768)	(0.102)	(0.0495)	(0.0906)	(0.0806)	(0.114)	(0.0867)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.931	0.931	0.931	0.931	0.931	0.931	0.931	0.931
Obs	3,817	3,817	3,817	3,817	3,817	3,817	3,817	3,817

COVID-19 = coronavirus disease, Obs. = observations.

Notes: Standard errors are in parentheses. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.

Source: Authors' own calculations.

Table 4: Results on Affiliate Imports

	Affiliate-level Imports from Japan							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.149***	-0.0190	-0.0659	-0.0538**	-0.0203	-0.0686	0.00765	0.0799*
	(0.0443)	(0.0391)	(0.0490)	(0.0242)	(0.0563)	(0.0507)	(0.0508)	(0.0478)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934
Obs	6,934	6,934	6,934	6,934	6,934	6,934	6,934	6,934
	Affiliate-level Imports from Headquarter							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.154***	-0.0193	-0.0565	-0.0536**	-0.0137	-0.0657	-0.0109	0.105**
	(0.0466)	(0.0408)	(0.0514)	(0.0255)	(0.0597)	(0.0533)	(0.0521)	(0.0482)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
Obs	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560
	Affiliate-level Imports from Other Firms in Japan							
COVID Restrictions	School Closure	Workplace Closure	Cancellation of Public Events	Restrictions on Gathering	Public Transport Closure	Stay at Home Requirements	Internal Movements Restrictions	International Trip Restrictions
	-0.153	-0.0687	-0.158	-0.0970*	-0.169	-0.230**	-0.0501	-0.0299
	(0.104)	(0.0803)	(0.101)	(0.0538)	(0.140)	(0.116)	(0.105)	(0.133)
Affilate Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
R-Squared	0.902	0.902	0.902	0.902	0.902	0.902	0.902	0.902
Obs	2,027	2,027	2,027	2,027	2,027	2,027	2,027	2,027

COVID-19 = coronavirus disease, Obs. = observations.

Notes: Standard errors are in parentheses. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.

Source: Authors' own calculations.

5. Conclusions

How will firms respond when the world faces economic uncertainty such as the COVID-19 pandemic? Furthermore, how do firms respond when governments implement precautionary measures such as lockdown policies? To answer these questions, we use annual Japanese foreign affiliate data to quantify how COVID-19 affects firm behavior from various perspectives through the lens of firms' overseas activities. The reduced form estimation results show that Japanese foreign affiliates have been negatively affected by the COVID-19 restrictions implemented in destination countries. More specifically, we examine how sales and sourcing patterns, as well as intra-firm trade, are affected by different COVID-19 preventive regulations, such as school closures and stay-at-home policies. We find that the magnitude of this negative impact is larger for firms whose headquarters and foreign affiliates are both in manufacturing. Combined with the baseline results, we conclude that Japanese MNEs have been negatively affected by COVID-19 through the stringent regulations destination countries imposed. This provides solid evidence that in both domestic and overseas markets, the pandemic, together with lockdown policies, has caused serious problems for MNEs with intense involvement in overseas activities.

Without further analysis, we cannot provide a more accurate prediction of how far-reaching the impact of COVID-19 will ultimately be on firms. For example, the period for parent–affiliate analysis is only until the end of 2020. When available, more recent data could be applied to verify whether the impact is long lasting. Furthermore, the influence of COVID-19 on firms may be heterogeneous across regions. A more in-depth investigation of geographical dimensions could be conducted to determine this. To investigate how different waves of lockdown policies have affected firm performance, more disaggregated data are necessary. Moreover, the impact of COVID-19 from the viewpoint of welfare gains or losses requires further evaluation. These issues will be addressed in future research.

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Premature Deindustrialization, Global Value Chains, and Dutch Disease in Asian Latecomer Economies

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Abstract

This study examines premature deindustrialization in Asian latecomer developing economies using the factors of participation in global value chains (GVC) and the Dutch disease. We first show the degree of deindustrialization based on country-specific fixed effects in estimating the manufacturing-population-income relationships. Second, we reveal the contributions of GVC participation and the Dutch disease to country-specific fixed effects by replacing fixed effects with these factors in the estimation. The econometric empirical estimations yielded several findings. First, the fixed effects model estimation results suggest the existence of deindustrialization and its risk in all Asian latecomer economies, with China, Japan, and Korea as benchmark cases. Second, the factor analyses revealed that the lack of GVC participation in Asian latecomer economies contributes around 40% on average to their country-specific deindustrialization. The contribution of the Dutch disease to deindustrialization averages around 10%, although its contribution in resource-rich developing economies is relatively larger.

Keywords: Premature deindustrialization, Global value chains, Dutch disease, Asian latecomer economies, Fixed effects model.

JEL Classification Codes: O14, O53.

1. Introduction

Premature deindustrialization is described in the literature as an economic phenomenon where latecomer economies transition into service economies without undergoing full-fledged industrialization (Dasgupta and Singh, 2007; Rodrik, 2016). While Dasgupta and Singh (2007) were the first to use the term "premature deindustrialization," they focused only on employment, not output, arguing that the manufacturing decline is not necessarily a pathological phenomenon. In Latin

American and African countries, deindustrialization has been pathological in the context of import substitution strategies. In India and East Asia countries, it has been accompanied by information technology and knowledge-based innovation as new drivers of growth.

Rodrik (2016) refined the arguments of premature deindustrialization, positing that it refers to the early shrinking of manufacturing employment and output in developing countries. He also argued that countries in Latin America and sub-Saharan Africa have been severely affected by premature deindustrialization, whereas Asian countries, which have comparative advantages in manufacturing, have managed to avoid this trend. Since Rodrik's (2016) seminal work, numerous empirical studies have attempted to identify the existence of premature deindustrialization in specific countries. Most of these empirical studies have considered Asian economies outside the scope of premature deindustrialization, as Dasgupta and Singh (2007) and Rodrik (2016) argued, although individual Asian countries are still at significantly diverse stages of development.

Taguchi and Tsukada (2022) examined the risk of premature deindustrialization in Asian latecomer developing economies. Diverging from the literature that treats Asian economies as a group with comparative advantages in manufacturing, their empirical analysis focused on individual Asian economies and compared the deindustrialization processes of forerunners and latecomers in economic development. They found that premature deindustrialization risk was higher for manufacturing trade-deficit and South Asian countries and suggested the need for Asian latecomer developing economies to participate in global value chains (GVC) to avoid premature deindustrialization.

Extending Taguchi and Tsukada (2022), we perform a factor analysis of premature deindustrialization in Asian latecomer developing economies. We assume that two factors affect premature deindustrialization: the degree of GVC participation and the Dutch disease effect.[1] GVC participation is a factor candidate because Taguchi and Tsukada (2022) identified a quantitative linkage to premature deindustrialization. The theoretical foundation for explaining GVC participation's contribution to preventing premature deindustrialization is the "productivity enhancement" that manufacturing firms obtain from GVC participation. Baldwin and Yan (2014) argued that exporters from forward GVC participation can enjoy learning-by-exporting through technological transfer, while importers from backward GVC participation can experience cost-saving effects. The productivity effects are considered more permanent, whereas the latter are more immediate. The Dutch disease effect is another potential factor as natural resource development and dependence are considered to crowd out manufacturing activities (see, e.g., Corden and Neary, 1982; Sachs and Warner, 1995, 2001; Rodrik, 2016). This study's empirical analysis involves two steps. First, to demonstrate the degree of premature deindustrialization, we follow Rodrik's (2016) framework and examine country-specific fixed effects in estimating the relationship among manufacturing, population, and

[1] Other variables, such as human capital and institutional qualities, may affect deindustrialization. However, they are not considered in this study due to data constraints and their collinearity with income levels.

income. Second, we reveal the contributions of the degree of GVC participation and Dutch disease effect to the country-specific fixed effects by substituting these factors for the fixed effects in the estimation.

The remainder of this paper proceeds as follows. Section 2 reviews the literature, focusing on hypotheses of premature deindustrialization and its linkage with GVC participation and the Dutch disease effect and clarifies this study's contributions. Section 3 describes the empirical analyses performed to examine premature deindustrialization in Asian latecomer developing economies and the factors that drove this deindustrialization. Section 4 concludes the paper.

2. Literature Review and Contributions

This section discusses literature related to the premature deindustrialization hypothesis and its linkage to GVC participation and the Dutch disease effect and clarifies this study's contributions.

While Dasgupta and Singh (2007) originated the premature deindustrialization hypothesis, they excluded output, focusing only on employment, and argued that a decline in manufacturing is not necessarily a pathological phenomenon. Rodrik (2016) constructed a simple two-sector theoretical model with manufacturing and non-manufacturing sectors to describe premature deindustrialization as early shrinkage in manufacturing employment and output in developing countries. His model demonstrates that developing countries that liberalize trade tend to be price-takers in global manufacturing markets. Those that lack a strong comparative advantage in manufacturing must become net importers of manufactured products; the decline in the relative price of manufacturing and increase in Chinese manufacturing leads deindustrialization in manufacturing employment and output. Rodrik (2016) also provided empirical evidence for these affirmations: late industrializers attain lower peak levels of industrialization than do early industrializers at lower income levels (post-1990 peak incomes are approximately 40% of pre-1990 peak incomes).

Since the seminal works of Dasgupta and Singh (2007) and Rodrik (2016), numerous empirical studies have been conducted to identify premature deindustrialization in various countries. These include Sato and Kuwamori (2019) in non-OECD countries, Nayyar et al. (2021) in lower-income developing countries, Daymard (2020) in Latin American and African countries, Caldentey and Vernengo (2021) in Latin American countries, Ssozi and Howard (2018) in Sub-Saharan African countries, and Taguchi and Tsukada (2022) in Asian latecomer economies.

Among these studies, Taguchi and Tsukada's (2022) contributions are worth noting. First, they targeted Asian latecomer developing economies, while most other studies have considered Asian economies outside the scope of premature deindustrialization. Second, they found a quantitative linkage between the degree of GVC participation and premature deindustrialization in the context of avoiding premature deindustrialization.

Another argument related to premature deindustrialization is the Dutch disease hypothesis, which is specific to resource-rich economies. The *Economist* coined the term "Dutch disease" in a November 1977 issue inspired by the repercussions of the late 1950s natural gas discoveries in the Netherlands. Corden and Neary (1982) provided the theoretical grounds for this hypothesis by illustrating the resource reallocation from tradable to non-tradable sectors caused by innovation in the natural resource sector. Rodrik (2016) also illustrated the Dutch disease in the context of premature deindustrialization: a resource boom denotes an increase in productivity growth and/or prices in the non-manufacturing sector, so the Dutch disease magnifies the deindustrializing consequences in countries with a comparative advantage in resources. Many quantitative studies have empirically verified the existence of the Dutch disease in resource-rich economies (e.g., Edwards, 1986; Harding and Venables, 2013; Islami, 2010; Sachs and Warner, 1995, 2001).

This study contributes to the literature by performing a factor analysis of premature deindustrialization in Asian latecomer developing economies, focusing on two factors: the degree of GVC participation and Dutch disease effect, based on Taguchi and Tsukada's (2022) identification of the quantitative linkage between the degree of GVC participation and premature deindustrialization and literature regarding the Dutch disease effect (e.g., Corden and Neary, 1982; Sachs and Warner, 1995 and 2001; Rodrik, 2016).

3. Empirical Analysis

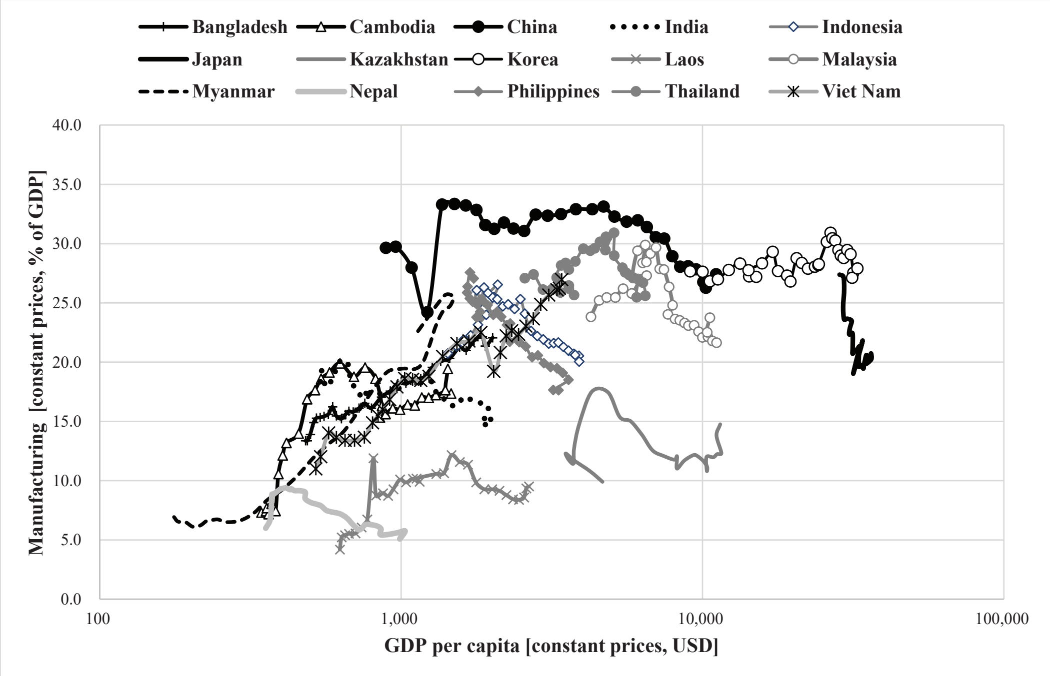
This section describes the empirical analyses performed to identify premature deindustrialization in Asian latecomer developing economies and the factors that caused this deindustrialization.

3.1. Descriptive Analysis

Figure 1 displays the trends in manufacturing as a percentage of gross domestic product (GDP) along with GDP per capita in constant 2015 prices for 1990-2021[2] in 15 selected Asian economies: Bangladesh, Cambodia, China, India, Indonesia, Japan, Kazakhstan, Korea, Laos, Malaysia, Myanmar, Nepal, Philippines, Thailand, and Viet Nam. These economies are selected to allow easy visualization of the different trends in their manufacturing-income nexus by excluding the economies with similar trends, while the subsequent analysis targets 23 Asian economies (explained later). The trajectories have an inverted U-shape, but their positions are observably different. China, Korea, and Japan, which have been successful in industrialization, have curves in high positions, while those of the other latecomer economies are positioned lower. This suggests that premature deindustrialization exists in Asian latecomer developing economies, with China, Korea, and Japan as benchmarks.

[2] The data were retrieved from UNCTAD Stat. See Section 3.3 and Table 1.

Figure 1: Trends in Manufacturing-income Nexuses in Selected Asian Economies



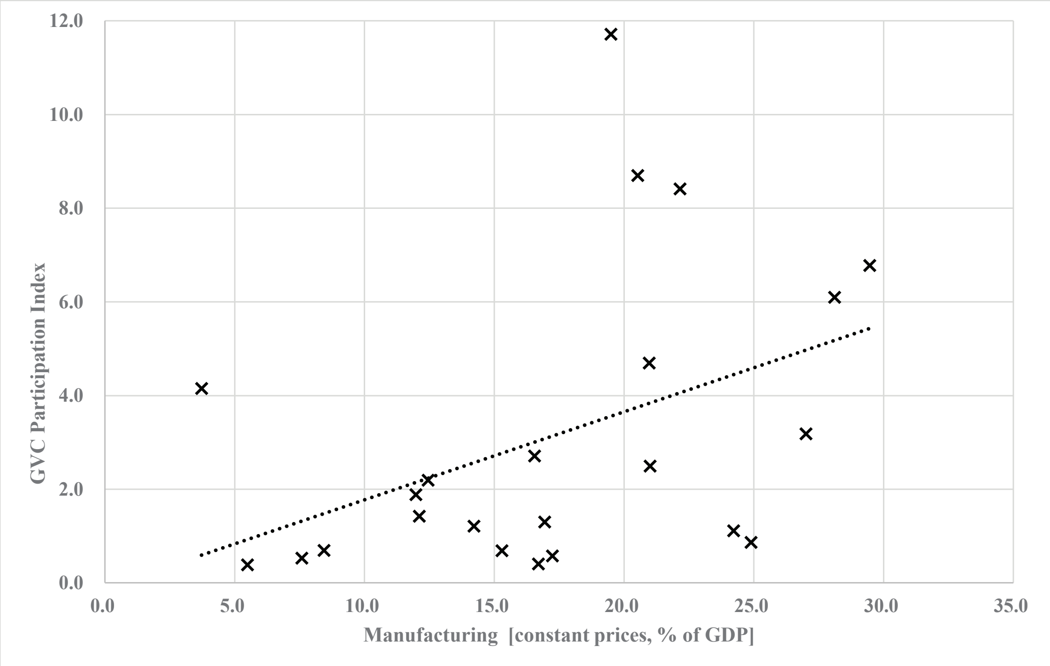
Source: Authors' description based on UNCTAD Stat.

Figures 2 and 3 are simple depictions of the relationships between manufacturing-GDP ratios and the indexes that are presumed to affect premature deindustrialization: the degree of GVC participation and the Dutch disease effect. Figure 2 shows a positive correlation between manufacturing-GDP ratios and GVC participation indexes[3] in 2017, with a total of 23 Asian economies[4] (Afghanistan, Brunei, Iran, Kyrgyzstan, Mongolia, Pakistan, Sri Lanka, and Uzbekistan are added to the sample economies in Figure 1). Figure 3 illustrates a negative association between manufacturing-GDP ratios and natural resource rents, which represent the abundance of natural resources.[5] These results align with our hypotheses of GVC participation and Dutch disease based on the reviewed literature.

These observations should be statistically evaluated using an econometric method because the variables interact and should be controlled by income and demographic trends.

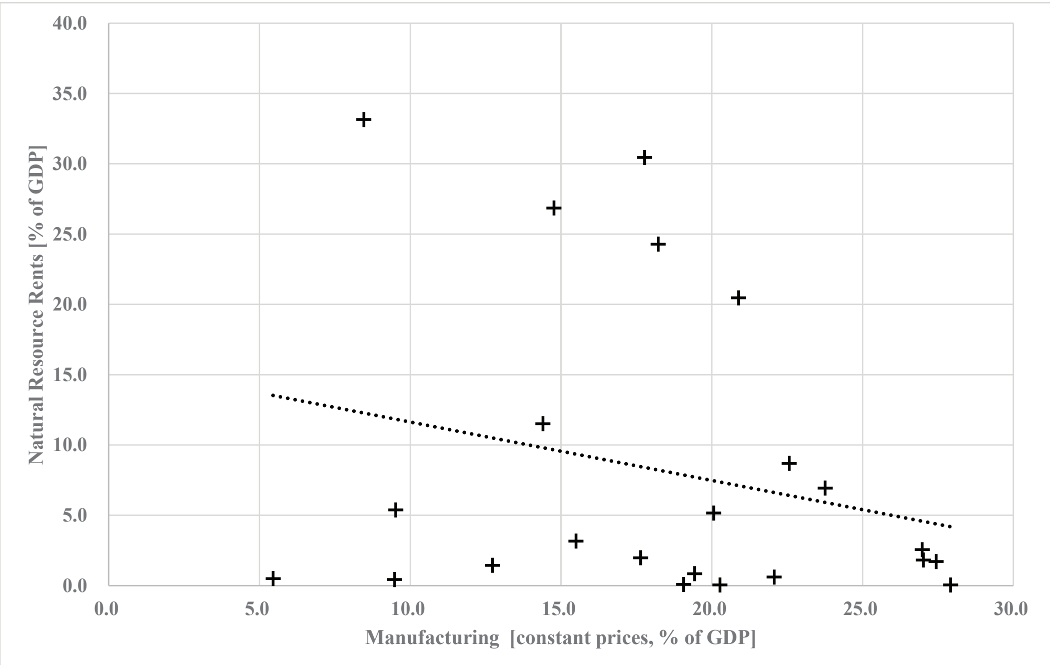
[3] The data are from the UNCTAD-Eora Global Value Chain database. See Section 3.3, Table 1, and the Appendix.
[4] Regarding Asia's area definition, we follow the UNCTAD Stat database. We exclude the following economies because of their small size and data constraints: Bhutan, Hongkong, Macao, Maldives, Singapore, Tajikistan, and Turkmenistan.
[5] The data are from the World Bank Open Data database; see Section 3.3 and Table 1.

Figure 2: Correlation between Manufacturing-GDP Ratios and GVC Participation



Source: Authors' description based on UNCTAD Stat and UNCTAD Eora Global Value Chain Database.

Figure 3: Correlation between Manufacturing-GDP Ratios and Natural Resource Rents



Source: Authors' description based on UNCTAD Stat and World Bank Open Data database.

3.2. Econometric Analysis: Methodology

For the empirical specification for the premature deindustrialization hypothesis, we apply Rodrik's (2016) equation for our baseline regressions, namely, the inverted U-shaped manufacturing-income nexus. Using Rodrik's specification, we first examine country-specific fixed effects using Equation 1 to represent the volume of deindustrialization. Then, using Equation 2, we investigate the factors that contribute to deindustrialization by replacing fixed effects with the degree of GVC participation and Dutch disease effect.

$$man_{it}=\alpha_0+\alpha_1 \ln pop_{it-1}+\alpha_2(\ln pop_{it-1})^2+\alpha_3 \ln ypc_{it-1}+\alpha_4(\ln ypc_{it-1})^2+f_i+f_t+\varepsilon_{it} \quad (1)$$

$$man_{it}=\beta_0+\beta_1 \ln pop_{it-1}+\beta_2(\ln pop_{it-1})^2+\beta_3 \ln ypc_{it-1}+\beta_4(\ln ypc_{it-1})^2+\beta_5 gvc_{it-1}+\beta_6 nrr_{it-1}+f_t+\varepsilon_{it} \quad (2)$$

where the subscripts *i* and *t* denote the country (23 Asian countries) and year (1990-2021 in Equation 1 and 1990-2017 in Equation 2), respectively; *man* is the manufacturing-GDP ratio in 2017 measured in constant USD prices; *pop* and *ypc* are the population size and GDP per capita of country *i* in constant 2015 USD prices; f_i and f_t are time-invariant country-specific and country-invariant time-specific fixed effects, respectively; *gvc* indicates the degree of GVC participation; *nrr* is natural resource rents as a percentage of GDP for materializing the Dutch disease effect; ε is the residual error term; $\alpha_{0\ldots4}$, and $\beta_{0\ldots6}$ are the estimated coefficients. ln indicates the logarithmic form, which is used to avoid scaling issues. The explanatory variables in Equations 1 and 2, ln*pop*, ln*ypc*, *gvc*, and *nrr* are lagged by one year. This helps avoid reverse causality in the model specifications, including the endogenous interaction between the dependent and independent variables. The data sources are described in Section 3.3 (Table 1).

In terms of the estimation model specifications, all equations include control variables for country population size and real GDP per capita. The ordinary hypothesis of premature deindustrialization proposed by Rodrik (2016) postulates an inverted-U-shaped path between a country's manufacturing-GDP ratio and population size and real GDP per capita. This hypothesis is supported if α_1, α_3, β_1, and $\beta_3 > 0$ and α_2, α_4, β_2, and $\beta_4 < 0$ are significant.

Equation 1 employs a fixed effects model (f_i) for the panel estimation to examine the degree of deindustrialization in the sample Asian countries. China, Japan, and Korea are used as benchmark countries for estimating country-specific effects because they successfully achieved manufacturing-driven development. A significantly negative coefficient of the country-specific effect suggests a lower manufacturing-GDP ratio in an Asian latecomer developing economy relative to the benchmark countries at their same development stages, implying the existence of premature deindustrialization.

In Equation 2, we replace the country-specific fixed effects with industrialization-related factors that possibly contribute to the fixed effects. We employ the degree of GVC participation (*gvc*) and

Dutch disease effect (*nrr*) as industrialization-related factors. Following Taguchi and Tsukada (2022), who identified a positive linkage between industrialization and GVC participation, we expect the coefficient of *gvc* to be significantly positive ($\beta_5 > 0$). The Dutch disease effect describes the phenomenon where a boom in the natural resources sector reduces manufacturing (Corden and Neary, 1982); thus, we expect the coefficient of *nrr* to be significantly negative ($\beta_6 < 0$).

The estimation techniques applied are ordinary least squares (OLS) and Poisson pseudo maximum likelihood (PPML) estimators. The PPML estimator is used because the sample data, including that of the developing countries, would be affected by heteroskedasticity and autocorrelation, in which case the OLS estimator leads to biased and inconsistent estimates. The PPML estimator corrects for the heteroscedastic error structure across panels and autocorrelation within panels, as Silva and Tenreyro (2006) and Kareem et al. (2016) suggest. Therefore, these two estimators are applied to ensure the robustness of the estimations. We used EViews (version 12) to process the data and estimations.

3.3. Econometric Analysis: Data

The data sources for the variables and the sample sizes for the estimation are as follows. The data for the manufacturing-GDP ratio (*man*), population size (*pop*), and real GDP per capita (*ypc*) are retrieved from the UNCTAD Stat database.[6] The data for GVC participation (*gvc*) are from the UNCTAD-Eora Global Value Chain database,[7] and the natural resource rents (*nrr*) data are from the World Bank Open Data database.[8]

The sample targets 23 economies, as shown in Section 3.1, and the sample periods are 1990–2021 for Equation 1 and 1990–2017 for Equation 2; the difference is due to the data constraints of the GVC participation index. The choice of this time frame from 1990 is justified not only by the availability of the UNCTAD-Eora Global Value Chain database, but also because it includes the critical periods of premature deindustrialization proposed by Rodrik (2016) (see Section 2) and the upsurge in China's forward GVC participation after its entry into the World Trade Organization in 2001 (Li et al. 2019).

We then construct a panel dataset of the sample economies and periods. Table 1 presents the variable list, and Table 2 reports the descriptive statistics for the variables.

For the subsequent estimation, we investigate the stationarity of the constructed panel data through panel unit root tests: the Levin, Lin, and Chu test (Levin et al., 2002) as a common unit root test and the Fisher-ADF and Fisher-PP tests (Choi, 2001; Maddala and Wu, 1999) as individual unit root tests. The common unit root test assumes a common unit root process across cross-sections, and the individual unit root test allows for individual unit root processes that vary across cross-sections. We

[6] See the website: https://unctadstat.unctad.org/EN/.
[7] See the website: https://worldmrio.com/unctadgvc/. The compilation of the GVC participation index is described in the Appendix.
[8] See the website: https://data.worldbank.org/.

run these tests based on the null hypothesis that a level of panel data has a unit root and include "individual intercept" and "individual intercept and trend" in the test equations. Table 3 shows that the Levin, Lin, and Chu test results reject the null hypothesis of a unit root at the conventional significance level for all variables in both test equations. The individual unit root tests do not necessarily reject the null hypothesis in all cases; however, the Fisher–PP tests reject the null hypothesis at the conventional level for all variables. Therefore, we assume there is no serious issue with unit roots in the panel data, allowing us to use the panel data in levels for subsequent estimations.

We next check the potential existence of a multicollinearity problem among the explanatory variables in Equation 2 by calculating the variance inflation factors (VIF). This method measures the level of collinearity between regressors, where a multicollinearity problem is identified if the factors are greater than 10. The VIFs in Table 4 reveal that, in the estimation with four variables, the VIF values of population size and real GDP per capita are far greater than 10, indicating the presence of collinearity. However, in the estimation with three variables, no multicollinearity problem is found. Nevertheless, population size and real GDP per capita are incorporated in Rodrik's estimation model (2016). Thus, the subsequent analyses explore two approaches: an estimation with four variables and one with three variables.

Table 1: Variables and Their Sources

Var.	Description	Sources
Dependent Variable		
man	*Manufacturing in US dollars at constant prices (2015), percentage of Gross Domestic Product (GDP)*	UNCTAD Stat
Explanatory Variables		
pop	*Populaiton in thousands*	UNCTAD Stat
ypc	*GDP in US dollars at constant prices (2015) per capita*	
gvc	*Forward participation in global value chains (GVC) in machinery, devided by gross export values*	UNCTAD-Eora
nrr	*Total natural resources rents, percantage of GDP*	World Bank

Source: Authors' description.

Table 2: Descriptive Statistics

Variables	Obs.	Median	Std. Dev.	Min.	Max
Dependent Variable					
man	730	17.355	7.124	3.724	33.357
Explanatory Variables					
lnpop	730	10.736	1.803	5.568	14.170
$(\ln pop)^2$	730	115.265	37.390	31.006	200.798
ln*ypc*	730	7.547	1.286	5.170	10.500
$(\ln ypc)^2$	730	56.961	21.062	26.734	110.254
gvc	644	1.173	2.637	0.228	11.709
nrr	719	3.214	8.771	0.012	42.217

Source: Authors' calculations.

Table 3: Panel Unit Root Tests

	individual intercept			*individual intercept and trend*		
	L. L. & C.	*Fisher ADF*	*Fisher PP*	*L. L. & C.*	*Fisher ADF*	*Fisher PP*
man	-2.324 **	75.187 ***	73.982 ***	-2.734 ***	65.823 **	73.833 ***
ln*pop*	-3.866 ***	96.840 ***	322.336 ***	-3.958 ***	203.084 ***	124.713 ***
$(\ln pop)^2$	-3.726 ***	70.500 **	309.183 ***	-3.981 ***	203.542 ***	106.929 ***
ln*ypc*	-3.757 ***	51.011	63.333 **	-1.749 **	51.802	75.494 ***
$(\ln ypc)^2$	-2.987 ***	48.548	59.854 *	-1.675 **	51.667	79.408 ***
gvc	-2.093 **	76.793 ***	81.202 ***	-1.742 **	48.127	68.777 **
nrr	-4.348 ***	86.576 ***	94.602 ***	-2.354 ***	74.091 ***	73.489 ***

Source: Authors' estimation.

Table 4: Variance Inflation Factors

	4 Variables	3 Variables	
ln*pop*	18.927	-	2.733
ln*ypc*	28.170	4.068	-
gvc	2.681	2.541	2.044
nrr	2.420	2.024	1.533

Source: Authors' estimation.

3.4. Econometric Analysis: Estimation Results

Tables 5 and 6 report the estimation results of the country-specific fixed effects model in Equation 1 and the alternative model containing GVC participation and the Dutch disease effects in Equation 2, respectively, with each result including OLS and PPML estimations. We summarize the results as follows.

First, regarding the control variables for a country's population size and real GDP per capita across all estimation results in Tables 5 and 6 (estimation i, iii, v, and vii), α_3 and $\beta_3 > 0$ and α_4 and $\beta_4 < 0$ in the coefficients of real GDP per capita are significant, whereas the opposite signs in the coefficients of population size (α_1 and $\beta_1 < 0$ and α_2 and $\beta_2 > 0$) are estimated. This supports the inverted-U-shaped path postulated by Rodrik between a country's manufacturing-GDP ratio and real GDP per capita, but not that between the ratio and population size. Considering the results and multicollinearity problem in population size and real GDP per capita noted in Section 3.3, we add the estimation containing only real GDP per capita as a control variable in Tables 5 and 6 (estimations ii, iv, vi, and viii). The turning points in real GDP per capita (computed using $-\alpha_3/2\alpha_4$ in Equation 1 and $-\beta_3/2\beta_4$ in Equation 2) fall within reasonable ranges of real GDP per capita at between 2,747 and 14,705 USD. However, the main research focus in this study is the position of a country's manufacturing–income curve, not its shape.

Second, focusing on the fixed effects model in Table 5, the coefficients of the country-specific dummies are significantly negative for all 20 economies (except the three benchmark countries) in all cases (although the coefficient for Thailand is insignificant only in estimation i). Among the 20 economies, focusing on estimation iv, those with larger dummy coefficient values are resource-rich economies such as Mongolia, Laos, Uzbekistan, Kazakhstan, Iran, and less-developed economies such as Nepal, Pakistan, Afghanistan, Myanmar, and Cambodia. Thus, all Asian latecomer economies have lower manufacturing GDP ratios than the benchmark countries of China, Japan, and Korea at their same development stages, suggesting deindustrialization in this set of economies. From the perspective of the premature deindustrialization hypothesis, a lower manufacturing-income path could indicate the existence of premature deindustrialization and its future "risk" This is because, thereafter, the lower country's manufacturing ratio will peak at a lower value and lower income level when compared with those in the benchmark countries.

Third, the alternative models in Table 6, in which we replace the country-specific dummies with the GVC participation and Dutch disease effects variables, produce the expected results. The degree of GVC participation (*gvc*) has significantly positive coefficients in all cases from estimations v to viii, while the coefficients of the Dutch disease indicator (*nrr*) are significantly negative. These results suggest that the degree of industrialization is affected by the degree of GVC participation and the Dutch disease effect. The joint estimation outcomes of the country-specific fixed effects and the possible industrialization-related factors (GVC participation and Dutch disease effects) raise the question of the quantitative degree of contributions of the industrialization-related factors to country-specific deindustrialization in the sample Asian latecomer economies.

3.5. Factor Analysis

The final step is to clarify the contributions of a lesser degree of GVC participation and Dutch disease effects to the country-specific deindustrialization in the Asian latecomer economies. We apply the combination of the two estimations: estimation iv in the fixed effects model in Table 5 and viii in the alternative model in Table 6. We use these because the PPML estimator is more effective than the OLS estimator for correcting heteroskedasticity and autocorrelation (discussed in Section 3.2) and excluding population size avoids multicollinearity problems (shown in Section 3.3). Tables 7 and 8 show the factor analyses of GVC participation (*gvc*) and the Dutch disease (*nrr*) effects, respectively, and Figure 4 illustrates both of their contributions.

In Tables 8 and 9, Column (a) shows the coefficients of the dummies in estimation iv of Table 5; Column (b) presents the sample-period-average values of the GVC participation and Dutch disease indicators (*gvc*, and *nrr*); Column (c) computes their deviations from the average of those of China, Japan, and Korea (the benchmark countries); and Column (d) reports the contributions of the GVC participation and Dutch disease indicators after multiplying their deviations by their estimated coefficients in estimation viii of Table 6. Column (e) computes the contribution ratios of the lower degree of GVC participation and Dutch disease effects to the country-specific deindustrialization fixed effects by dividing (d) by (a). Figure 4 visualizes the contributions of the lesser degree of GVC participation and Dutch disease effects in Column (d) against the country-specific deindustrialization fixed effects in Column (a), indicated by white dots and the bar graphs.

We summarize the analytical results as follows. Regarding the GVC participation effect in Table 7 (Column (e)) and Figure 4, lower GVC participation in Asian latecomer economies contributes about 40% on average to their country-specific deindustrialization (except in Malaysia and the Philippines). The contributions to industrialization of the Dutch disease effects in Table 8 (Column (e)) and Figure 4 average around 10%. However, resource-rich economies such as Brunei, Iran, Kazakhstan, Mongolia, and Uzbekistan have relatively larger contributions to their deindustrialization. To make the analysis more understandable, we use Indonesia and Mongolia as examples. Their degrees of deindustrialization compared to those of China, Japan, and Korea (the benchmark countries) are 8.5% in Indonesia and 21.9% in Mongolia. Their contributions of the lack of GVC participation are 2.3% point and 6.5% point, respectively, and those of the Dutch disease effect are 0.7% point and 3.8% point, respectively. Thus, Indonesia’s deindustrialization comes mainly from its lack of GVC participation, whereas that of Mongolia originates from both its lower GVC participation and the Dutch disease effect. The verified contributions of the lack of GVC participation and the Dutch disease effect to country-specific deindustrialization in the sample Asian latecomer economies are consistent with the arguments of Taguchi and Tsukada (2022), Corden and Neary (1982), Rodrik (2016), and Sachs and Warner (1995, 2001).

These factor analyses suggest policy implications for mitigating and avoiding premature deindustrialization and its risk. For the less-developed Asian economies that have faced premature deindustrialization and its associated risk, participating in GVC activities like their forerunners such as China, Japan, and Korea could help lessen the risk of deindustrialization. GVC participation facilitates recovery of deindustrialization by approximately 40%. Numerous reports from international organizations (e.g., UNCTAD 2013; World Bank 2020) have recommended developing GVC participation strategies, such as those related to infrastructure and human resource development, institutional improvements, and policy frameworks to create industrial clusters and networks. For resource-rich developing economies, the Dutch disease effect may accelerate premature deindustrialization. Thus, to offset this, resource revenues should be mobilized for productive uses, such as infrastructure development, to activate manufacturing activities (e.g., Coutinho, 2011; Sachs, 2007).

Table 5: Estimation Results for Fixed Effects Model in Equation 1

	OLS		PPML	
Estimation	i	ii	iii	iv
ln pop_{-1}	-17.441 ***		-23.052 ***	
	(-4.709)		(-4.224)	
$(\ln pop)^2_{-1}$	0.686 ***		0.898 ***	
	(4.541)		(3.920)	
ln ypc_{-1}	29.907 ***	31.365 ***	25.833 ***	22.443 ***
	(16.466)	(17.983)	(9.713)	(10.365)
$(\ln ypc)^2_{-1}$	-1.806 ***	-1.878 ***	-1.594 ***	-1.417 ***
	(-16.125)	(-18.649)	(-9.003)	(-10.264)
Afghanistan	-16.490 ***	-11.988 ***	-19.899 ***	-16.721 ***
Bangladesh	-8.424 ***	-8.680 ***	-9.830 ***	-12.246 ***
Brunei	-38.168 ***	-7.709 ***	-48.809 ***	-7.372 ***
Cambodia	-16.023 ***	-9.468 ***	-20.378 ***	-13.766 ***
India	-9.863 ***	-9.688 ***	-10.378 ***	-12.617 ***
Indonesia	-6.185 ***	-7.298 ***	-6.206 ***	-8.467 ***
Iran	-16.148 ***	-15.890 ***	-16.482 ***	-16.111 ***
Kazakhstan	-22.583 ***	-17.843 ***	-24.466 ***	-17.767 ***
Kyrgyzstan	-21.263 ***	-10.258 ***	-26.790 ***	-13.660 ***
Laos	-29.409 ***	-19.116 ***	-34.390 ***	-21.725 ***
Malaysia	-8.408 ***	-5.330 ***	-9.712 ***	-5.120 ***
Mongolia	-35.611 ***	-20.695 ***	-41.746 ***	-21.901 ***
Myanmar	-10.038 ***	-7.960 ***	-13.702 ***	-13.770 ***
Nepal	-20.294 ***	-16.339 ***	-23.314 ***	-20.415 ***
Pakistan	-15.068 ***	-15.663 ***	-15.945 ***	-18.408 ***
Philippines	-7.862 ***	-7.770 ***	-8.549 ***	-9.023 ***
Sri Lanka	-14.088 ***	-0.817 ***	-16.361 ***	-11.006 ***
Thailand	-3.916	-3.481 ***	-4.353 **	-3.737 ***
Uzbekistan	-20.590 ***	-17.304 ***	-22.777 ***	-19.301 ***
Viet Nam	-0.072 ***	-9.724 ***	-10.492 ***	-11.351 ***
Turning point of *ypc* (USD)	3,950	4,229	3,300	2,747
Period fixed effects	Yes	Yes	Yes	Yes
Period	1991-2021	1991-2021	1991-2021	1991-2021
Country fixed effects	Yes	Yes	Yes	Yes
No. of Countries	23	23	23	23
No. of Observations	707	707	707	707

Note: ** and *** denote rejection of the null hypothesis at the 95% and 99% significance levels, respectively. T-statistics are shown in parentheses.

Source: Authors' estimation.

Table 6: Estimation Results for Alternative Model in Equation 2

	OLS		PPML	
Estimation	v	vi	vii	viii
ln pop_{-1}	-2.577 ***		-2.729 ***	
	(-3.053)		(-3.391)	
$(\ln pop)^2_{-1}$	0.180 ***		0.186 ***	
	(4.633)		(4.886)	
ln ypc_{-1}	20.839 ***	23.554 ***	12.345 ***	14.249 ***
	(12.096)	(12.838)	(9.535)	(11.661)
$(\ln ypc)^2_{-1}$	-1.121 ***	-1.298 ***	-0.643 ***	-0.785 ***
	(-10.575)	(-11.747)	(-7.563)	(-10.026)
gvc_{-1}	0.557 ***	0.727 ***	0.805 ***	1.146 ***
	(5.339)	(7.047)	(7.247)	(11.729)
nrr_{-1}	-0.212 ***	-0.277 ***	-0.163 ***	-0.186 ***
	(-8.524)	(-10.702)	(-8.433)	(-9.684)
Turning point of *ypc* (USD)	10,861	8,733	14,705	8,712
Period fixed effects	Yes	Yes	Yes	Yes
Period	1991-2017	1991-2017	1991-2017	1991-2017
Country fixed effects	No	No	No	No
No. of Countries	23	23	23	23
No. of Observations	609	621	621	621

Note: *** denotes rejection of the null hypothesis at the 99% significance level. T-statistics are shown in parentheses.
Source: Authors' estimation.

Table 7: Factor Analysis: GVC Participation Effect

	Fixed Effects	*gvc*	(b) - ave. *gvc*	(c) × 1.146	(d) / (a) *100
	(a)	(b)	(c)	(d)	(e)
Afghanistan	-16.721	1.706	-4.480	-5.133	30.7
Bangladesh	-12.248	1.014	-5.172	-5.926	48.4
Brunei	-7.372	2.316	-3.869	-4.433	60.1
Cambodia	-13.766	0.524	-5.662	-6.487	47.1
India	-12.617	1.620	-4.565	-5.231	41.5
Indonesia	-8.467	4.174	-2.011	-2.304	27.2
Iran	-16.111	1.189	-4.997	-5.725	35.5
Kazakhstan	-17.767	2.156	-4.029	-4.617	26.0
Kyrgyzstan	-13.660	0.500	-5.686	-6.515	47.7
Laos	-21.725	0.646	-5.539	-6.347	29.2
Malaysia	-5.120	8.649	-	-	-
Mongolia	-21.901	0.533	-5.652	-6.476	29.6
Myanmar	-13.770	1.061	-5.124	-5.871	42.6
Nepal	-20.415	0.462	-5.724	-6.558	32.1
Pakistan	-18.408	1.154	-5.031	-5.765	31.3
Philippines	-9.023	11.174	-	-	-
Sri Lanka	-11.006	1.342	-4.844	-5.550	50.4
Thailand	-3.737	3.398	-2.788	-3.194	85.5
Uzbekistan	-19.301	0.710	-5.476	-6.274	32.5
Viet Nam	-11.351	0.790	-5.396	-6.182	54.5
Benchmark	0.000	6.185	-	-	

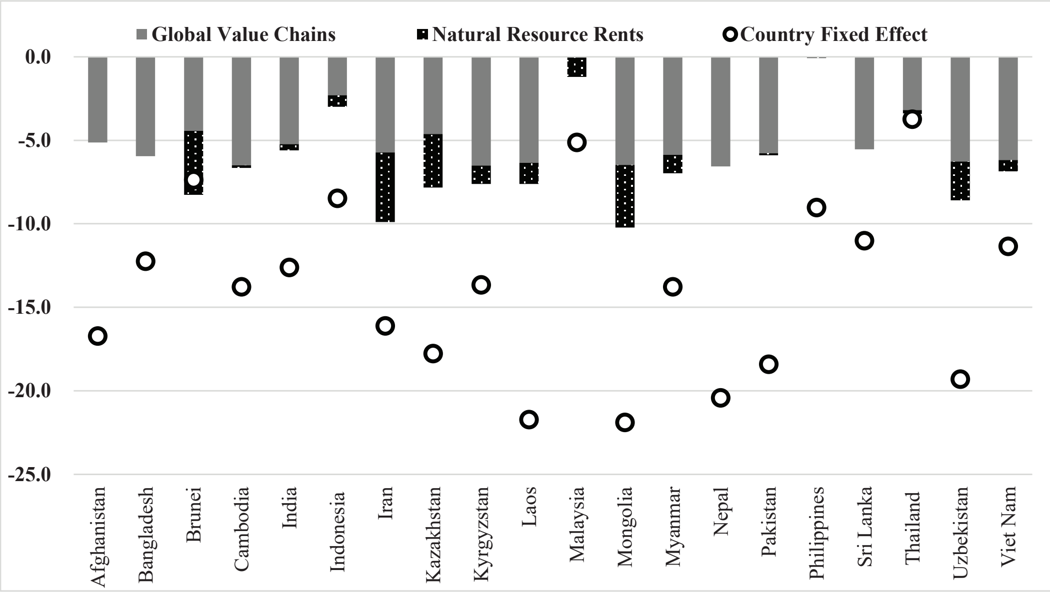
Source: Authors' calculations.

Table 8: Factor Analysis: Dutch Disease Effect

	Fixed Effects	*nrr*	(b) - ave. *nrr*	(c) × -0.186	(d) / (a) *100
	(a)	(b)	(c)	(d)	(e)
Afghanistan	-16.721	0.613	-	-	-
Bangladesh	-12.248	0.962	0.032	-0.006	0.0
Brunei	-7.372	21.518	20.588	-3.826	51.9
Cambodia	-13.766	1.791	0.860	-0.160	1.2
India	-12.617	2.920	1.990	-0.370	2.9
Indonesia	-8.467	4.642	3.712	-0.690	8.1
Iran	-16.111	23.408	22.478	-4.177	25.9
Kazakhstan	-17.767	18.218	17.288	-3.213	18.1
Kyrgyzstan	-13.660	6.830	5.899	-1.096	8.0
Laos	-21.725	7.742	6.812	-1.266	5.8
Malaysia	-5.120	7.406	6.476	-1.203	23.5
Mongolia	-21.901	21.119	20.189	-3.752	17.1
Myanmar	-13.770	6.851	5.921	-1.100	8.0
Nepal	-20.415	0.819	-	-	-
Pakistan	-18.408	1.667	0.737	-0.137	0.7
Philippines	-9.023	1.338	0.408	-0.076	0.8
Sri Lanka	-11.006	0.111	-	-	-
Thailand	-3.737	2.133	1.203	-0.224	6.0
Uzbekistan	-19.301	13.436	12.506	-2.324	12.0
Viet Nam	-11.351	4.569	3.639	-0.676	6.0
Benchmark	0.000	0.930	-	-	

Source: Authors' calculations.

Figure 4: Factor Contributions



Source: Authors' calculations.

4. Summary and Conclusion

This study examined premature deindustrialization in Asian latecomer developing economies and investigated two factors that affect deindustrialization: GVC participation and the Dutch disease. We first showed the degree of deindustrialization based on country-specific fixed effects in estimating the manufacturing-population-income relationships. Second, we revealed the contributions of GVC participation and the Dutch disease effects to the country-specific fixed effects by replacing fixed effects with the factors in the estimation.

The empirical estimations yielded several findings. First, the fixed effects model estimation results suggested deindustrialization and its risk in all 20 sample Asian latecomer economies, with China, Japan, and Korea as the benchmark economies. Second, the outcomes of the factor analyses revealed that the lack of GVC participation in Asian latecomer economies contributed by about 40% on average to their country-specific deindustrialization, except in Malaysia and the Philippines. The contributions of the Dutch disease effect to deindustrialization were around 10% on average, although the resource-rich developing economies have relatively larger contributions to their deindustrialization.

The policy implications in this study are the following. Participating in GVC activities would be useful for the less-developed Asian economies that have faced premature deindustrialization and its risk to facilitate recovery of their deindustrialization. For resource-rich developing economies to offset the Dutch disease effect, resource revenues should be mobilized for productive uses, such as infrastructure development, to activate manufacturing activities.

A limitation of this study is the lack of detailed research on individual economies. Examining the complexity of premature deindustrialization mechanisms and policy performance in specific countries through detailed case studies would allow developing concrete country-specific recommendations and prescriptions for mitigating and avoiding premature deindustrialization.

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Appendix: GVC Participation Index

This appendix illustrates the compilation of the GVC participation index using the UNCTAD-Eora Global Value Chain database. Regarding GVC forms, Koopman et al. (2010) presented the following two types of participation in a vertical specialization chain:

GVC Participation = FV/E + IV/E

where FV, IV, and E represent "foreign value-added embodied in gross exports," "domestic value-added embodied as intermediate inputs in other countries' gross exports," and "gross exports," respectively. The first item (FV/E), representing downstream GVC participation, corresponds with GVC backward participation, while the second item (IV/E), indicating upstream GVC participation, is called GVC forward participation, following, for example, the World Bank (2020).

This study compiles the GVC participation index based on the forward participation form in the machinery sectors of manufacturing industries. The reason for focusing on "forward" participation is that it is strongly linked to a sustainable increase in manufacturing activities through industrial upgrading. Advanced manufacturing makes it possible to provide sophisticated intermediate inputs for exporters. The World Bank (2020) argued that forward GVC participation tends to increase along with innovative manufacturing activities. The reason for targeting machinery sectors is that GVC activities with many multilayered vertical production processes are typically observed in machinery sectors, as Kimura (2006) argued.

Based on the forward participation form in machinery sectors, the GVC participation index (of 23 sample economies) can be computed using the UNCTAD-Eora Global Value Chain database. Its data source is shown in Note 5 in the text, and its methodological background is described by Casella et al. (2019). The database provides the country/ sector-by-country matrix from 1990 to 2017 with global coverage (189 countries and a "Rest of World" region). It reports, for each country of exports, the value contributed by all other countries/sectors in the world, where the rows show the country/sector originating the value added, and the columns show the country exporting that value added. The GVC forward participation index in the machinery sectors of a sample economy is calculated as follows: A sample economy's domestic values in the machinery sectors embodied as intermediate inputs in all other countries' gross exports (given in the row in the matrix) are divided by a sample economy's gross exports (given in the column).

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Revisiting the Dynamics of International Business Cycles: A New Approach[1]

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Abstract

This study introduces a new method for analyzing international business cycle (IBC) dynamics by extending the *connectedness* measures of Diebold and Yilmaz (2015). Although connectedness measures capture the presence, direction, and magnitude of the effects better than other methods, they typically require a long sample period, which limits their use with time-series data. We present a feasible procedure for constructing time-varying measures of connectedness based on data for 33 countries with only 40 years of quarterly gross domestic product (GDP) data. The remarkable growth of the Chinese economy since the early 2000s, which covers the latter half of our sample period, has drawn significant attention because of its impact on both East Asian countries and the global economy. As an application of our proposed methodology, we analyze the total connectedness for the entire sample as well as for subsample groups, such as the G7, BRICS, and ASEAN, to assess the impact of the Chinese economy on each. In East Asia, along with China's rise, recent decades witnessed broader economic growth and increased trade and investment, leading to a more complex macroeconomic interdependence. In response, this study also examines the regional dynamics and bilateral relations among East Asian countries, with a particular focus on China, Japan, and South Korea.

Keywords: Business cycle; Connectedness; Global Vector Autoregression; Trade Linkage.
JEL Classification Codes: C32, C53, F62.

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1. Introduction

Economic interdependence between countries has been rising in recent years. This can be attributed to various factors such as the expansion of trade integration, creation of global supply chains, growth of international financial markets, and implementation of coordinated fiscal and monetary policies by national governments and central banks. Consequently, numerous empirical studies examine the transmission of international business cycles, including notable works by Duval et al. (2016), Di Giovanni et al. (2017), Davis (2014), and Chiquiar and Ramos-Francia (2005). These studies use various empirical analysis methods, such as the pairwise correlation of GDP by Backus et al. (1995) and Baxter (1995), and dynamic latent factor models proposed by Kose et al. (2003). In recent years, Diebold and Yılmaz's (2015) connectedness measure has also become a powerful analytical method.

This study presents a novel analytical approach based on that of Diebold and Yılmaz (2015), which is an influential contribution to the field. Our approach combines Pesaran et al.'s (2004) global vector autoregressive (GVAR) model with Diebold and Yılmaz's (2014) connectedness measure to derive a new index, which has three key features.

First, our methodology has the advantage of expanding the number of countries that can be analyzed. With the growth of emerging economies and the intricate blending of economies in close geographic proximity, it is advantageous to widen the scope of an analysis. To examine the connection between business cycles in six G7 countries (excluding Canada), Diebold and Yılmaz (2015) estimate a six-variate VAR model using monthly industrial production indices for these countries and calculated connectedness. However, dimensionality prevents the application of their approach when the sample size in the time dimension is limited (as data are available only quarterly) or when the sample size in the cross-sectional dimension is extensive (with an increasing number of countries). To address this problem, we use a GVAR model.[2]

Second, our method allows us to quantify business cycle linkages and determine the direction of the impact between different levels of units, such as country versus country or country versus a group of countries. Diebold and Yılmaz (2014) advance the literature by proposing *connectedness* concept. In this study, we develop more detailed connectedness measures to deal with the relationship between a country and a region or network connectivity within a region.

Third, we introduce a novel approach for computing time-varying connectedness measures. To create a time-varying measure of connectedness, Diebold and Yılmaz (2014) estimate a rolling sample. Although this approach is preferable for maintaining an objective analysis,[3] it cannot deal with a large sample of countries, and only quarterly data are available, resulting in a small sample size in the time

[2] See Binder and Soofi-Siavash (2017) for a combined analysis of the Diebold-Yilmaz connectedness index and the GVAR model, available at https://drive.google.com/file/d/16NAw89kPCD4XbLoSImHTz8veKMnqG1IA/view.
[3] To explain their use of rolling-sample estimation, they wrote, "Our goal was always the empirical description of connectedness and its evolution, 'getting the facts straight' with minimal assumptions." See Diebold and Yilmaz (2023).

direction, as in this study. Thus, this study employs a time-varying weighted formulation, which is a characteristic of GVAR. Specifically, we include changes in trade dependence over time. This point is important, as several previous studies indicate that trade intensity is highly related to business cycle synchronization between countries (Frankel and Rose 1998; Inklaar et al. 2008; Rana et al. 2012).

We focus on the economic interdependence in East Asia as an application of this innovative approach. We analyze this region because, as Vu (2015) notes, it differs from other regions such as Latin America and Africa in that intra-regional trade and investment are thriving. Additionally, East Asian economies are firmly connected through a network of production and trade of intermediate goods. Therefore, East Asia is an appropriate case study for our analytical method. Economic relations among East Asian countries have undergone significant transformation over the past four decades. In the 1980s, following the Plaza Accord, economic interdependence deepened and supply chains were established through the overseas expansion of Japanese firms. This was followed by outward FDI of firms in other countries such as Korea, Taiwan and several ASEAN members. Around 2000, the Chinese economy's influence grew, further transforming economic relations within the region. Therefore, East Asian economies provide an excellent case study for the proposed approach.

The remainder of this paper is organized as follows. Section 2 explains the construction of connectedness measures using the GVAR model. Section 3 describes the data. Section 4 presents the estimation results and the calculated connectedness measures. The final section concludes this paper.

2. Connectedness Measures and the GVAR Model

This section first presents the definitions of the connectedness measures and then explains how to calculate the forecast error variance decomposition (FEVD) in the GVAR model, which is essential in the calculation of these measures.

2.1. Measures of Connectedness

Table 1 presents a conceptual representation of connectedness in Diebold and Yılmaz (2014). The central part of this table shows the H step-ahead FEVD matrix $D^H = [d_{ij}^H]$ computed from the VAR model. By d_{ij}^H, we denote the fraction of the variance of the forecast error of variable i's H step-ahead owing to shocks in variable j. In addition, the connectedness table extends D^H with the right column containing the sums of the rows, the bottom row containing the sums of the columns, and the element in the right bottom containing the grand mean in all cases of $i \neq j$.

Based on this information, Diebold and Yılmaz (2014) define several measures of connectedness that capture the connections of individuals to individuals, individuals to the rest of the whole, and connectedness as a whole. In the following sections, these definitions are reviewed.

Table 1. Connectedness Table Schematic

	x_1	x_2	$\cdots$	x_N	From others to i
x_1	d_{11}^H	d_{12}^H	$\cdots$	d_{1N}^H	$C_{1\leftarrow G}^H$
x_2	d_{21}^H	d_{22}^H	$\cdots$	d_{2N}^H	$C_{2\leftarrow G}^H$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
x_N	d_{N1}^H	d_{N2}^H	$\cdots$	d_{NN}^H	$C_{N\leftarrow G}^H$
To others from j	$C_{G\leftarrow 1}^H$	$C_{G\leftarrow 2}^H$	$\cdots$	$C_{G\leftarrow N}^H$	C_G^H

Notes: Modified version of Table 1 in Diebold and Yilmaz (2014). d_{ij}^H denotes the fraction of country i's H step-ahead forecast error variable due to shocks in country j. Hence, the H step-ahead total directional connectedness 'from others to i' is given by $C_{i\leftarrow G}^H = 100 \cdot \left(\sum_{j\in G, j\neq i} d_{ij}^H\right)/\left(\sum_{j\in G} d_{ij}^H\right)$, and the H step-ahead total directional connectedness 'to others from j' is $C_{G\leftarrow j}^H = 100 \cdot \left(\sum_{i\in G, i\neq j} d_{ij}^H\right)/\left(\sum_{i\in G} d_{ij}^H\right)$, with G denoting the remaining countries in the sample.

The first indicator expresses the connection between country i and country j and is the most basic measure of connectedness. The (gross) pairwise directional connectedness (PDC) from country j to country i is defined as

$$C_{i\leftarrow j}^H = d_{ij}^H. \tag{1}$$

In general, $C_{i\leftarrow j}^H \neq C_{j\leftarrow i}^H$, so we have $N^2 - N$ PDC. Then, from the asymmetry $C_{i\leftarrow j}^H \neq C_{j\leftarrow i}^H$, we use these to define net PDC as follows

$$C_{ij}^H = C_{j\leftarrow i}^H - C_{i\leftarrow j}^H. \tag{2}$$

This measure indicates the net effect of shocks occurring in each country on the GDP forecast errors of the other country.

The second measure is the connectedness between country i and other countries. We define total directional connectedness (TDC) from others to i as

$$C_{i\leftarrow G}^H = 100 \cdot \frac{\sum_{j\in G, j\neq i} d_{ij}^H}{\sum_{j\in G} d_{ij}^H}. \tag{3}$$

This value can be calculated for each country; therefore, N possible values exist. Then, as an inverse relationship, the TDC to others from i is

$$C_{G\leftarrow i}^H = 100 \cdot \frac{\sum_{j\in G, j\neq i} d_{ji}^H}{\sum_{j\in G} d_{ji}^H}. \tag{4}$$

This also exists in N ways. Based on these two connectedness measures, we define the net TDC of i as

$$C_{i,G}^H = C_{G\leftarrow i}^H - C_{i\leftarrow G}^H. \tag{5}$$

This indicator shows whether, on a net basis, country i has more impact on other countries or receives a greater impact from other countries.

The third indicator is the total connectedness (TC) of the entire sample. TC is the sum of the off-diagonal elements of D^H divided by the sum of all the elements of D^H.

$$C_G^H = 100 \cdot \frac{\sum_{i\in G}\sum_{j\in G, j\neq i} d_{ij}^H}{\sum_{i\in G}\sum_{j\in G} d_{ij}^H} \tag{6}$$

This study proposes two new indicators to capture connectedness within a region.[4] The first is the connection between country i and other countries in a group. This indicator is similar to TDC but differs in that the countries that make up “the others” are the others in a group, not all “others.” The purpose is to measure the possibility that the connectedness of country i to all countries in the sample differs from that of a particular group of countries when looking at the connectedness of country i to the rest of the group.

We first define TDC from others in group R to i as

$$C_{i\leftarrow R}^H = 100 \cdot \frac{\sum_{j\in R, j\neq i} d_{ij}^H}{\sum_{j\in R} d_{ij}^H}. \tag{7}$$

We calculate this value for each country in group R. We can define TDC to others in group R from j similarly. Using these settings, we define net pairwise within-group R directional connectedness as

$$C_{i,R}^H = C_{R\leftarrow i}^H - C_{i\leftarrow R}^H. \tag{8}$$

The second new indicator is the TC within-group R, which is the sum of off-diagonal elements of D^H in group R divided by the sum of all elements of D^H also in group R.

$$C_R^H = 100 \cdot \frac{\sum_{i\in R}\sum_{j\in R, j\neq i} d_{ij}^H}{\sum_{i\in R}\sum_{j\in R} d_{ij}^H} \tag{9}$$

In the following section, we use these indicators to analyze the connectedness among East Asian countries.

2.2. Specification of GVAR Model

The standard GVAR model comprises VARX* models estimated separately for each economy. A VARX* model for country i consists of several equations for its domestic variables x_{it}. These equations include the lags of the domestic variables and weakly exogenous variables, or "star" variables (x_{it}^*), which are derived from the variables of other sample countries, as explanatory variables. The global variables ω_t are added, when needed. Thus, for country i, the model is written as

$$x_{it} = a_{i0} + a_{i1}t + \sum_{n=1}^{p_i} \phi_{in} x_{i,t-n} + \sum_{s=0}^{q_i} \lambda_{is} x_{it-s}^* + \sum_{s=0}^{q_i} \psi_{is}\omega_{t-s} + u_{it} \tag{10}$$

[4] This is similar to how Demirer et al. (2018) analyze 150 bank connections by aggregating the matrix D by country to provide an overview of the relationships.

where $\Theta_i = \{a_{i0}, a_{i1}, \phi_{i1}, \phi_{i2}, \dots, \phi_{ip_i}, \lambda_{i0}, \lambda_{i1}, \dots, \lambda_{iq_i}, \psi_{i0}, \psi_{i1}, \dots, \psi_{iq_i}\}$ represents the regression coefficients, t denotes the linear time trend, and u_{it} is the error term with $\mathrm{E}(u_{it}^2) = \sigma_{u_i}^2$. Typically, x_{it}^* is defined as

$$x_{it}^* = \sum_{j=1, j\neq i}^{N} w_{ij} x_{jt}, \tag{11}$$

where w_{ij} is a weight parameter capturing the linkages between countries i and j. In this study, we assume that the domestic variable x_{it} represents only real GDP, while the global variable ω_t represents the oil price. Therefore, the star variable x_{it}^* is a variable that aggregates the impact of foreign GDP in accordance with its link to country i.

Next, we also consider a model to explain the behavior of the oil price ω_t,

$$\omega_t = \mu_0 + \mu_1 t + \sum_{j=1}^{p_\omega} \phi_j \omega_{t-j} + \sum_{j=1}^{q_\omega} \lambda_j \tilde{x}_{t-j} + \eta_t, \tag{12}$$

where $\Theta_{\mathrm{du}} = \{\mu_0, \mu_1, \phi_1, \phi_2, \dots, \phi_{p_\omega}, \lambda_1, \lambda_{2,} \dots, \lambda_{q_\omega}\}$ denotes the coefficients, while η_t signifies the error vector with $\mathrm{E}(\eta_t^2) = \sigma_\eta^2$. Furthermore, $\tilde{x}_{t-1}$ serves as a feedback variable to capture the exogenous factors that could impact commodity price changes. Typically, it is defined as

$$\tilde{x}_t = \sum_{i=1}^{N} w_i x_{it}$$

where w_i is another weight parameter representing the relative size of sample countries. Since we use real GDP as the domestic variable, $\tilde{x}_{t-1}$ captures the impact of lagged global output fluctuation on the crude oil price.

The GVAR model extends the standard VAR by incorporating the star variable x_{it}^*, which allows the analysis of how domestic shocks spread to foreign countries and how foreign shocks affect the home country. Given the susceptibility to external factors of small open economies, such as East Asian nations, accounting for fluctuations originating abroad in the domestic economy is imperative. Thus, GVAR serves as an effective analytical framework for examining interactions of an open economy with its external economies at various levels.

Furthermore, the inclusion of a feedback variable $\tilde{x}_t$ links international crude oil prices to the GDP of each country, thereby endogenizing the oil prices within the system. Endogenizing oil prices is feasible for large open economies, such as the US, by incorporating them into the domestic model. However, for small open economies, such as those in East Asia, oil prices are largely treated as an externally determined factor. In early GVAR models, oil prices were considered endogenous in the US model but treated as exogenous in models for smaller open economies. However, the rapid expansion of the Chinese economy during the sample period and its impact on global commodity prices, including oil, raises questions about limiting the endogenous treatment of commodity prices to the US model. To address this, second-generation GVAR models introduced an independent VAR model for the international market block, which includes crude oil prices. Additionally, a variable representing global factors is incorporated to make international commodity prices endogenous within the system.

2.3. Derivation of the Generalized FEVD

Since the general case requires complicated notations, in the following, to illustrate the idea, we set $p_i = 2$ and $q_i = 1$ for all i and $p_\omega = 2$ and $q_\omega = 1$. We note, however, that in the actual analysis, we work with the general case. The generalized FEVD (GFEVD) was derived from Eq. (10) and Eq. (12). Initially, a variable vector $\mathbf{z}_{it}$ is defined that includes the home GDP x_{it} and foreign GDP x_{it}^* of country i.

$$\mathbf{z}_{it} = \begin{pmatrix} x_{it} \\ x_{it}^* \end{pmatrix}$$

Furthermore, we can express the model for country i described in Eq. (10) as

$$\mathbf{G}_{i0}\mathbf{z}_{it} = a_{i0} + a_{i1}\, t + \mathbf{G}_{i1}\mathbf{z}_{i,t-1} + \mathbf{G}_{i2}\mathrm{z}_{i,t-2} + \psi_{i0}\omega_t + \psi_{i1}\omega_{t-1} + u_{it}, \tag{13}$$

where $\mathbf{G}_{i0} = (1, -\lambda_{i0})$, $\mathbf{G}_{i1} = (\phi_{i1}, \lambda_{i1})$, and $\mathbf{G}_{i2} = (\phi_{i2}, \lambda_{i2})$.

Subsequently, we establish two identities between $\mathbf{z}_{it}$, $\tilde{x}_t$, and $\mathbf{x}_t = (x_{1t}, \dots, x_{Nt})'$ using the link matrices $\mathbf{W}_i$ and $\widetilde{\mathbf{W}}$ outlined in Section 3.

$$\mathbf{z}_{it} = \mathbf{W}_i\mathbf{x}_t, \qquad \tilde{x}_t = \widetilde{\mathbf{W}}\mathbf{x}_t \tag{14}$$

With this, we write Eq. (13) as

$$\mathbf{G}_{i0}\mathbf{W}_i\mathbf{x}_t = a_{i0} + a_{i1}t + \mathbf{G}_{i1}\mathbf{W}_i\,\mathbf{x}_{t-1} + \mathbf{G}_{i2}\mathbf{W}_i\mathbf{x}_{t-2} + \psi_{i0}\omega_t + \psi_{i1}\omega_{t-1} + u_{it}.$$

Thus, if we stack up the models for N countries, we obtain

$$\mathbf{G}_0\mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{G}_1\mathbf{x}_{t-1} + \mathbf{G}_2\mathbf{x}_{t-2} + \mathbf{\Psi}_0\omega_t + \mathbf{\Psi}_1\omega_{t-1} + \mathrm{u}_t, \tag{15}$$

where the corresponding relevant coefficient matrices are

$$\mathbf{a}_j = \begin{pmatrix} a_{1j} \\ \vdots \\ a_{Nj} \end{pmatrix},\ \mathbf{G}_j = \begin{pmatrix} \mathbf{G}_{1j}\mathbf{W}_1 \\ \vdots \\ \mathbf{G}_{Nj}\mathbf{W}_N \end{pmatrix},\ \mathbf{\Psi}_j = \begin{pmatrix} \psi_{1j} \\ \vdots \\ \psi_{Nj} \end{pmatrix},\ \mathbf{u}_t = \begin{pmatrix} u_{1t} \\ \vdots \\ u_{Nt} \end{pmatrix}.$$

We can also reformulate the model for oil prices using the link matrix

$$\omega_t = \mu_0 + \mu_1 t + \phi_1\omega_{t-1} + \phi_2\omega_{t-2} + \lambda_1\widetilde{\mathbf{W}}\mathbf{x}_{t-1} + \eta_t. \tag{16}$$

Next, we define the variable vector $\mathbf{y}_t$ as:

$$\mathbf{y}_t = \begin{pmatrix} \mathbf{x}_t \\ \omega_t \end{pmatrix}.$$

Therefore, we can formulate a global model combining Eqs. (16) and (15) as

$$\mathbf{H}_0\mathbf{y}_t = \mathbf{h}_0 + \mathbf{h}_1 t + \mathbf{H}_1\,\mathbf{y}_{t-1} + \mathbf{H}_2\mathbf{y}_{t-2} + \boldsymbol{\zeta}_t, \tag{17}$$

where

$$\mathbf{H}_0 = \begin{pmatrix} \mathbf{G}_0 & -\mathbf{\Psi}_0 \\ \mathbf{0} & 1 \end{pmatrix},\ \mathbf{h}_0 = \begin{pmatrix} \mathbf{a}_0 \\ \mu_0 \end{pmatrix},\ \mathbf{h}_1 = \begin{pmatrix} \mathbf{a}_1 \\ \mu_1 \end{pmatrix},\ \mathbf{H}_1 = \begin{pmatrix} \mathbf{G}_1 & \Psi_1 \\ \lambda_1\widetilde{\mathbf{W}} & \phi_1 \end{pmatrix},\ \mathbf{H}_2 = \begin{pmatrix} \mathbf{G}_2 & \mathbf{0} \\ \mathbf{0} & \phi_2 \end{pmatrix},\ \boldsymbol{\zeta}_t = \begin{pmatrix} \mathbf{u}_t \\ \eta_t \end{pmatrix}.$$

Note that we assume that the covariance matrix of $\boldsymbol{\zeta}_t$ is diagonal. Subsequently, we multiply both sides of Eq. (17) using $\mathbf{H}_0^{-1}$ from the left to derive the first-order autoregressive expression for $\mathbf{y}_t$.

$$\begin{aligned}\mathbf{y}_t &= \mathbf{H}_0^{-1}\mathbf{h}_0 + \mathbf{H}_0^{-1}\mathbf{h}_1\, t + \mathbf{H}_0^{-1}\mathbf{H}_1\mathbf{y}_{t-1} + \mathbf{H}_0^{-1}\mathbf{H}_2\mathbf{y}_{t-2} + \mathbf{H}_0^{-1}\boldsymbol{\zeta}_t \\ &= \mathbf{c}_0 + \mathbf{c}_1 t + \mathbf{C}_1\mathbf{y}_{t-1} + \mathbf{C}_2\mathbf{y}_{t-2} + \boldsymbol{\epsilon}_t. \end{aligned} \tag{18}$$

The moving average expression corresponding to Eq. (18) is

$$\mathbf{y}_t = \mathbf{d}_t + \sum_{s=0}^{\infty} \mathbf{B}_s \boldsymbol{\epsilon}_{t-s} = \mathbf{d}_t + \mathbf{B}_0\boldsymbol{\epsilon}_t + \mathbf{B}_1\boldsymbol{\epsilon}_{t-1} + \mathbf{B}_2\boldsymbol{\epsilon}_{t-2} + \cdots, \tag{19}$$

where $\mathbf{d}_t$ is the deterministic component and we define the coefficient matrices $\mathbf{B}$ recursively as

$$\mathbf{B}_s = \begin{cases} \mathbf{C}_1\mathbf{B}_{s-1} + \mathbf{C}_2\mathbf{B}_{s-2} & s = 1,2,\ldots \\ \mathbf{I} & s = 0 \\ \mathbf{0} & s < 0 \end{cases}.$$

Therefore, for instance, the coefficient of the impulse response at horizon H to a shock to ζ_t can be calculated using the formula $\mathbf{B}_h\mathbf{H}_0^{-1}$.

Lastly, we calculate GFEVD as

$$d_{ij}^H = \frac{(\sigma_{jj})^{-1} \sum_{h=0}^{H} \left(\mathbf{e}_i'\mathbf{B}_h(\mathbf{H}_0)^{-1}\,\boldsymbol{\Sigma}_\zeta \mathbf{e}_j\right)^2}{\sum_{h=0}^{H} \mathbf{e}_i'\mathbf{B}_h(\mathbf{H}_0)^{-1}\,\boldsymbol{\Sigma}_\zeta((\mathbf{H}_0)^{-1})'(\mathbf{B}_h)'\mathbf{e}_j}, \tag{20}$$

which indicates the extent to which a shock in the j-th variable affects the H step-ahead forecast error variance of the i-th variable. $\mathbf{e}_i$ is the selection vector whose i-th element is 1 and the rest are 0, and σ_{jj} is the variance of the disturbance term in the j-th expression (or the j-th diagonal element of Σ_ζ). Note that in the GFEVD, the shocks are not orthogonalized, so the sum of the relative contribution to the forecast error variance is not necessarily equal to one. Therefore, we use the following standardization:

$$\tilde{d}_{ij}^H = \frac{d_{ij}^H}{\sum_{j=1}^{N} d_{ij}^H}. \tag{21}$$

In the following, we denote GFEVD by d_{ij} to simplify the notation; however, we calculated all connectedness measures in this study using the standardized value $\widetilde{D}^H = [\tilde{d}_{ij}^H]$.

3. Data

In this study, we use the real GDP by country (log-transformed values) and oil prices (log-transformed values) from the Mohaddes and Raissi (2020) dataset in the analysis.[5] This data set includes 10 countries from the East Asia and Pacific region: Australia (AUS), China (CHN), Indonesia (IDN), Japan (JPN), Korea (KOR), Malaysia (MYS), New Zealand (NZL), the Philippines (PHL), Singapore (SGP), Thailand (THA);[6] 13 countries from Europe and Central Asia: Austria (AUT), Belgium (BEL),

[5] The Mohaddes and Raissi (2020) dataset covers the fourth quarter of 1979 to the fourth quarter of 2019. In addition to the data used in this study, the dataset includes the long-term interest rate, stock prices, and the bilateral exchange rate against the dollar.

[6] Unfortunately, we could not include other East Asian economies such as Hong Kong, Taiwan, and Vietnam due to

Finland (FIN), France (FRA), Germany (DEU), Italy (ITA), the Netherlands (NLD), Norway (NOR), Spain (ESP), Sweden (SWE), Switzerland (CHE), Turkey (TUR), the United Kingdom (GBR); 5 countries from Latin America: Argentina (ARG), Brazil (BRA), Chile (CHL), Mexico (MEX), Peru (PER); 2 countries from North America: Canada (CAN), the United States (USA). The other three countries are Saudi Arabia (SAU) in the Middle East and North Africa, India (IND) in South Asia, and South Africa (ZAF) in Sub-Saharan Africa. The sample comprises 33 countries.

We calculate foreign GDP x^*_{it} using the matrix $\mathbf{W}_i$, which depicts the relations between countries. We derive this matrix from the annual trade flow data provided by Mohaddes and Raissi (2020).[7] Based on annual trade flow data, we calculate the linkage coefficient w_{ij} between countries i and j as

$$w_{ij} = \frac{T_{ij}}{\sum_{k=1}^{N} T_{ik}}, \tag{22}$$

where T_{ij} denotes the trade volume, defined as the sum of annual exports and imports between countries i and j. For example, Japan's foreign GDP is

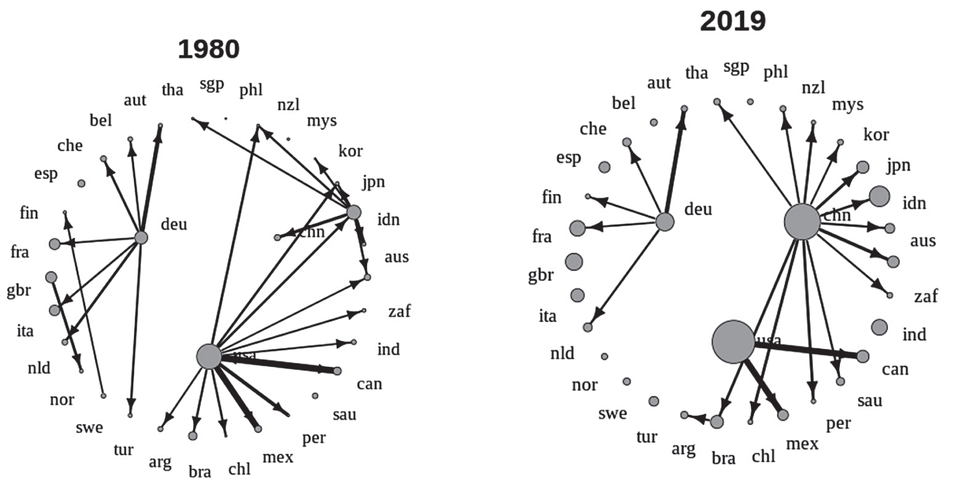
$$x^*_{jpn,t} = \sum_{j=1, j\neq jpn}^{33} w_{jpn,j}\, x_{j,t}\,. \tag{23}$$

As China's economy has experienced significant growth over the last 30 years, its economic relationships with other countries, specifically those in East Asia, have changed significantly. Figure 1 displays the linkage coefficients of individual countries and GDP at both ends of the sample period, namely 1980 and 2019. The three inner circles represent the United States, Germany, and China, and the outer circles represent the other 30 sample countries. The size of each circle corresponds to the size of the economy, and the arrows indicate influencing relationships. In Figure 1, arrows with linkage coefficient values of less than 20.5% were removed to emphasize the more critical relationships.

data availability.

7 The values for the three most recent years were updated using rates of change calculated from annual export and import values (in USD) obtained from the latest Direction of Trade Statistics (DOTS). Because of data availability and that this study concentrates on the real economic interrelationships rather than financial ones, data on trade volume were employed. Another approach would be to use capital investment and asset portfolio data.

Figure 1: Trade Networks



Note: See Table A.1 in the Appendix for the country codes. The circles on the circumference indicate the size of the economy based on real GDP, and the arrows indicate that the relevance calculated from trade flows is 20.5% or higher; the arrow thickness indicates the strength of the relevance.

From Figure 1, the trade relationship, measured by the linkage coefficient defined in Eq. (22), evolves dynamically over time. To account for these changes, we modify $\mathbf{W}_i$ in Eq. (14) to be time-varying so we can capture the changes in the trade relationship over time accurately. We compute the linkage coefficient based on the trade volume in the previous year. Accordingly, the weighted coefficient of foreign GDP changes annually, and the GFEVD, as defined in Eq. (20), also fluctuates to reflect various evaluation time points. Thus, the connectedness measures vary over time.

Finally, the feedback variable $\tilde{\mathbf{x}}_t$ in the oil price model is the weighted average of each country's log-transformed GDP value. We calculate the weights used to determine the average (represented by the $\widetilde{\mathbf{W}}$ matrix in Eq. (14)) using the share obtained from the 2014-2016 average nominal GDP in PPP (in current international dollars) for each country, as reported by the World Bank's WDI. This variable serves as a proxy for global business cycle fluctuations and covers various aspects of oil demand. Examining the crude oil supply factors is also valuable for price fluctuations; however, we did not include them in this study.

4. Results

4.1. GVAR Model Estimation

We conduct the estimation model-by-model, following the standard VAR model. As the sample consists of quarterly data, we set the lag lengths for the domestic and foreign variables included in the model at $p_i = 4$ and $q_i = 4$, respectively, for all i. In the oil price model, we set the number of lags at four periods for both the own and feedback variables.

When analyzing multiple countries simultaneously, the presence of outliers can cause the system to become unstable and divergent. The sample period covers the Asian currency crisis with the substantial devaluation of currencies in Thailand and other Asian nations during 1997-1998, and the global financial crisis between 2007-2008. The other local shocks include the severe acute respiratory syndrome (SARS) outbreak in China from November 2002 to the first half of 2003, the Great East Japan Earthquake in Japan in March 2011, and significant flooding in Thailand in the latter half of the same year. These events not only affected domestic economic activities in each country, but also affected supply chains. These large shocks posed risks to the stability of the entire system, making it difficult to handle them in the GVAR model. Therefore, we treated them as outliers.

Historical data should be used to identify outliers. However, owing to the large number of countries covered, we apply statistical criteria to identify outliers and assign dummy variables to manage them. Specifically, if the maximum absolute value of the residuals did not fall within three standard deviations of the error variance, then we assign dummy variables. We perform iterations until we remove all anomalies for each country. We follow the same approach for the crude oil price model.

4.2. Measures of Business Cycle Connectedness

We compute the connectedness measures presented in this study using the GFEVD for the next 12 quarters (three years). The Appendix provides the tables reporting the connectedness estimates for 1985, 1995, 2005, and 2015.

We begin by examining its effect, which is represented by the diagonal element in the connectedness table. Table 2 presents the effects in each country at 10-year intervals from 1985. For clarity, we highlight the eight countries with low own effects (1/4 of the total sample). The table shows that several European countries experienced few effects, which can be attributed to their close economic ties. This result applies similarly to Canada, where the United States is likely to have a strong influence. In South America, Peru and Brazil experienced a notable decrease in the effects of their home countries from 1985 to 2015 (i.e., they became more vulnerable to foreign influence). Meanwhile, the values for China, Indonesia, and South Korea in East Asia increase, although only slightly. In contrast, the Philippines and Japan experienced decreases of approximately 9 and 5%, respectively.

Table 2: Own Effect: 1985, 1995, 2005, and 2015

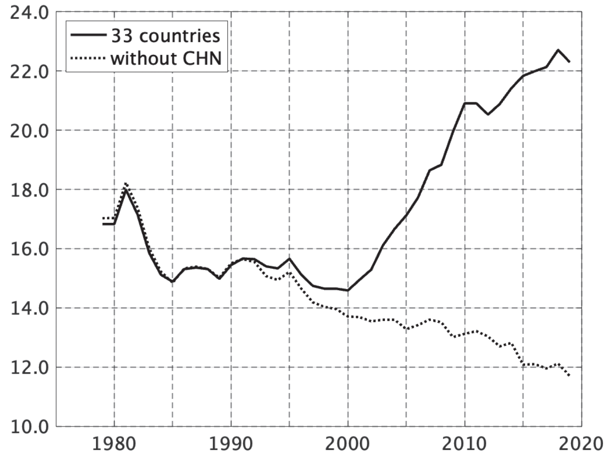
	1985		1995		2005		2015	
	own	rank	own	rank	own	rank	own	rank
ARG	0.755	18	0.752	18	0.756	18	0.759	16
AUS	0.933	1	0.935	2	0.932	2	0.910	4
AUT	0.359	31	0.321	32	0.341	32	0.336	32
BEL	0.299	33	0.280	33	0.317	33	0.320	33
BRA	0.818	13	0.796	13	0.771	15	0.688	18
CAN	0.616	27	0.614	25	0.599	27	0.565	25
CHN	0.825	11	0.834	11	0.846	9	0.840	9
CHL	0.933	2	0.932	3	0.932	3	0.919	3
FIN	0.658	24	0.634	24	0.624	24	0.574	24
FRA	0.596	28	0.574	29	0.593	28	0.562	26
DEU	0.701	20	0.695	20	0.693	19	0.644	19
IND	0.593	29	0.586	28	0.632	22	0.596	22
IDN	0.914	4	0.919	4	0.920	4	0.925	2
ITA	0.357	32	0.330	31	0.357	31	0.369	31
JPN	0.870	8	0.851	9	0.845	10	0.815	10
KOR	0.824	12	0.823	12	0.837	11	0.840	8
MYS	0.665	23	0.667	23	0.668	21	0.603	21
MEX	0.850	10	0.837	10	0.830	12	0.808	12
NLD	0.497	30	0.488	30	0.521	30	0.540	29
NOR	0.890	6	0.887	6	0.892	5	0.873	6
NZL	0.861	9	0.862	8	0.868	7	0.882	5
PER	0.678	22	0.672	22	0.586	29	0.460	30
PHL	0.905	5	0.900	5	0.863	8	0.814	11
ZAF	0.679	21	0.676	21	0.628	23	0.545	28
SAU	0.926	3	0.937	1	0.937	1	0.934	1
SGP	0.886	7	0.876	7	0.880	6	0.855	7
ESP	0.775	17	0.756	17	0.762	17	0.775	15
SWE	0.628	25	0.591	27	0.610	25	0.558	27
CHE	0.786	15	0.759	16	0.769	16	0.745	17
THA	0.816	14	0.788	14	0.815	13	0.794	14
TUR	0.785	16	0.777	15	0.793	14	0.798	13
GBR	0.617	26	0.599	26	0.606	26	0.593	23
USA	0.738	19	0.727	19	0.689	20	0.633	20
poil	0.969		0.966		0.960		0.953	

Note: The highlighted countries are the eight countries with small home country effect values (corresponding to 1/4 of the total sample).

4.2.1. Total Connectedness

We now assess various measures of connectedness. First, we examine the overall connectedness. Figure 2 shows the TC for all 33 countries in the sample. The TC value decreased from 18% in 1981 to around 15% in 1985. It remained around 15% until around 2000, after which it increased, reaching a level of more than 22% in 2019. Excluding China, the calculation of TC demonstrates a long-term decline over the sample period. This finding implies that the increase in global connectedness can be attributed to the Chinese economy.

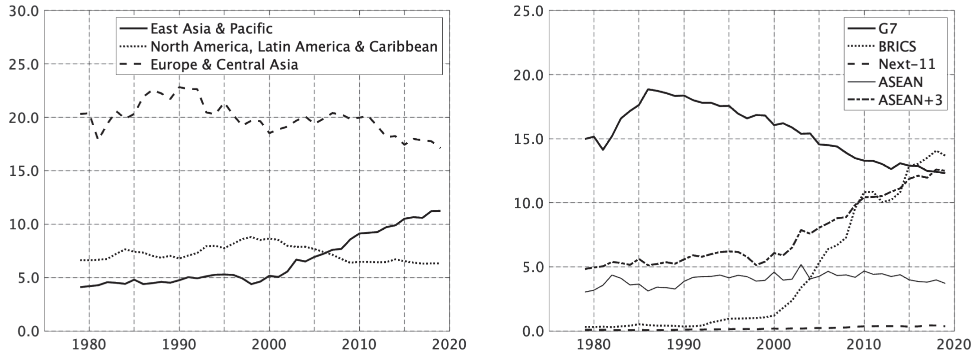
Figure 2: Total Connectedness



Note: TC is $C_G^H = 100 \cdot (\sum_{i,j \in G, i \neq j} d_{ij}^H)/(\sum_{i,j \in G} d_{ij}^H)$. This calculation excludes the part related to oil prices. The forecasting horizon H is set to 12.

Next, we examine the TC of the subgroups. We first group countries by geographic location. The left panel of Figure 3 illustrates the following three regions: East Asia & Pacific; North America, Latin America, & the Caribbean; and Europe & Central Asia. Regional variations are evident from Figure 3; while Europe & Central Asia maintain the highest levels throughout the period, they show a decreasing trend with an amplitude of 20-year cycles. In contrast, North America, Latin America & the Caribbean, East Asia & the Pacific display lower levels, although the magnitude in East Asia & the Pacific increased consistently since 2000.

Figure 3: Total Connectedness within Different Groups



Note: The within-region TC is calculated as $C_R^H = 100 \cdot \left(\sum_{i,j \in R, i \neq j} d_{ij}^H\right)/\left(\sum_{i,j \in R} d_{ij}^H\right)$. The figure on the left depicts different geographic regions, while the figure on the right shows various groups, including the G7, BRICS, ASEAN, and Next-11. The forecasting horizon H, is set to 12.

In another grouping, we analyze the G7, BRICS, Next 11,[8] ASEAN, and ASEAN+3. The G7 group peaked in the mid-1980s and gradually declined until the end of the sample period, ultimately reaching the same level as the other groups. By contrast, the BRICS group showed a considerable increase starting in 2000, which aligns with the growth of the Chinese economy. However, the level of TC observed in the Next-11 remained notably low despite an upward trend that began around 1985. As for Asia, the TC of ASEAN countries remained stable throughout the sample period, though many of these countries experienced the Asian currency crisis in the late 1990s. In contrast, ASEAN+3, which incorporates China, Japan, and Korea, showed a considerable decline during the Asian currency crisis; however, this trend was reversed and replaced by a consistent upward trend.

4.2.2. Total Directional Connectedness

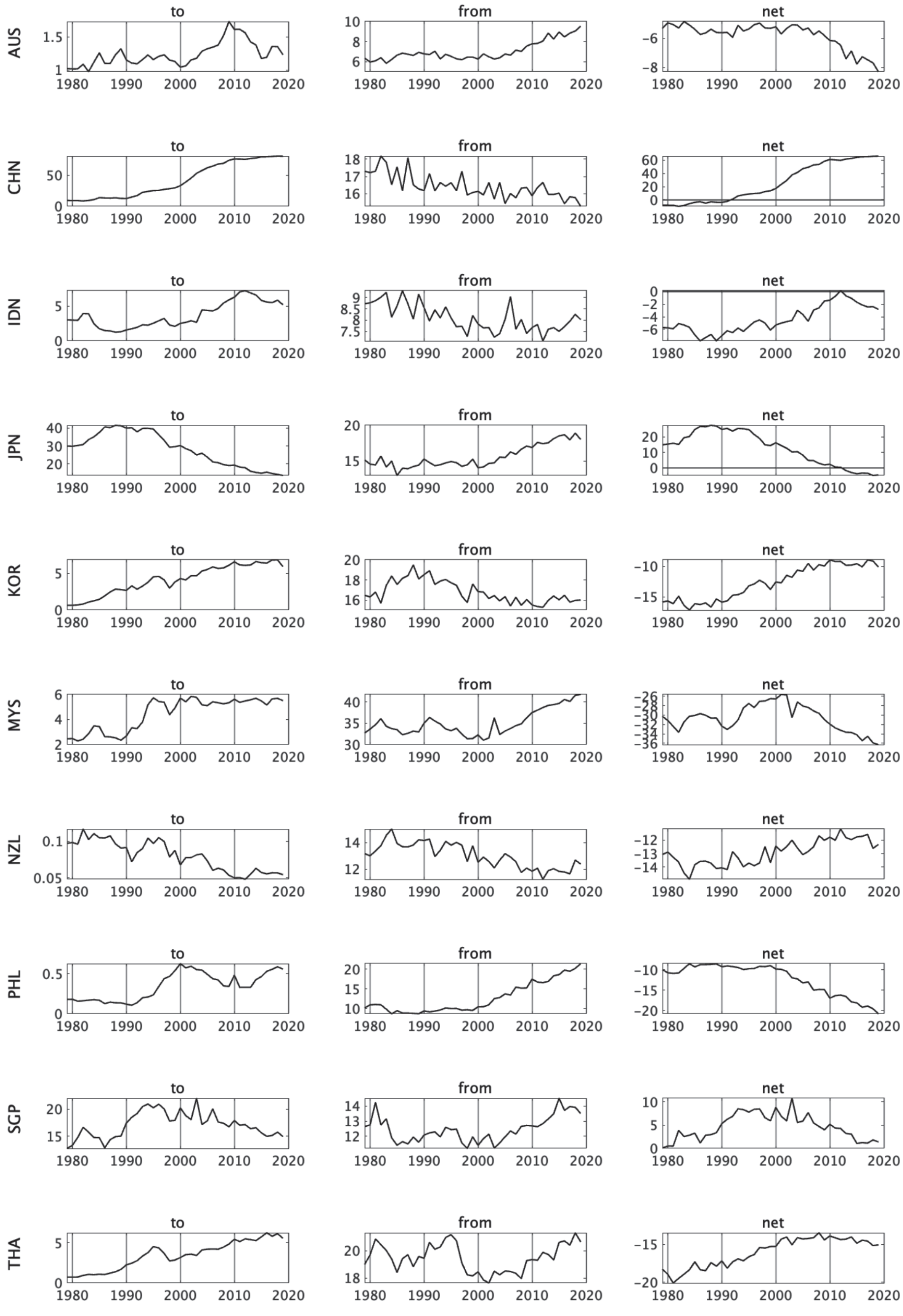
Here, we focus on East Asia and examine the directional connectedness of their business cycles across countries within and beyond the region.

Figure 4 displays the TDC between the 10 East Asian countries in the dataset and other 32 countries. The graph illustrates the changes over time in terms of TDC to others ($C_{G\leftarrow i}^{H}$), TDC from others ($C_{i\leftarrow G}^{H}$), and net TDC (C_i^{H}). Here, G denotes the rest of the sample countries.

As Figure 4 shows, only three countries (Japan, China, and Singapore) had positive net TDC values during the sample period. This finding implies that these three countries are net transmitters of business cycle shocks. During the mid-1980s and the mid-1990s, Column 3 indicates that Japan was the main driver of connectedness. During this period, Japan's gross TDC to other countries reached approximately 40%, whereas Japan's TDC from other countries was approximately 15%, resulting in Japan's net TDC of up to 25%. However, Japan's net TDC declined since mid-1990s. By contrast, China's influence grew rapidly, reaching 60% around 2010.

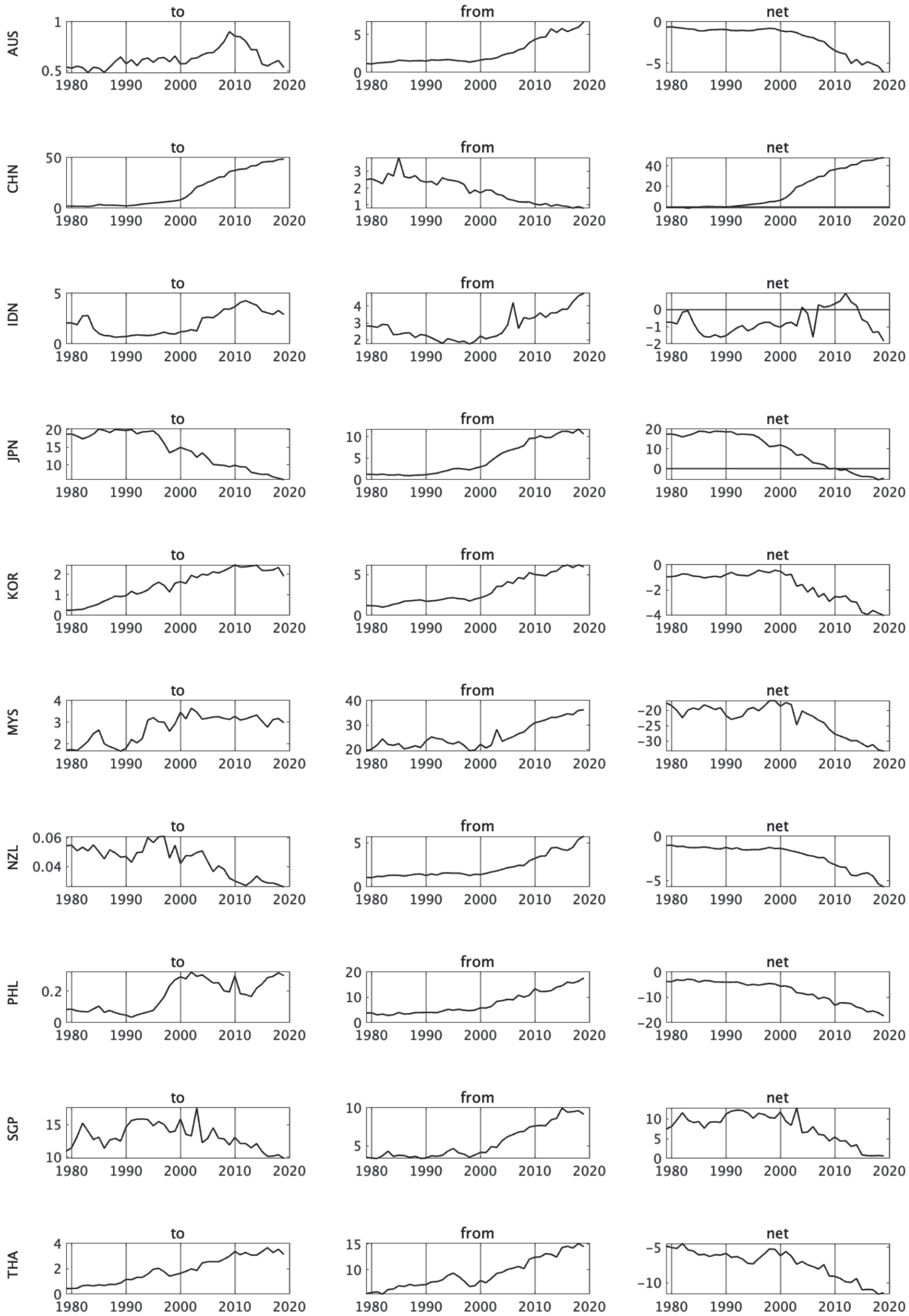
[8] The Next Eleven are Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, South Korea, Turkey, and Vietnam.

Figure 4: Total Directional Connectedness



Note: The forecasting horizon, H, is set to 12.

Figure 5: Total Directional Connectedness within the East Asia and Pacific Region

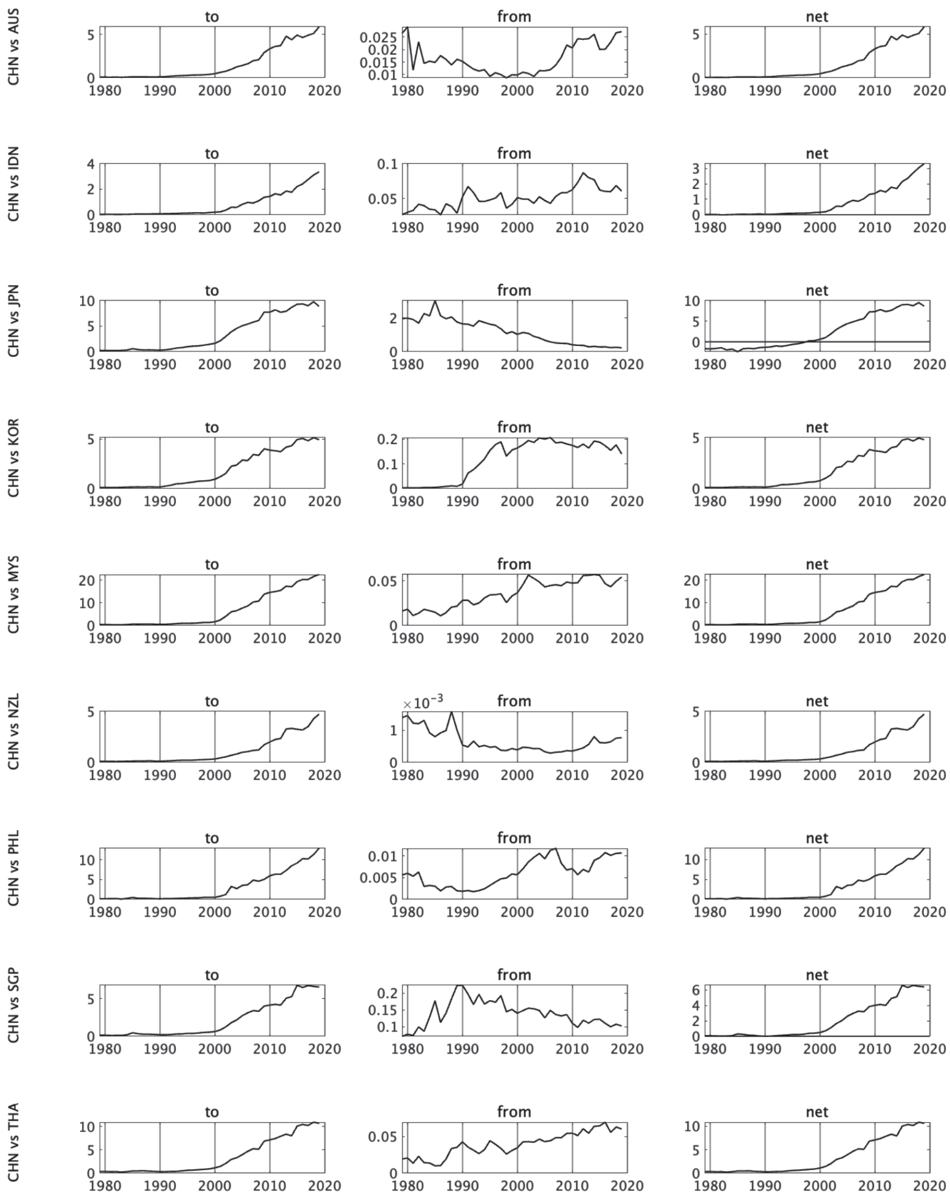


Note: The forecasting horizon, H, is set to 12.

We next limit the measurement of directional connectedness to East Asia. Based on these data, we observe no significant changes in trends for Japan and China. However, some countries, such as Korea, New Zealand, and Thailand, show notable variations. Take the case of Korea. In relation to the world overall, Korea shows a trend of declining negative net TDC margin since the early 1990s, as displayed in Figure 4. However, as Figure 5 indicates, in relation to the East Asian region Korea shows a steady increase in the negative net TDC margin at the regional level, suggesting an increasing influence of other countries in the region. This result illustrates the need to examine connectedness at different unit levels, as we mentioned in the Introduction.

4.2.3. Pairwise Directional Connectedness

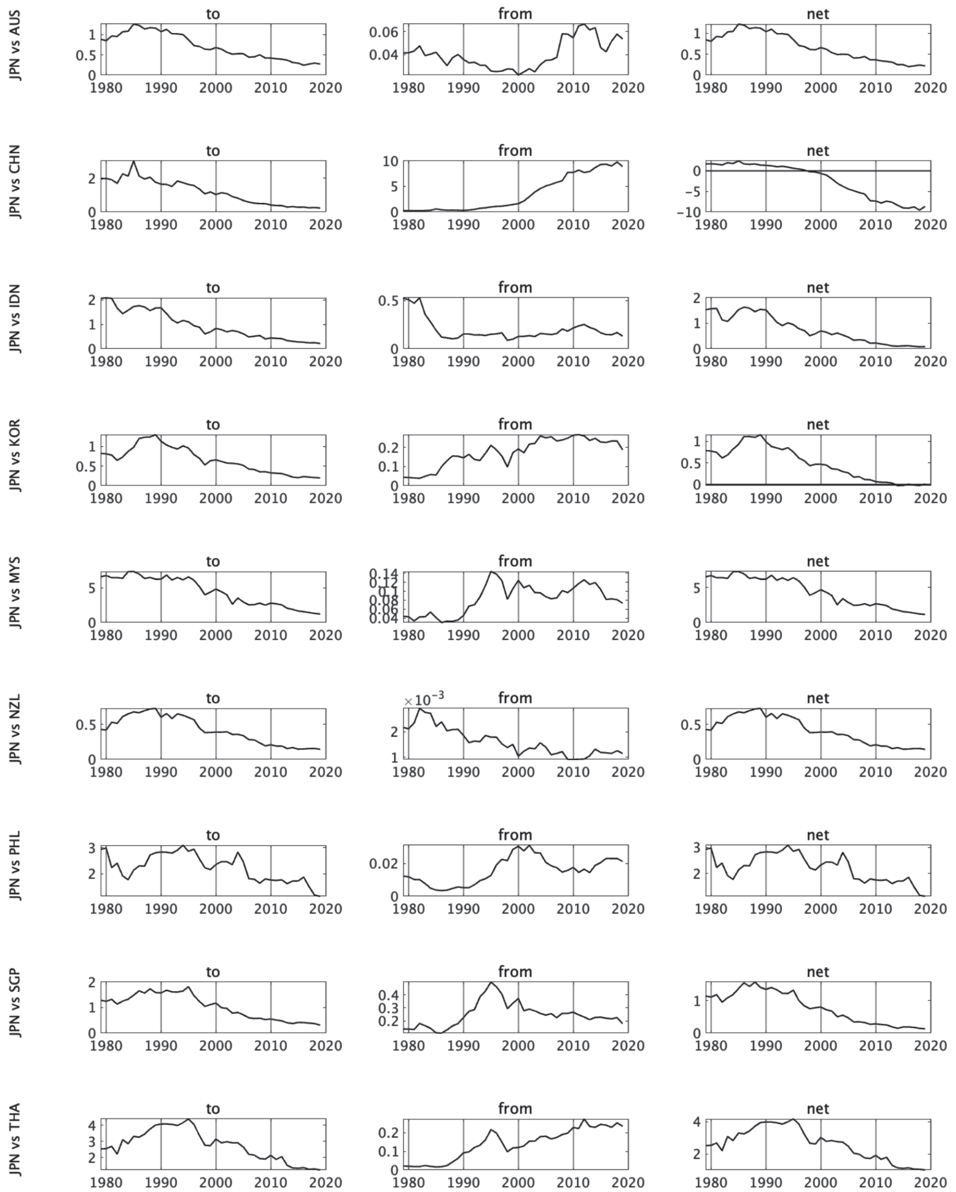
Figure 6: China's PDC within East Asia and Pacific



Note: The forecasting horizon H is set to 12.

Finally, we examine the interdependence of East Asian nations. As we observed above, the waning impact of the Japanese economy and the growing influence of the Chinese economy lead us to consider the relationship between China, Japan, and Korea with other Asian countries. Figure 6 shows the three PDCs in China. From the left to right columns, they correspond to China's gross PDC to country j ($C^H_{j\leftarrow chn}$), China's gross PDC from country j ($C^H_{chn\leftarrow j}$), and China's net PDC with country j ($C^H_{chn,j} = C^H_{j\leftarrow chn} - C^H_{chn\leftarrow j}$). Figures 7 and 8 show the PDCs for Japan and South Korea, respectively.

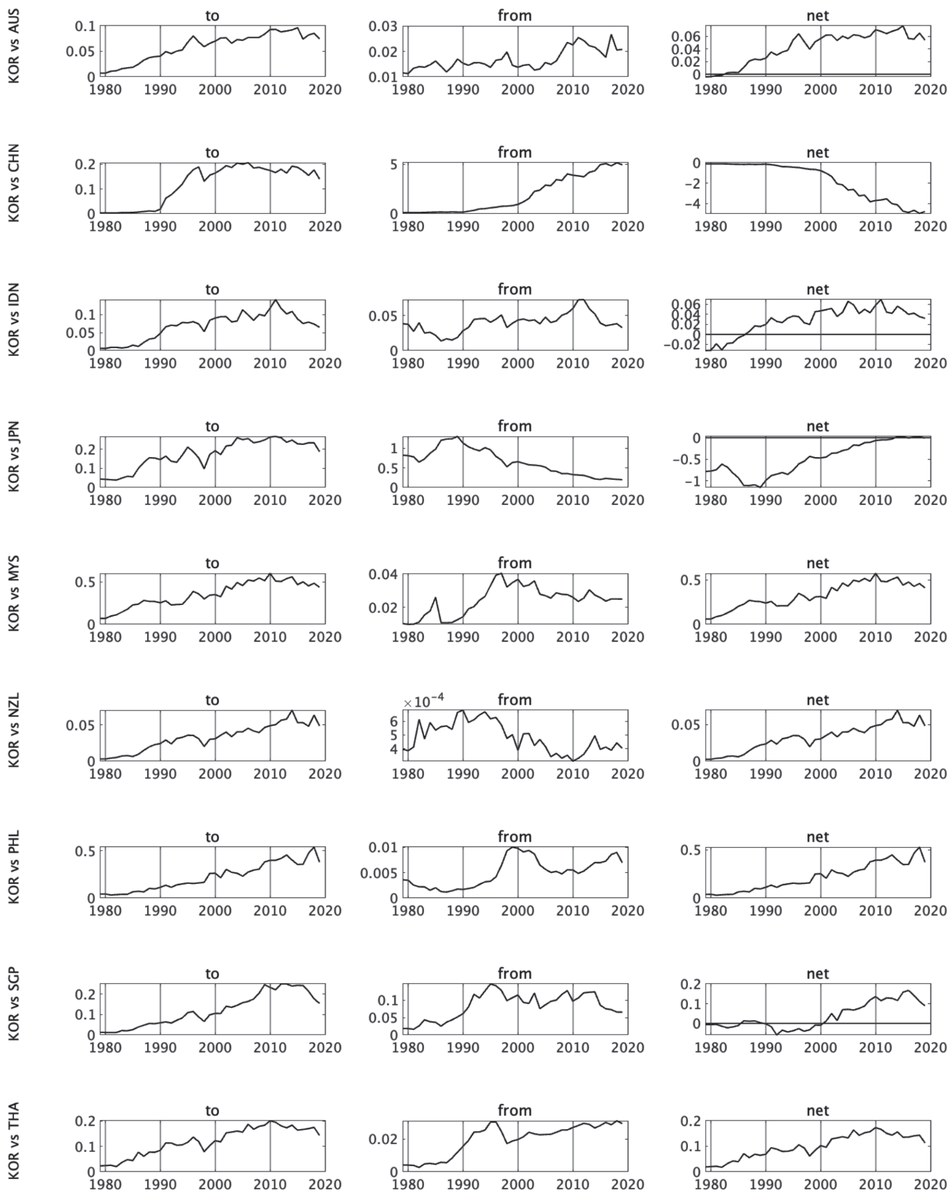
Figure 7: Japan's PDC within East Asia and Pacific



Note: The forecasting horizon H is set to 12.

In Figure 6, China has been a net transmitter of business cycle shocks in East Asia since 2000. Looking at the most recent figures, Malaysia has more than 20% of the influence from China; Japan, the Philippines, and Thailand have approximately 10%, followed by Singapore and South Korea.

Figure 8: Korea's PDC within East Asia and Pacific



Note: The forecasting horizon, H, is set to 12.

In contrast, as Figure 7 depicts, except for China and Korea, Japan's influence as a transmitter of business cycle shocks remained positive, although it diminished over the sample period. In relation to China, Japan has been a net recipient since 2000. Similarly, with Korea, the net effect reached almost zero in recent years.

Korea's role is more complex; Figure 8 shows that it was mainly a net recipient in relation with China and Japan over the period. However, it is a net transmitter to Australia, Malaysia, New Zealand, the Philippines, and Thailand, and its role in Indonesia and Singapore varies periodically.

5. Conclusion

During the past few decades, with rapid economic growth, East Asia has also experienced a deepening of economic integration, with active intraregional economic activities such as trade and investments. This development contributed to the complex and possibly time-varying macroeconomic interdependence of the countries in the region.

To better understand this interdependence, we introduce a novel analytical approach as a contribution to the field by building on the work of Diebold and Yılmaz (2015). Our method combines Pesaran et al.'s (2004) GVAR model with Diebold and Yılmaz's (2014) connectedness measure, resulting in a new index for analyzing the international transmission of business cycle shocks.

Using quarterly GDP and oil price data for 33 countries from 1979 to 2019, we analyze the growing interdependence of business cycles between regions and countries, with a focus on East Asia, using various measures of connectedness. The analysis yielded three key findings.

First, in terms of TC, we find that global connectedness increased from 15% in the 1980s to over 22% in 2019, driven largely by the rise of the Chinese economy, with regional and group-specific variations, including a steady rise in East Asia and significant changes in the G7 and BRICS countries.

Second, the analysis of directional connectedness shows that Japan, China, and Singapore were net transmitters of business cycle shocks, with Japan's influence peaking in the 1980s-90s and China's dominance increasing from the 2000s. The regional variations in East Asia highlight the importance of considering connectedness at different levels.

Finally, an examination of the PDC reveals another feature. Korea was primarily a net recipient of business cycle shocks from China and Japan, although its role varies with other countries, as it acts as a net transmitter to Australia, Malaysia, and other countries. Its influence in East Asia fluctuated and recent trends indicate a more complex and shifting pattern.

Overall, these results show that a country's connectedness within a group can vary significantly depending on the grouping method, with both the sign and magnitude of this connectedness fluctuating over time. This finding demonstrates the utility of our methodology for analyzing IBCs.

More should be done to address several limitations of this study. The first limitation is the robustness of the results. Because we derive the connectedness indices in this study from GVAR estimates, it would be valuable to test the consistency of the results by exploring alternative specifications such as a difference GVAR or a co-integrated GVAR.

The second limitation concerns the construction of the foreign variables. This study uses trade flows to capture the real side of linkages, which is crucial for deriving time-varying connectedness. However, examining whether similar results could be obtained using financial variables such as portfolio investment data, would be interesting. Additionally, a combination of real and financial variables may provide a more comprehensive measure of foreign linkages.

Finally, the effect of time variation warrants further investigation. In this study, we use time-varying linkage coefficients to capture dynamic linkages, which is the strength of the GVAR framework. Alternatively, incorporating the time variation directly into the GVAR coefficients may be worthwhile and yield additional insights.

Research to address these limitations will be the subject of future work.

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Appendix

A. List of Countries

Table A.1: Codes and Names for Countries and Group of Countries

iso3	Code	Country	Region	G7	OECD	ASEAN	N-11
ARG	213	Argentina	Latin America & Caribbean				
AUS	193	Australia	East Asia & Pacific		X		
AUT	122	Austria	Europe & Central Asia		X		
BEL	124	Belgium	Europe & Central Asia		X		
BRA	223	Brazil	Latin America & Caribbean				
CAN	156	Canada	North America	X	X		
CHN	160	China	East Asia & Pacific				
CHL	228	Chile	Latin America & Caribbean		X		
FIN	172	Finland	Europe & Central Asia		X		
FRA	132	France	Europe & Central Asia	X	X		
DEU	134	Germany	Europe & Central Asia	X	X		
IND	534	India	South Asia				
IDN	536	Indonesia	East Asia & Pacific			X	X
ITA	136	Italy	Europe & Central Asia	X	X		
JPN	158	Japan	East Asia & Pacific	X	X		
KOR	542	Korea	East Asia & Pacific		X		X
MYS	548	Malaysia	East Asia & Pacific			X	
MEX	273	Mexico	Latin America & Caribbean		X		
NLD	138	Netherlands	Europe & Central Asia		X		
NOR	142	Norway	Europe & Central Asia		X		
NZL	196	New Zealand	East Asia & Pacific		X		
PER	293	Peru	Latin America & Caribbean				
PHL	566	Philippines	East Asia & Pacific			X	X
ZAF	199	South Africa	Sub-Saharan Africa				
SAU	456	Saudi Arabia	Middle East & North Africa				
SGP	576	Singapore	East Asia & Pacific			X	
ESP	184	Spain	Europe & Central Asia		X		
SWE	144	Sweden	Europe & Central Asia		X		
CHE	146	Switzerland	Europe & Central Asia		X		
THA	578	Thailand	East Asia & Pacific			X	
TUR	186	Turkey	Europe & Central Asia		X		X
GBR	112	United Kingdom	Europe & Central Asia	X	X		
USA	110	United States	North America	X	X		

B. Connectedness Tables

Tables B.1, B.2, B.3, and B.4 are the connectedness tables as of 1985, 1995, 2005, 2015, respectively. We highlight cells with a value greater than 0.005 because of the small font size. We also highlight the diagonal because they are their own effect, so their values are clearly larger than those in the other cells. We can also see that for all countries, the impact of oil price shocks is relatively non-negligible relative to shocks from other countries.

Table B.1: Connectedness Table: 1985

	ARG	AUS	AUT	BEL	BRA	CAN	CHN	CHL	FIN	FRA	DEU	IND	IDN	ITA	JPN	KOR	MYS	MEX	NLD	NOR	NZL	PER	PHL	ZAF	SAU	SGP	ESP	SWE	CHE	THA	TUR	GBR	USA	poil	FROM
ARG	***0.755***	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.235***	0.245
AUS	0.000	***0.933***	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.013***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.004	***0.043***	0.067
AUT	0.000	0.000	***0.359***	0.003	0.001	0.001	***0.005***	0.000	0.001	***0.018***	***0.320***	0.000	0.000	***0.010***	***0.013***	0.000	0.000	0.000	***0.018***	0.002	0.000	0.000	0.000	0.000	***0.015***	0.001	0.002	0.002	***0.009***	0.000	0.001	***0.030***	***0.024***	***0.159***	0.641
BEL	0.001	0.000	0.001	***0.299***	0.001	0.002	0.005	0.000	0.001	***0.045***	***0.184***	0.001	0.000	***0.006***	***0.011***	0.000	0.000	0.001	***0.059***	0.002	0.000	0.000	0.000	0.000	***0.016***	0.001	0.002	0.002	0.004	0.000	0.001	***0.057***	***0.028***	***0.271***	0.701
BRA	0.002	0.000	0.000	0.000	***0.818***	0.002	***0.007***	0.000	0.000	0.001	***0.007***	0.000	0.000	0.000	***0.007***	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	***0.008***	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.022***	***0.119***	0.182
CAN	0.000	0.000	0.000	0.000	0.001	***0.616***	0.004	0.000	0.000	0.001	***0.005***	0.000	0.000	0.000	***0.021***	0.001	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.003	***0.262***	***0.079***	0.384
CHN	0.000	0.000	0.000	0.000	0.000	0.000	***0.825***	0.000	0.000	0.000	0.002	0.000	0.000	0.000	***0.030***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.004	***0.134***	0.175
CHL	0.001	0.000	0.000	0.000	0.001	0.000	0.001	***0.933***	0.000	0.000	0.003	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	***0.006***	***0.048***	0.067
FIN	0.000	0.000	0.001	0.002	0.001	0.002	0.004	0.000	***0.658***	***0.010***	***0.088***	0.000	0.000	0.003	***0.016***	0.000	0.000	0.000	***0.010***	***0.007***	0.000	0.000	0.000	0.000	***0.016***	0.001	0.001	***0.022***	0.002	0.000	0.000	***0.043***	***0.025***	***0.086***	0.342
FRA	0.000	0.000	0.000	0.005	0.001	0.001	0.003	0.000	0.001	***0.596***	***0.102***	0.000	0.000	***0.008***	***0.008***	0.000	0.000	0.000	***0.016***	0.001	0.000	0.000	0.000	0.000	***0.014***	0.001	0.004	0.001	0.003	0.000	0.000	***0.034***	***0.021***	***0.179***	0.404
DEU	0.000	0.000	0.001	0.003	0.001	0.001	0.004	0.000	0.001	***0.019***	***0.701***	0.000	0.000	***0.005***	***0.010***	0.000	0.000	0.000	***0.022***	0.002	0.000	0.000	0.000	0.000	***0.009***	0.001	0.002	0.002	0.004	0.000	0.001	***0.029***	***0.021***	***0.160***	0.299
IND	0.000	0.001	0.000	0.001	0.001	0.002	0.003	0.000	0.000	0.003	***0.021***	***0.593***	0.000	0.001	***0.031***	0.001	0.002	0.000	0.003	0.000	0.000	0.000	0.000	0.000	***0.053***	***0.006***	0.000	0.000	0.001	0.000	0.000	***0.011***	***0.026***	***0.240***	0.407
IDN	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	***0.914***	0.000	***0.017***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.060***	0.086
ITA	0.001	0.000	0.001	0.002	0.001	0.002	***0.006***	0.000	0.001	***0.023***	***0.098***	0.000	0.000	***0.357***	***0.011***	0.000	0.000	0.001	***0.011***	0.001	0.000	0.000	0.000	0.001	***0.020***	0.001	0.002	0.001	0.004	0.000	0.001	***0.023***	***0.029***	***0.400***	0.643
JPN	0.000	0.000	0.000	0.000	0.000	0.001	***0.006***	0.000	0.000	0.000	0.001	0.000	0.002	0.000	***0.870***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.008***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	***0.012***	***0.096***	0.130
KOR	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.010***	***0.824***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.008***	***0.151***	0.176
MYS	0.000	0.001	0.000	0.000	0.000	0.000	***0.006***	0.000	0.000	0.001	0.005	0.000	0.002	0.000	***0.073***	0.002	***0.665***	0.000	0.001	0.000	0.000	0.000	0.001	0.000	***0.008***	***0.102***	0.000	0.000	0.000	0.004	0.000	0.003	***0.016***	***0.108***	0.335
MEX	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.004	0.000	0.000	***0.850***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	***0.028***	***0.110***	0.150
NLD	0.000	0.000	0.000	***0.005***	0.001	0.001	0.002	0.000	0.001	***0.014***	***0.112***	0.000	0.000	0.003	***0.005***	0.000	0.000	0.000	***0.497***	0.001	0.000	0.000	0.000	0.000	***0.008***	0.001	0.001	0.001	0.002	0.000	0.000	***0.028***	***0.014***	***0.302***	0.503
NOR	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.002	***0.023***	0.000	0.000	0.001	0.004	0.000	0.000	0.000	0.003	***0.890***	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.005	0.001	0.000	0.000	***0.020***	***0.007***	***0.039***	0.110
NZL	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.007***	0.000	0.000	0.000	0.000	0.000	***0.861***	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.003	***0.121***	0.139
PER	***0.009***	0.000	0.000	0.001	0.002	0.001	***0.008***	0.002	0.000	0.002	***0.011***	0.000	0.000	0.001	***0.020***	0.001	0.000	0.000	0.002	0.000	0.000	***0.678***	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.004	***0.041***	***0.213***	0.322
PHL	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.000	0.001	0.000	***0.021***	0.001	0.003	0.000	0.000	0.000	0.000	0.000	***0.905***	0.000	***0.007***	***0.006***	0.000	0.000	0.000	0.001	0.000	0.001	***0.016***	***0.030***	0.095
ZAF	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.000	0.000	0.002	***0.012***	0.000	0.000	0.001	***0.012***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	***0.679***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	***0.006***	***0.010***	***0.268***	0.321
SAU	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.009***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.926***	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	***0.059***	0.074
SGP	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.001	0.000	0.003	0.000	***0.015***	0.000	***0.010***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	***0.886***	0.000	0.000	0.000	0.001	0.000	0.001	***0.007***	***0.065***	0.114
ESP	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.003	***0.008***	0.000	0.000	0.001	0.003	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	***0.775***	0.000	0.000	0.000	0.000	0.003	***0.006***	***0.193***	0.225
SWE	0.000	0.001	0.000	0.002	0.001	0.004	***0.005***	0.000	***0.010***	***0.009***	***0.080***	0.000	0.000	0.003	***0.019***	0.000	0.000	0.001	***0.010***	***0.015***	0.000	0.000	0.000	0.000	***0.007***	0.001	0.001	***0.628***	0.002	0.000	0.001	***0.036***	***0.039***	***0.121***	0.372
CHE	0.000	0.000	0.001	0.001	0.000	0.001	0.004	0.000	0.000	***0.009***	***0.067***	0.000	0.000	0.003	***0.007***	0.000	0.000	0.000	***0.005***	0.000	0.000	0.000	0.000	0.000	***0.007***	0.001	0.001	0.001	***0.786***	0.000	0.000	***0.014***	***0.013***	***0.077***	0.214
THA	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.001	0.004	0.000	0.001	0.000	***0.033***	0.000	0.004	0.000	0.001	0.000	0.000	0.000	0.000	0.000	***0.007***	***0.017***	0.000	0.000	0.000	***0.816***	0.000	0.001	***0.009***	***0.100***	0.184
TUR	0.000	0.000	0.000	0.001	0.000	0.001	0.002	0.000	0.000	0.003	***0.030***	0.000	0.000	0.002	0.005	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	***0.016***	0.000	0.001	0.000	0.001	0.000	***0.785***	***0.007***	***0.011***	***0.131***	0.215
GBR	0.000	0.001	0.000	0.002	0.001	0.002	***0.006***	0.000	0.001	***0.006***	***0.037***	0.001	0.000	0.002	***0.013***	0.000	0.000	0.001	***0.008***	0.002	0.000	0.000	0.000	0.000	0.003	0.001	0.000	0.002	0.002	0.000	0.001	***0.617***	***0.030***	***0.263***	0.383
USA	0.000	0.001	0.000	0.001	0.002	***0.031***	***0.006***	0.000	0.000	0.002	***0.016***	0.000	0.001	0.001	***0.068***	0.002	0.000	***0.008***	0.002	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.001	0.001	0.000	0.000	***0.006***	***0.738***	***0.104***	0.262
poil	0.000	0.000	0.000	0.000	0.000	0.000	***0.019***	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	***0.969***	0.031
TO	0.019	0.012	0.007	0.032	0.019	0.059	0.134	0.004	0.019	0.176	1.245	0.007	0.016	0.049	0.525	0.012	0.024	0.019	0.182	0.034	0.001	0.001	0.002	0.004	0.245	0.153	0.021	0.042	0.038	0.009	0.008	0.368	0.752	4.764	8.998

Note: Cells with values greater than 0.005 are bold and italicized.

Table B.2: Connectedness Table: 1995

	ARG	AUS	AUT	BEL	BRA	CAN	CHN	CHL	FIN	FRA	DEU	IND	IDN	ITA	JPN	KOR	MYS	MEX	NLD	NOR	NZL	PER	PHL	ZAF	SAU	SGP	ESP	SWE	CHE	THA	TUR	GBR	USA	poil	FROM
ARG	***0.752***	0.000	0.000	0.000	***0.007***	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.232***	0.248
AUS	0.000	***0.935***	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.009***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.001	0.004	***0.043***	0.065
AUT	0.000	0.000	***0.321***	0.003	0.001	0.001	***0.015***	0.000	0.001	***0.020***	***0.345***	0.000	0.001	***0.010***	***0.020***	0.002	0.001	0.000	***0.015***	0.001	0.000	0.000	0.000	0.000	0.004	0.004	***0.007***	0.002	***0.008***	0.002	0.001	***0.026***	***0.019***	***0.168***	0.679
BEL	0.001	0.000	0.001	***0.280***	0.001	0.001	***0.013***	0.000	0.002	***0.045***	***0.200***	0.001	0.001	***0.007***	***0.020***	0.001	0.001	0.001	***0.046***	0.001	0.000	0.000	0.000	0.000	0.004	0.004	***0.009***	0.002	0.004	0.002	0.001	***0.048***	***0.021***	***0.280***	0.720
BRA	***0.022***	0.000	0.000	0.000	***0.796***	0.001	***0.007***	0.001	0.000	0.001	***0.008***	0.000	0.000	0.001	***0.009***	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.002	***0.015***	***0.128***	0.204
CAN	0.000	0.000	0.000	0.000	0.000	***0.614***	***0.010***	0.000	0.000	0.001	0.005	0.000	0.000	0.000	***0.019***	0.001	0.001	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.000	0.002	***0.253***	***0.084***	0.386
CHN	0.000	0.000	0.000	0.000	0.000	0.000	***0.834***	0.000	0.000	0.000	0.002	0.000	0.000	0.000	***0.016***	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.001	0.005	***0.136***	0.166
CHL	0.003	0.000	0.000	0.000	0.001	0.000	0.002	***0.932***	0.000	0.000	0.002	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	***0.049***	0.068
FIN	0.001	0.001	0.001	0.002	0.001	0.001	***0.013***	0.000	***0.634***	***0.011***	***0.099***	0.000	0.001	0.003	***0.025***	0.002	0.001	0.000	***0.010***	0.005	0.000	0.000	0.000	0.000	0.003	0.005	0.005	***0.013***	0.002	0.002	0.001	***0.037***	***0.021***	***0.102***	0.366
FRA	0.000	0.000	0.001	0.004	0.001	0.001	***0.009***	0.000	0.001	***0.574***	***0.111***	0.000	0.001	***0.007***	***0.015***	0.001	0.001	0.000	***0.011***	0.001	0.000	0.000	0.000	0.000	0.004	0.004	***0.014***	0.001	0.003	0.001	0.001	***0.030***	***0.015***	***0.188***	0.426
DEU	0.000	0.000	0.002	0.003	0.001	0.001	***0.012***	0.000	0.001	***0.019***	***0.695***	0.000	0.001	***0.005***	***0.019***	0.002	0.001	0.000	***0.015***	0.001	0.000	0.000	0.000	0.000	0.003	0.004	***0.006***	0.001	0.004	0.002	0.001	***0.024***	***0.017***	***0.159***	0.305
IND	0.000	0.001	0.000	0.001	0.000	0.001	***0.008***	0.000	0.000	0.003	***0.026***	***0.586***	0.002	0.001	***0.028***	0.002	0.003	0.000	0.003	0.000	0.000	0.000	0.000	0.000	***0.031***	***0.014***	0.001	0.000	0.001	0.002	0.000	***0.011***	***0.023***	***0.249***	0.414
IDN	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	***0.919***	0.000	***0.011***	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.059***	0.081
ITA	0.001	0.000	0.001	0.002	0.001	0.001	***0.013***	0.000	0.001	***0.022***	***0.108***	0.001	0.001	***0.330***	***0.016***	0.001	0.001	0.001	***0.009***	0.001	0.000	0.000	0.000	0.000	0.004	0.003	***0.008***	0.001	0.004	0.001	0.002	***0.020***	***0.020***	***0.426***	0.670
JPN	0.000	0.000	0.000	0.000	0.000	0.000	***0.010***	0.000	0.000	0.000	0.002	0.000	0.002	0.000	***0.851***	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.000	0.000	0.000	0.002	0.000	0.001	***0.010***	***0.110***	0.149
KOR	0.000	0.000	0.000	0.000	0.000	0.000	***0.006***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.010***	***0.823***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	***0.005***	***0.149***	0.177
MYS	0.000	0.000	0.000	0.000	0.000	0.000	***0.010***	0.000	0.000	0.001	***0.006***	0.000	0.002	0.000	***0.066***	0.003	***0.667***	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.002	***0.104***	0.000	0.000	0.000	***0.006***	0.000	0.003	***0.020***	***0.107***	0.333
MEX	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.000	***0.837***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.037***	***0.116***	0.163
NLD	0.000	0.000	0.001	0.004	0.001	0.001	***0.006***	0.000	0.001	***0.013***	***0.109***	0.000	0.001	0.003	***0.010***	0.001	0.001	0.000	***0.488***	0.001	0.000	0.000	0.000	0.000	0.003	0.003	0.004	0.001	0.002	0.001	0.001	***0.024***	***0.011***	***0.309***	0.512
NOR	0.000	0.000	0.000	0.001	0.000	0.001	0.003	0.000	0.002	0.003	***0.023***	0.000	0.000	0.001	***0.006***	0.000	0.000	0.000	0.004	***0.887***	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.005	0.001	0.000	0.000	***0.012***	***0.007***	***0.041***	0.113
NZL	0.000	0.004	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.006***	0.000	0.000	0.000	0.000	0.000	***0.862***	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.003	***0.119***	0.138
PER	***0.006***	0.000	0.000	0.000	0.003	0.001	***0.023***	***0.011***	0.000	0.001	***0.011***	0.000	0.001	0.001	***0.017***	0.002	0.001	0.001	0.002	0.000	0.000	***0.672***	0.000	0.000	0.001	0.001	0.002	0.000	0.001	0.001	0.000	0.004	***0.031***	***0.207***	0.328
PHL	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.003	0.000	0.001	0.000	***0.029***	0.002	0.001	0.000	0.000	0.000	0.000	0.000	***0.900***	0.000	***0.007***	***0.009***	0.000	0.000	0.000	0.002	0.000	0.001	***0.013***	***0.027***	0.100
ZAF	0.000	0.000	0.000	0.000	0.000	0.000	***0.011***	0.000	0.000	0.001	***0.012***	0.000	0.000	0.001	***0.011***	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	***0.676***	0.001	0.002	0.001	0.000	0.000	0.000	0.000	0.005	***0.007***	***0.266***	0.324
SAU	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.937***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.050***	0.063
SGP	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.002	0.000	0.001	0.000	***0.018***	0.001	***0.014***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.876***	0.000	0.000	0.000	0.004	0.000	0.001	***0.007***	***0.068***	0.124
ESP	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.004	***0.013***	0.000	0.000	0.001	0.003	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.001	***0.756***	0.000	0.000	0.000	0.000	0.003	0.004	***0.206***	0.244
SWE	0.001	0.001	0.001	0.003	0.001	0.002	***0.015***	0.000	***0.009***	***0.011***	***0.098***	0.001	0.001	0.003	***0.022***	0.001	0.001	0.001	***0.012***	***0.011***	0.000	0.000	0.000	0.000	0.003	0.004	0.003	***0.591***	0.003	0.002	0.001	***0.029***	***0.028***	***0.142***	0.409
CHE	0.000	0.000	0.001	0.001	0.000	0.000	***0.009***	0.000	0.000	***0.010***	***0.081***	0.000	0.001	0.003	***0.012***	0.001	0.001	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.003	0.001	***0.759***	0.001	0.001	***0.012***	***0.011***	***0.081***	0.241
THA	0.000	0.000	0.000	0.000	0.000	0.000	***0.006***	0.000	0.000	0.001	0.004	0.000	0.001	0.000	***0.044***	0.001	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	***0.025***	0.000	0.000	0.000	***0.788***	0.000	0.001	***0.009***	***0.113***	0.212
TUR	0.000	0.000	0.000	0.001	0.000	0.001	***0.005***	0.000	0.000	0.004	***0.035***	0.000	0.000	0.002	***0.006***	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	***0.009***	0.001	0.001	0.000	0.001	0.000	***0.777***	***0.006***	***0.009***	***0.136***	0.223
GBR	0.000	0.000	0.000	0.002	0.001	0.001	***0.012***	0.000	0.001	***0.007***	***0.038***	0.001	0.001	0.002	***0.017***	0.001	0.001	0.001	***0.005***	0.001	0.000	0.000	0.000	0.000	0.001	0.004	0.001	0.001	0.002	0.001	0.001	***0.599***	***0.025***	***0.274***	0.401
USA	0.001	0.001	0.000	0.001	0.001	***0.026***	***0.023***	0.000	0.000	0.002	***0.013***	0.000	0.001	0.001	***0.057***	0.004	0.002	***0.013***	0.001	0.000	0.000	0.000	0.000	0.000	0.002	***0.008***	0.000	0.000	0.001	0.002	0.000	0.004	***0.727***	***0.107***	0.273
poil	0.000	0.000	0.000	0.000	0.000	0.000	***0.021***	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	***0.966***	0.034
TO	0.038	0.011	0.008	0.031	0.024	0.045	0.286	0.016	0.020	0.183	1.364	0.008	0.024	0.051	0.556	0.039	0.041	0.025	0.148	0.023	0.001	0.001	0.002	0.003	0.097	0.223	0.069	0.030	0.038	0.037	0.015	0.310	0.663	4.932	9.360

Note: Cells with values greater than 0.005 are bold and italicized.

Table B.3: Connectedness Table: 2005

	ARG	AUS	AUT	BEL	BRA	CAN	CHN	CHL	FIN	FRA	DEU	IND	IDN	ITA	JPN	KOR	MYS	MEX	NLD	NOR	NZL	PER	PHL	ZAF	SAU	SGP	ESP	SWE	CHE	THA	TUR	GBR	USA	poil	FROM
ARG	***0.756***	0.000	0.000	0.000	***0.008***	0.000	0.004	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	***0.226***	0.244
AUS	0.000	***0.932***	0.000	0.000	0.000	0.000	***0.014***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.005***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.002	***0.039***	0.068
AUT	0.000	0.000	***0.341***	0.003	0.001	0.001	***0.071***	0.000	0.001	***0.016***	***0.329***	0.000	0.001	***0.008***	***0.010***	0.002	0.001	0.001	***0.014***	0.001	0.000	0.000	0.000	0.000	***0.005***	0.003	***0.012***	0.002	***0.006***	0.001	0.003	***0.024***	***0.019***	***0.122***	0.659
BEL	0.000	0.000	0.001	***0.317***	0.001	0.001	***0.077***	0.000	0.001	***0.038***	***0.171***	0.001	0.001	***0.005***	***0.012***	0.002	0.001	0.001	***0.047***	0.002	0.000	0.000	0.000	0.000	***0.006***	0.003	***0.014***	0.002	0.002	0.001	0.003	***0.040***	***0.023***	***0.225***	0.683
BRA	***0.016***	0.000	0.000	0.000	***0.771***	0.001	***0.030***	0.002	0.000	0.001	***0.005***	0.000	0.000	0.000	0.004	0.001	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.001	***0.012***	***0.149***	0.229
CAN	0.000	0.000	0.000	0.000	0.000	***0.599***	***0.052***	0.000	0.000	0.001	0.004	0.000	0.000	0.000	***0.007***	0.001	0.000	***0.006***	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.002	***0.238***	***0.084***	0.401
CHN	0.000	0.000	0.000	0.000	0.000	0.000	***0.846***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.007***	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.004	***0.135***	0.154
CHL	0.004	0.000	0.000	0.000	0.001	0.000	***0.011***	***0.932***	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.042***	0.068
FIN	0.000	0.000	0.001	0.002	0.001	0.001	***0.080***	0.001	***0.624***	***0.010***	***0.097***	0.000	0.001	0.003	***0.010***	0.002	0.001	0.001	***0.014***	0.004	0.000	0.000	0.000	0.000	***0.006***	0.002	***0.007***	***0.018***	0.001	0.001	0.003	***0.023***	***0.018***	***0.068***	0.376
FRA	0.000	0.000	0.001	***0.005***	0.001	0.001	***0.047***	0.000	0.001	***0.593***	***0.102***	0.000	0.001	***0.006***	***0.007***	0.001	0.001	0.001	***0.013***	0.001	0.000	0.000	0.000	0.000	***0.006***	0.003	***0.022***	0.001	0.002	0.001	0.002	***0.024***	***0.014***	***0.146***	0.407
DEU	0.000	0.000	0.002	0.003	0.001	0.001	***0.065***	0.000	0.001	***0.015***	***0.693***	0.000	0.001	0.004	***0.009***	0.002	0.001	0.001	***0.014***	0.001	0.000	0.000	0.000	0.000	0.004	0.003	***0.011***	0.001	0.003	0.001	0.003	***0.022***	***0.017***	***0.121***	0.307
IND	0.000	0.001	0.000	0.001	0.001	0.001	***0.097***	0.000	0.000	0.002	***0.015***	***0.632***	***0.006***	0.001	***0.010***	0.005	0.003	0.001	0.002	0.000	0.000	0.000	0.000	0.001	***0.011***	***0.026***	0.002	0.000	0.002	0.002	0.001	***0.007***	***0.019***	***0.150***	0.368
IDN	0.000	0.000	0.000	0.000	0.000	0.000	***0.008***	0.000	0.000	0.000	0.000	0.000	***0.920***	0.000	***0.006***	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	***0.010***	0.000	0.000	0.000	0.001	0.000	0.000	0.001	***0.050***	0.080
ITA	0.001	0.000	0.001	0.002	0.001	0.001	***0.060***	0.000	0.001	***0.018***	***0.084***	0.001	0.001	***0.357***	***0.007***	0.002	0.001	0.001	***0.009***	0.001	0.000	0.000	0.000	0.000	***0.007***	0.002	***0.015***	0.001	0.003	0.001	0.005	***0.017***	***0.018***	***0.383***	0.643
JPN	0.000	0.000	0.000	0.000	0.000	0.000	***0.051***	0.000	0.000	0.000	0.001	0.000	0.002	0.000	***0.845***	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.000	0.000	0.002	0.000	0.000	***0.006***	***0.080***	0.155
KOR	0.000	0.000	0.000	0.000	0.000	0.000	***0.029***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	***0.005***	***0.837***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.120***	0.163
MYS	0.000	0.001	0.000	0.000	0.000	0.000	***0.077***	0.000	0.000	0.001	0.004	0.001	***0.008***	0.000	***0.030***	0.005	***0.668***	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.004	***0.083***	0.000	0.000	0.000	***0.011***	0.000	0.001	***0.015***	***0.087***	0.332
MEX	0.000	0.000	0.000	0.000	0.000	0.001	***0.012***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.000	0.000	***0.830***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.031***	***0.122***	0.170
NLD	0.000	0.000	0.000	0.005	0.001	0.000	***0.051***	0.000	0.001	***0.011***	***0.090***	0.000	0.001	0.002	***0.006***	0.001	0.001	0.001	***0.521***	0.001	0.000	0.000	0.000	0.000	0.005	0.003	***0.006***	0.001	0.001	0.001	0.002	***0.019***	***0.011***	***0.257***	0.479
NOR	0.000	0.000	0.000	0.001	0.000	0.001	***0.013***	0.000	0.001	0.002	***0.017***	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.003	***0.892***	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.000	0.000	0.001	***0.011***	***0.006***	***0.044***	0.108
NZL	0.000	0.004	0.000	0.000	0.000	0.000	***0.010***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	***0.868***	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.107***	0.132
PER	0.004	0.000	0.000	0.000	0.003	0.001	***0.078***	***0.010***	0.000	0.001	***0.005***	0.000	0.001	0.000	***0.006***	0.001	0.000	0.002	0.001	0.000	0.000	***0.586***	0.000	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.001	***0.029***	***0.266***	0.414
PHL	0.000	0.000	0.000	0.000	0.000	0.000	***0.035***	0.000	0.000	0.000	0.002	0.000	0.002	0.000	***0.025***	0.002	0.004	0.000	0.001	0.000	0.000	0.000	***0.863***	0.000	***0.006***	***0.017***	0.000	0.000	0.000	0.003	0.000	0.001	***0.009***	***0.029***	0.137
ZAF	0.000	0.000	0.000	0.000	0.000	0.001	***0.032***	0.000	0.000	0.001	***0.008***	0.000	0.001	0.000	***0.007***	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	***0.628***	0.001	0.001	0.001	0.000	0.000	0.001	0.000	0.003	***0.006***	***0.304***	0.372
SAU	0.000	0.000	0.000	0.000	0.000	0.000	***0.007***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.937***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.046***	0.063
SGP	0.000	0.000	0.000	0.000	0.000	0.000	***0.027***	0.000	0.000	0.000	0.001	0.000	***0.008***	0.000	***0.007***	0.002	***0.010***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.880***	0.000	0.000	0.000	0.003	0.000	0.001	0.004	***0.050***	0.120
ESP	0.000	0.000	0.000	0.000	0.000	0.000	***0.011***	0.000	0.000	0.004	***0.011***	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	***0.762***	0.000	0.000	0.000	0.001	0.003	0.003	***0.198***	0.238
SWE	0.000	0.001	0.001	0.003	0.001	0.002	***0.069***	0.000	***0.011***	***0.009***	***0.078***	0.001	0.001	0.002	***0.010***	0.002	0.001	0.002	***0.010***	***0.015***	0.000	0.000	0.000	0.000	0.004	0.002	***0.006***	***0.610***	0.001	0.001	0.004	***0.020***	***0.025***	***0.109***	0.390
CHE	0.000	0.000	0.001	0.001	0.000	0.000	***0.033***	0.000	0.000	***0.007***	***0.064***	0.000	0.000	0.003	***0.005***	0.001	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.005	0.000	***0.769***	0.001	0.001	***0.008***	***0.010***	***0.080***	0.231
THA	0.000	0.000	0.000	0.000	0.000	0.000	***0.040***	0.000	0.000	0.000	0.002	0.000	0.004	0.000	***0.027***	0.002	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.005***	***0.014***	0.000	0.000	0.000	***0.815***	0.000	0.001	***0.006***	***0.078***	0.185
TUR	0.000	0.000	0.000	0.001	0.000	0.000	***0.027***	0.000	0.000	0.003	***0.023***	0.000	0.000	0.002	0.003	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.003	0.000	0.001	0.000	***0.793***	***0.006***	***0.006***	***0.121***	0.207
GBR	0.000	0.000	0.000	0.002	0.001	0.001	***0.048***	0.000	0.000	***0.005***	***0.029***	0.001	0.001	0.001	***0.007***	0.001	0.001	0.001	0.005	0.001	0.000	0.000	0.000	0.000	0.001	0.002	0.002	0.001	0.001	0.001	0.003	***0.606***	***0.021***	***0.256***	0.394
USA	0.001	0.000	0.000	0.000	0.001	***0.023***	***0.114***	0.000	0.000	0.001	***0.010***	0.001	0.001	0.000	***0.018***	0.003	0.001	***0.025***	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.000	0.000	0.000	0.001	0.001	0.003	***0.689***	***0.097***	0.311
poil	0.000	0.000	0.000	0.000	0.000	0.000	***0.029***	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.960***	0.040
TO	0.029	0.012	0.008	0.031	0.024	0.039	1.408	0.018	0.021	0.148	1.163	0.013	0.042	0.040	0.264	0.049	0.036	0.047	0.148	0.030	0.001	0.001	0.004	0.005	0.099	0.191	0.109	0.031	0.027	0.036	0.033	0.243	0.588	4.391	9.330

Note: Cells with values greater than 0.005 are bold and italicized.

Table B.4: Connectedness Table: 2015

	ARG	AUS	AUT	BEL	BRA	CAN	CHN	CHL	FIN	FRA	DEU	IND	IDN	ITA	JPN	KOR	MYS	MEX	NLD	NOR	NZL	PER	PHL	ZAF	SAU	SGP	ESP	SWE	CHE	THA	TUR	GBR	USA	poil	FROM
ARG	***0.759***	0.000	0.000	0.000	***0.006***	0.000	***0.014***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	***0.218***	0.241
AUS	0.000	***0.910***	0.000	0.000	0.000	0.000	***0.049***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.002	***0.030***	0.090
AUT	0.000	0.000	***0.336***	0.002	0.001	0.001	***0.176***	0.000	0.001	***0.012***	***0.282***	0.001	0.001	***0.005***	***0.005***	0.003	0.001	0.001	***0.018***	0.001	0.000	0.000	0.000	0.000	***0.007***	0.003	***0.007***	0.001	***0.008***	0.001	0.004	***0.017***	***0.020***	***0.083***	0.664
BEL	0.000	0.000	0.001	***0.320***	0.001	0.001	***0.192***	0.000	0.001	***0.028***	***0.131***	0.002	0.002	0.004	***0.007***	0.003	0.001	0.002	***0.051***	0.001	0.000	0.000	0.000	0.000	***0.010***	***0.007***	***0.009***	0.002	0.003	0.002	0.005	***0.033***	***0.027***	***0.153***	0.680
BRA	***0.008***	0.000	0.000	0.000	***0.688***	0.000	***0.102***	0.001	0.000	0.000	0.003	0.001	0.001	0.000	0.002	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.001	0.000	0.001	***0.008***	***0.178***	0.312
CAN	0.000	0.000	0.000	0.000	0.001	***0.565***	***0.121***	0.000	0.000	0.000	0.004	0.001	0.001	0.000	0.004	0.001	0.000	***0.008***	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.001	0.000	0.002	***0.200***	***0.087***	0.435
CHN	0.000	0.000	0.000	0.000	0.000	0.000	***0.840***	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.004	***0.144***	0.160
CHL	0.001	0.000	0.000	0.000	0.001	0.000	***0.038***	***0.919***	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.035***	0.081
FIN	0.000	0.000	0.001	0.002	0.001	0.001	***0.159***	0.000	***0.574***	***0.007***	***0.095***	0.001	0.001	0.002	0.005	0.002	0.001	0.001	***0.022***	0.004	0.000	0.000	0.000	0.000	***0.006***	0.002	0.005	***0.017***	0.002	0.001	0.003	***0.016***	***0.016***	***0.053***	0.426
FRA	0.000	0.000	0.001	***0.005***	0.001	0.000	***0.138***	0.000	0.000	***0.562***	***0.101***	0.001	0.001	0.004	0.004	0.002	0.001	0.001	***0.017***	0.001	0.000	0.000	0.000	0.000	***0.009***	0.004	***0.015***	0.001	0.003	0.001	0.003	***0.018***	***0.015***	***0.089***	0.438
DEU	0.000	0.000	0.002	0.002	0.001	0.000	***0.167***	0.000	0.001	***0.011***	***0.644***	0.001	0.001	0.003	0.004	0.002	0.001	0.001	***0.021***	0.001	0.000	0.000	0.000	0.000	***0.006***	0.003	***0.006***	0.001	0.004	0.001	0.004	***0.017***	***0.017***	***0.079***	0.356
IND	0.000	0.001	0.000	0.000	0.001	0.000	***0.200***	0.000	0.000	0.001	***0.008***	***0.596***	***0.009***	0.000	***0.005***	0.004	0.004	0.001	0.001	0.000	0.000	0.000	0.000	0.001	***0.054***	***0.013***	0.001	0.000	0.002	0.003	0.001	0.003	***0.014***	***0.074***	0.404
IDN	0.000	0.000	0.000	0.000	0.000	0.000	***0.022***	0.000	0.000	0.000	0.000	0.000	***0.925***	0.000	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	***0.008***	0.000	0.000	0.000	0.001	0.000	0.000	0.001	***0.036***	0.075
ITA	0.001	0.000	0.001	0.002	0.001	0.001	***0.158***	0.000	0.000	***0.014***	***0.078***	0.002	0.001	***0.369***	0.004	0.002	0.001	0.002	***0.011***	0.000	0.000	0.000	0.000	0.000	***0.010***	0.002	***0.011***	0.001	0.004	0.001	***0.007***	***0.013***	***0.019***	***0.283***	0.631
JPN	0.000	0.000	0.000	0.000	0.000	0.000	***0.093***	0.000	0.000	0.000	0.001	0.000	0.002	0.000	***0.815***	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.000	0.000	0.002	0.000	0.000	***0.005***	***0.070***	0.185
KOR	0.000	0.000	0.000	0.000	0.000	0.000	***0.049***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.002	***0.840***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.100***	0.160
MYS	0.000	0.001	0.000	0.000	0.000	0.000	***0.194***	0.000	0.000	0.000	0.004	0.001	***0.011***	0.000	***0.017***	0.005	***0.603***	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.004	***0.068***	0.000	0.000	0.000	***0.013***	0.000	0.001	***0.008***	***0.067***	0.397
MEX	0.000	0.000	0.000	0.000	0.000	0.000	***0.027***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	***0.808***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.026***	***0.135***	0.192
NLD	0.000	0.000	0.000	0.004	0.001	0.000	***0.140***	0.000	0.001	***0.008***	***0.078***	0.001	0.001	0.001	0.003	0.002	0.001	0.001	***0.540***	0.001	0.000	0.000	0.000	0.000	0.005	0.003	0.004	0.001	0.001	0.001	0.002	***0.016***	***0.011***	***0.173***	0.460
NOR	0.000	0.000	0.000	0.001	0.000	0.000	***0.038***	0.000	0.000	0.001	***0.017***	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.004	***0.873***	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.001	***0.008***	0.004	***0.044***	0.127
NZL	0.000	0.002	0.000	0.000	0.000	0.000	***0.033***	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	***0.882***	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.002	***0.075***	0.118
PER	0.001	0.000	0.000	0.000	0.002	0.001	***0.214***	0.002	0.000	0.000	0.004	0.001	0.001	0.000	0.004	0.003	0.000	0.002	0.001	0.000	0.000	***0.460***	0.000	0.000	0.002	0.001	0.001	0.000	0.001	0.001	0.000	0.001	***0.016***	***0.283***	0.540
PHL	0.000	0.000	0.000	0.000	0.000	0.000	***0.092***	0.000	0.000	0.000	0.003	0.000	0.004	0.000	***0.017***	0.004	0.003	0.000	0.000	0.000	0.000	0.000	***0.814***	0.000	0.003	***0.014***	0.000	0.000	0.000	***0.006***	0.000	0.000	***0.006***	***0.032***	0.186
ZAF	0.000	0.000	0.000	0.000	0.000	0.000	***0.088***	0.000	0.000	0.001	***0.006***	0.001	0.001	0.000	0.003	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	***0.545***	0.004	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.005	***0.338***	0.455
SAU	0.000	0.000	0.000	0.000	0.000	0.000	***0.021***	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	***0.934***	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.002	***0.037***	0.066
SGP	0.000	0.000	0.000	0.000	0.000	0.000	***0.068***	0.000	0.000	0.000	0.001	0.000	***0.008***	0.000	0.004	0.002	***0.008***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.855***	0.000	0.000	0.000	0.003	0.000	0.000	0.003	***0.042***	0.145
ESP	0.000	0.000	0.000	0.000	0.000	0.000	***0.024***	0.000	0.000	0.003	***0.010***	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	***0.775***	0.000	0.000	0.000	0.001	0.002	0.003	***0.175***	0.225
SWE	0.000	0.000	0.001	0.003	0.001	0.001	***0.164***	0.000	***0.009***	***0.006***	***0.071***	0.001	0.001	0.002	0.005	0.002	0.001	0.002	***0.014***	***0.016***	0.000	0.000	0.000	0.000	***0.005***	0.002	0.003	***0.558***	0.002	0.001	0.005	***0.015***	***0.018***	***0.090***	0.442
CHE	0.000	0.000	0.000	0.001	0.000	0.000	***0.087***	0.000	0.000	0.003	***0.034***	0.002	0.001	0.001	0.003	0.001	0.001	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.005	0.004	0.002	0.000	***0.745***	0.001	0.002	***0.009***	***0.010***	***0.083***	0.255
THA	0.000	0.001	0.000	0.000	0.000	0.000	***0.101***	0.000	0.000	0.000	0.002	0.000	0.004	0.000	***0.013***	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.004	***0.008***	0.000	0.000	0.000	***0.794***	0.000	0.001	0.005	***0.060***	0.206
TUR	0.000	0.000	0.000	0.000	0.000	0.000	***0.072***	0.000	0.000	0.002	***0.016***	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	***0.005***	0.001	0.002	0.000	0.001	0.000	***0.798***	0.004	***0.005***	***0.084***	0.202
GBR	0.000	0.000	0.000	0.001	0.001	0.001	***0.112***	0.000	0.000	0.003	***0.024***	0.001	0.000	0.001	0.003	0.001	0.001	0.001	0.005	0.001	0.000	0.000	0.000	0.000	0.002	0.001	0.001	0.001	0.002	0.001	0.003	***0.593***	***0.017***	***0.222***	0.407
USA	0.000	0.000	0.000	0.000	0.001	***0.012***	***0.196***	0.001	0.000	0.001	***0.007***	0.001	0.001	0.000	***0.008***	0.003	0.001	***0.033***	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000	0.001	0.001	0.001	0.002	***0.633***	***0.091***	0.367
poil	0.000	0.000	0.000	0.000	0.000	0.000	***0.036***	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	***0.953***	0.047
TO	0.016	0.011	0.007	0.026	0.025	0.022	3.383	0.008	0.015	0.103	0.984	0.024	0.057	0.026	0.142	0.058	0.035	0.063	0.177	0.026	0.001	0.001	0.004	0.004	0.161	0.158	0.067	0.026	0.034	0.049	0.045	0.182	0.497	3.741	10.18

Note: Cells with values greater than 0.005 are bold and italicized.

C. Calculation of the GFEVD

We calculate FEVD using the following steps.

1. Apply the data to estimate the coefficient matrix $\widehat{\Theta}_i$ of the country-specific VARX* model and the variance of the error term $\hat{\sigma}_i^2$ $(i = 1, \dots, N)$. Similarly, estimate $\widehat{\Theta}_{\text{du}}$ and $\hat{\sigma}_\eta^2$ of the crude oil price model. The diagonal matrices are assumed for the covariance matrix of the disturbance vector in Eq. (17).

$$\boldsymbol{\zeta}_t = \begin{pmatrix} \mathbf{u}_t \\ \eta_t \end{pmatrix}$$

It seems safe to assume no correlation for the error terms among the VARXs for each country because foreign variables are included at the same time as the explained variable. However, it is not clear from the formulation whether the error terms between the country and international crude oil price models are simultaneously uncorrelated. However, when $N \to \infty$, ω_t can function as a proxy variable for a common factor that cannot be directly observed and can be approximated by x^*, so we determined that assuming uncorrelation would pose few problems.

2. Generate the error variance σ_i^2 for each $i = 1, \dots, N$ separately using the inverse Wishart distribution and generate the coefficient matrix based on the normal distribution

$$N\left(\text{vec}\left(\widehat{\Theta}_i\right), \hat{\sigma}_i^2 \otimes (\mathbf{X}_i'\mathbf{X}_i)^{-1}\right)$$

subject to this covariance matrix and the data matrix $\mathbf{X}_i$ for each VARX*. We generate the error variance and regression coefficient matrices in a manner similar to that for the oil price model.

3. Using the generated $\sigma_i^{2(s)}$ and $\sigma_\eta^{2(s)}$, construct the covariance matrix:

$$\boldsymbol{\Sigma}_\zeta^{(s)} = \text{diag}\left(\sigma_1^{2(s)}, \sigma_2^{2(s)}, \dots, \sigma_N^{2(s)}, \sigma_\eta^{2(s)}\right) = \begin{pmatrix} \sigma_1^{2(s)} & 0 & \cdots & 0 & 0 \\ 0 & \sigma_2^{2(s)} & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & \sigma_N^{2(s)} & 0 \\ 0 & 0 & \cdots & 0 & \sigma_\eta^{2(s)} \end{pmatrix}.$$

Calculate $\mathbf{B}_j^{(s)} (j = 1,2, \dots)$ from $\widehat{\Theta}_i^{(s)}$ and $\widehat{\Theta}_{\text{du}}^{(s)}$ as follows.

(a) First, using

$$\Theta_i^{(s)} = \left\{a_{i0}^{(s)}, a_{i1}^{(s)}, \phi_{i1}^{(s)}, \phi_{i2}^{(s)}, \lambda_{i0}^{(s)}, \lambda_{i1}^{(s)}, \psi_{i0}^{(s)}, \psi_{i1}^{(s)}\right\}, \Theta_{\text{du}}^{(s)} = \left\{\mu_0^{(s)}, \mu_1^{(s)}, \phi_1^{(s)}, \phi_2^{(s)}, \lambda_1^{(s)}\right\}$$

construct

$$\mathbf{G}_{i0}^{(s)} = \left(1, -\lambda_{i0}^{(s)}\right), \ \mathbf{G}_{i1}^{(s)} = \left(\phi_{i1}^{(s)}, \lambda_{i1}^{(s)}\right), \text{ and } \mathbf{G}_{i2}^{(s)} = \left(\phi_{i2}^{(s)}, \lambda_{i2}^{(s)}\right).$$

Then, from these vectors and the trade weight matrix, we have

$$\mathbf{G}_j^{(s)} = \begin{pmatrix} \mathbf{G}_{1j}^{(s)}\,\mathbf{W}_1 \\ \vdots \\ \mathbf{G}_{Nj}^{(s)}\,\mathbf{W}_N \end{pmatrix}.$$

Then, construct $\mathbf{H}_0^{(s)}$, $\mathbf{H}_1^{(s)}$, and $\mathbf{H}_2^{(s)}$.

$$\mathbf{H}_0^{(s)} = \begin{pmatrix} \mathbf{G}_0^{(s)} & -\Psi_0^{(s)} \\ \mathbf{0} & 1 \end{pmatrix},\ \mathbf{H}_1^{(s)} = \begin{pmatrix} \mathbf{G}_1^{(s)} & \Psi_1^{(s)} \\ \lambda_1^{(s)}\widetilde{\mathbf{W}} & \phi_1^{(s)} \end{pmatrix}, \mathbf{H}_2^{(s)} = \begin{pmatrix} \mathbf{G}_2^{(s)} & \mathbf{0} \\ \mathbf{0} & \phi_2^{(s)} \end{pmatrix}$$

(b) Next, construct $\mathbf{C}_1^{(s)}$ and $\mathbf{C}_2^{(s)}$ as follows:

$$\mathbf{C}_1^{(s)} = \left(\mathbf{H}_0^{(s)}\right)^{-1}\mathbf{H}_1^{(s)},\ \mathbf{C}_2^{(s)} = \left(\mathbf{H}_0^{(s)}\right)^{-1}\mathbf{H}_2^{(s)}$$

(c) Construct $\boldsymbol{B}_j^{(s)}(j = 1,2,\ldots)$.[9]

$$\mathbf{B}_j^{(s)} = \begin{cases} \mathbf{C}_1^{(s)}\mathbf{B}_{j-1}^{(s)} + \mathbf{C}_2^{(s)}\mathbf{B}_{j-2}^{(s)} & j = 1,2,\ldots \\ \mathbf{I} & j = 0 \\ \mathbf{0} & j < 0 \end{cases}.$$

4. Calculate the GFEVD as

$$d_{ij}^{H(s)} = \frac{\left(\sigma_{jj}^{(s)}\right)^{-1}\sum_{h=0}^{H}\left(\mathbf{e}_i'\mathbf{B}_h^{(s)}\left(\mathbf{H}_0^{(s)}\right)^{-1}\boldsymbol{\Sigma}_\zeta^{(s)}\mathbf{e}_j\right)^2}{\sum_{h=0}^{H}\mathbf{e}_i'\mathbf{B}_h^{(s)}\left(\mathbf{H}_0^{(s)}\right)^{-1}\boldsymbol{\Sigma}_\zeta^{(s)}\left(\left(\mathbf{H}_0^{(s)}\right)^{-1}\right)'\left(\mathbf{B}_h^{(s)}\right)'\mathbf{e}_j}$$

This value indicates the extent to which a shock in the j-th variable affects the H step-ahead forecast error variance of the i-th variable. $\mathbf{e}_i$ is the selection vector whose i-th element is 1 and the rest are 0s, $\sigma_{jj}^{(s)}$ is the variance of the disturbance term in the j-th expression (or the j-th diagonal element of $\boldsymbol{\Sigma}_\zeta^{(s)}$). Note that in the GFEVD, the shocks are not orthogonalized, so the sum of the relative variance contribution of the forecast error variance is not necessarily equal to 1. Therefore, we apply the following standardization:

$$\tilde{d}_{ij}^{H(s)} = \frac{d_{ij}^{H(s)}}{\sum_{j=1}^{N} d_{ij}^{H(s)}}.$$

We calculate the connectedness measures for this study based on $\tilde{d}_{ij}^{H(s)}$ rather than $d_{ij}^{H(s)}$.

5. Repeat steps 2 through 4 a sufficient number of iterations. In this study, we used 1,000 replications.

[9] We can obtain the eigenvalue of Eq. (18) from the companion form $\begin{pmatrix} \mathbf{y}_t \\ \mathbf{y}_{t-1} \end{pmatrix} = \begin{pmatrix} \mathbf{C}_1 & \mathbf{C}_2 \\ \mathbf{I} & \mathbf{0} \end{pmatrix}\begin{pmatrix} \mathbf{y}_{t-1} \\ \mathbf{y}_{t-2} \end{pmatrix} + \begin{pmatrix} \boldsymbol{\epsilon}_t \\ \mathbf{0} \end{pmatrix}$.