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Asia-Pacific Stock Market Connectedness: A Network Approach

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Executive Summary

This paper addresses network connectedness in stock returns and volatilities across the Asia-Pacific economies over the pre- and post-GFC periods. This study also uses the MSCI-classified group-specific latent factors to examine their connectedness among the developed and emerging markets in different Asia-Pacific regions. We find that (i) based on the return connectedness measures, global financial hubs - Singapore and Hong Kong - and Australia play an important role as efficient return information transmitters across stock markets, (ii) the United States is an overwhelming volatility transmitter as a net source of shocks during the global financial crisis, and subsequent volatility spillovers spread the crisis shock to each other in the region, (iii) comparing the results between the pre- and post-GFC periods, Canada was a net volatility transmitter before the GFC but has changed to a net volatility receiver after the GFC, and Korea has magnified the position of a net volatility receiver after the GFC, and (iv) in terms of the degree of total spillovers in returns and volatilities at large, stock market connectedness in the Pacific Rim was reinforced after the GFC. These findings support the potential feasibility of financial cooperation and uphold a cause of regionally coordinated macro-financial policies against systemic risk vulnerability.

Keywords: APEC, Stock markets, MSCI, Spillovers, Networks
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Asia-Pacific Stock Market Connectedness: A Network Approach*

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I. Introduction

As economic activities are interconnected each other, increasing degree of connectedness is manifested across markets. Financial liberalization has become an apparent trend and global financial markets are more connected than ever before. In the Asia-Pacific region, the APEC[1] process of growing economic cooperation has been followed by various agendas of international trade and regional economic connectivity. Gradual economic integration and financial market co-movements in the Pacific Rim, in particular after the global financial crisis (GFC hereafter), highlight the necessity of financial cooperation within the APEC framework.

As of 2016, the APEC share of global population reached 39%. The APEC economy accounted for 60% of the global GDP, and 47% of global trade in goods and services. Despite its importance in the global economy, the Asia-Pacific financial

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1 The Asia-Pacific Economic Cooperation (APEC) is the trans-regional economic architecture, established in 1989. APEC, as an inter-governmental forum, has functioned to promote free trade in the Asia-pacific region toward regional economic integration.

market connectedness has received little attention in the literature. In particular, APEC carries forward the agenda 'Improving Connectivity and Deepening Regional Economic Integration' in 2019. Against this backdrop of global market integration, growing interests require research to investigate the transmission mechanism of stock market movements and financial market connectedness in the region.

Capital liberalization, financial regulation reform, and IT development have accelerated international financial market connectedness and expedited various studies concerning financial market spillover effects. It is also important to understand financial market connectedness of inter-market information spillovers and risk transmissions because extraordinary return movements or extreme risk behavior are closely related to the likelihood of financial crisis and its contagion. That is, financial market connectedness sheds light on systemic risk which goes beyond a single market's own risk vulnerability. Accordingly, systematic understanding of financial market connectedness is required for monitoring financial markets and improving economic connectivity in the region. This study aims to analyze network connectedness of Asia-Pacific stock markets in terms of stock returns and volatilities.

A growing body of research in economic connectedness has been studied on various kinds of markets. Ahmad et al. (2018) examine financial connectedness of return and volatility spillovers among BRICS economies and global bond market indices of the United States, European Monetary Union, and Japan for the period of 1997-2016. They identify the net transmitter of shocks within BRICS, and show that the United States is the strongest transmitter of shocks to BRICS bond indices. Demirer et al. (2018) estimate the high-dimensional network links of 150 banks over the period of 2003-2014. They find that global bank equity connectedness has a strong geographic component and increases during crises, whereas country sovereign bond connectedness does not. Toyoshima and Hamori (2018) analyze return and volatility spillovers across global crude oil markets between 1991 and 2018. They find that the West Texas Intermediate futures market contributes the least to both return and volatility spillovers.

Financial market interdependence among the Asia-Pacific economies has

received little attention. This study explores the stock market connectedness in two dimensions: (i) connectedness among eighteen individual stock markets and (ii) connectedness among four MSCI-classified groups of stock markets.[2] In order to examine connectedness of the MSCI-classified groups, I first estimate a dynamic factor model to extract the latent group-specific components of the Asia-Pacific stock markets. The connectedness measures are then applied to the estimated MSCI-group-specific factors.

This study accounts for the following issues: (i) identifying major transmitters and receivers of stock market shocks, (ii) different aspects of stock market connectedness before and after the GFC, (iii) time-varying aspect of connectedness in stock volatilities, and (iv) network implications of the Asia-Pacific stock market. To this end, our approach is based on various financial market spillover measures, proposed by Diebold and Yilmaz (2012), and the network analysis of net pairwise spillover relations to identify the shock transmitters and receivers.

The remainder of the paper is organized as follows. Section 2 presents brief reviews of empirical methodologies used in this study and describes the data for estimation. The four estimated latent factors of stock returns by MSCI stock market classification are also presented in this section: (i) developed markets in North America, (ii) developed markets in the Pacific, (iii) emerging markets in Asia, and (iv) emerging markets in Latin America. Section 3 and 4 analyze network connectedness of stock returns and market volatilities, respectively. Section 5 concludes with policy implications.

2 The MSCI (Morgan Stanley Capital International) global market classification framework reflects the criteria of economic development, size and liquidity requirements, and market accessibility.

II. Empirical Methodology and Data

2.1. Spillover Index[3]

Diebold and Yilmaz (2012) approach is invoked in this study. We consider a covariance-stationary N-variable vector autoregression (VAR). The connectedness measures are based on variance decomposition of Eq. (1), which decomposes the forecast error variances of each variable into the portions that are attributable to the various innovation shocks.

$$X_t = \sum_{i=1}^{p} \Phi_i X_{t-i} + \Xi_t, \quad \Xi_t \sim i.i.d(0, \Sigma) \tag{1}$$

Eq. (1) is transformed into the moving average representation of Eq. (2). The coefficient matrices A_is contain the impact multipliers of the system.

$$X_t = \sum_{i=0}^{\infty} A_i \Xi_{t-i}, \quad t = 1, 2, \cdots, T \tag{2}$$

The forecast error variance decompositions calculate the fraction of the H-step-ahead error variance in forecasting x_i that is due to shocks to x_j, $\forall j \neq i$, for each i. In case that VAR innovations are contemporaneously correlated, the identification with Cholesky factorization is inappropriate because the variance decompositions depend on the ordering of the variables in a system. Due to this reason Diebold and Yilmaz (2012) employ the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998), in which variance decompositions are invariant to variable ordering. The generalized responses are independent of variable ordering and thus suitable for the analysis of financial markets.

3 Most of section 2.1 is borrowed from Diebold and Yilmaz (2012).

Variance Shares

Pesaran and Shin (1998) calculate generalized forecast error variances of Eq. (3),

$$\Theta_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)} \tag{3}$$

where σ_{jj} is jth diagonal element, e_j is a vector with jth element unity and zeros elsewhere, A_h is the coefficient matrix in the infinite moving-average representation from the VAR, the subscript h denotes the forecast period, and Σ is the variance matrix for the error vector Ξ. Since the sum of the elements in the rows of variance decompositions Θ_{ij} may not be equal to one, Diebold and Yilmaz (2012) normalize each entry of the variance decomposition matrix by the row sum as:

$$\tilde{\theta}_{ij}(H) = \frac{\theta_{ij}(H)}{\sum_{j=1}^{N} \theta_{ij}(H)}. \tag{4}$$

Total Spillovers

Based on the generalized variance decomposition, the total spillover index is calculated by Eq. (5). The total spillover index measures the contribution of spillovers of shocks across the stock markets to the total forecast error variance.

$$S(H) = \frac{\sum_{i,j=1(5)}^{N} \tilde{\theta}_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}(H)} \times 100 \tag{5}$$

Directional Spillovers

We also examine the direction of spillovers across the stock markets. The directional spillovers are calculated by using the normalized elements of the generalized variance decomposition matrix. First, the directional spillovers received by market i from all other markets j is calculated by Eq. (6).

$$S_{i\_}(H) = \frac{\sum_{j=1(7)}^{N} \tilde{\theta}_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}(H)} \times 100 \quad (6)$$

Second, we calculate the directional spillovers transmitted by market i to all other markets by Eq. (7).

$$S_{\_i}(H) = \frac{\sum_{j=1(9)}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}^{g}(H)} \times 100 \quad (7)$$

Net Spillovers

The net spillover index from market i to all other markets j is calculated by Eq. (8). It is the difference between the gross shocks transmitted to and those received from all other markets. The net spillovers summarize information about how much each market contributes to other markets in net terms.

$$S_i(H) = S_{\_i}(H) - S_{i\_}(H) \quad (8)$$

Net Pairwise Spillovers

The net pairwise spillover index between market i and j is the difference between the gross shocks transmitted from i to j and those transmitted from j to i.

$$S_{ij}(H) = \left(\frac{\tilde{\theta}_{ji}(H)}{\sum_{i,k=1}^{N} \tilde{\theta}_{ik}(H)} - \frac{\tilde{\theta}_{ij}(H)}{\sum_{j,k=1}^{N} \tilde{\theta}_{jk}(H)} \right) \times 100 \quad (9)$$

2.2. Dynamic Factor Model

The factor models are useful to decompose the behavior of economic variables into a few components driven by unobservable factors: such as (i) a common component to all the variables, (ii) components of group-specific effects on them, and

(iii) idiosyncratic components. Moreover, since the factor models can handle large datasets from an econometric point of view, they alleviate the curse of dimensionality of standard VAR models - i.e. number of parameters growing with the square of the number of variables.

This study examines stock market connectedness by using latent factors of four MSCI-classified groups in the Asia-Pacific region. To estimate the latent components, we apply Otrok and Whiteman (1998)'s Bayesian procedure to a dynamic factor model. That is, we extract mutually exclusive components from a latent factor model: a common factor, group-specific factors, and idiosyncratic components. The common factor is common across all eighteen Asia-Pacific stock markets of our interest, and the group-specific factors are specific to each stock market category by MSCI classification. Therefore, the dynamic factor model is represented by Eq. (10):

$$y_{i,t} = \alpha_i + \beta_i F_t + \gamma_i f_{j,t} + \varepsilon_{i,t} \tag{10}$$

where

$$F_t = \Gamma_F(L)F_{t-1} + \vartheta_t,$$
$$f_{j,t} = \Gamma_f(L)f_{j,t-1} + \omega_t,$$
$$\varepsilon_{i,t} = \Gamma_\varepsilon(L)\varepsilon_{i,t-1} + \upsilon_{i,t}.$$

The data vector $y_{i,t}$ consists of stationary time series at time t for a stock market i. The factor F_t is a common factor shared by all eighteen markets in the Asia-Pacific region, and thus it is referred to as APEC common factor. The factor $f_{j,t}$ is an MSCI-group-specific factor, and $\varepsilon_{i,t}$ is an idiosyncratic component. Estimating this dynamic factor model enables us to examine market connectedness in accordance with the degree of stock market development in different geographic locations. The β_i and γ_i are factor loadings to measure the quantitative impact of the factors, and the factors follow autoregressive processes to capture the dynamic properties. The Bayesian estimation of the factor model (10) follows the procedure in Otrok and Whiteman (1998). The estimation uses Markov-Chain Monte Carlo method and a data-augmenting algorithm to generate draws from the joint posterior as in Otrok and Whiteman (1998).

2.3. Data and Latent Factor Estimation

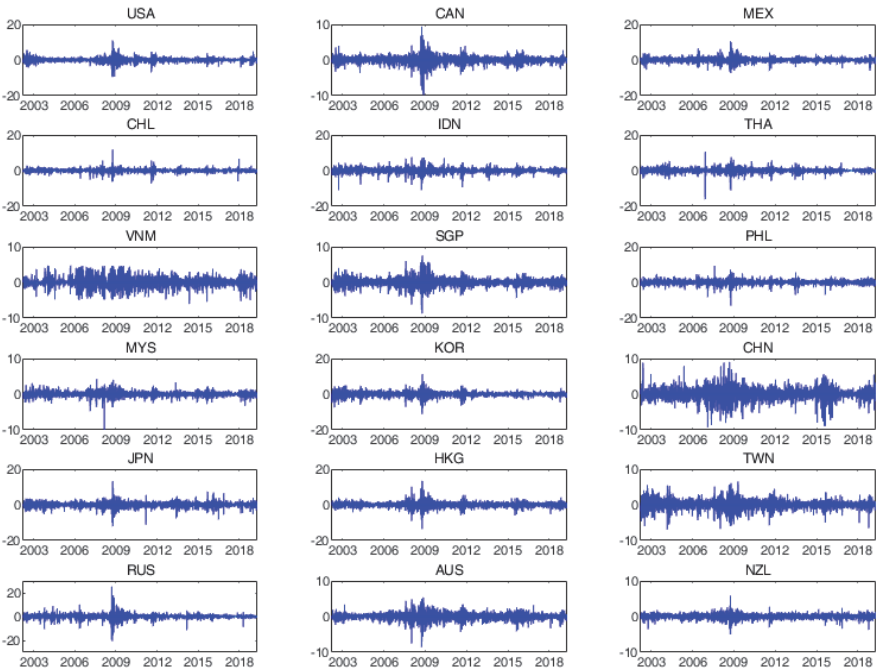
This study uses the daily closing prices of eighteen stock market indices in the Asia-Pacific region. The time series of daily stock market indices span the period from March 2002 to March 2019, taken from Thomson Reuters. The criteria to collect data were availability and MSCI market classification, which belong to developed and emerging markets in different region. The indices and stock markets to which they belong are presented in Table A.1 in Appendix. To compare between the pre- and post-GFC periods, we split the whole sample period into two subsamples. As widely acknowledged, the critical point of the global financial crisis is the Lehman's bankruptcy on September 15, 2008, and we use the collapse of the Lehman Brothers as the breakpoint.

The sample includes eighteen APEC member economies: Canada (CAN), the United States (USA), Australia (AUS), Hong Kong (HKG), Japan (JPN), New Zealand (NZL), and Singapore (SGP), Chinese Taipei (Taiwan hereafter, TWN), Indonesia (IDN), Malaysia (MYS), People's Republic of China (China hereafter, CHN), Republic of Korea (Korea hereafter, KOR), the Philippines (PHL), and Thailand (THA), Chile (CHL), and Mexico (MEX), Russia (RUS), and Viet Nam (VNM).

The daily stock returns are calculated as the percentage log difference of each closing price index. Due to nonsynchronous trading across different regions, market index in America at $(t-1)$ is matched to that in Asia at t. In cases of stock market holidays, the index of previous date substitutes the value of the trading holiday. Since we frequently observe asymmetric response of volatility to positive and negative shocks in stock markets, daily conditional volatilities are computed by estimating EGARCH(1,1) model in order to capture asymmetries in the volatility.[4] The series of stock returns and volatilities are presented in Figures 1 and 2.

4 Since the standard GARCH model cannot take asymmetry and leverage effects into consideration, the exponential GARCH (EGARCH) model was developed to resolve these limitations.

Figure 1. Daily Stock Returns



Source: Thomson Reuters.

Figure 2. Daily Market Volatilities

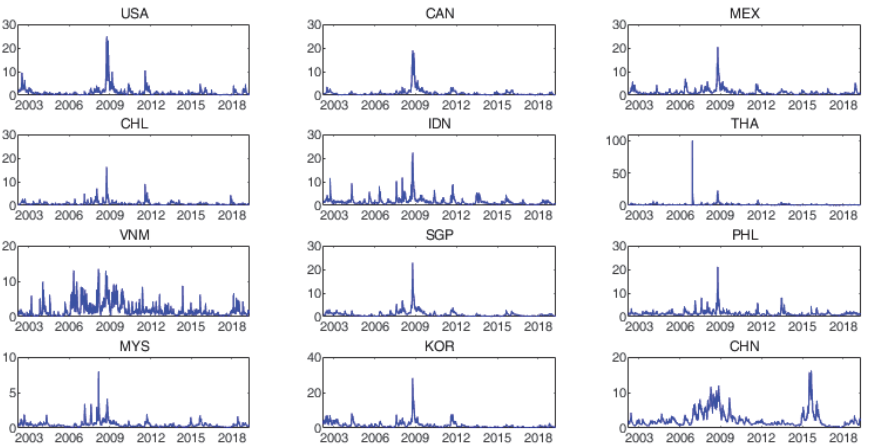
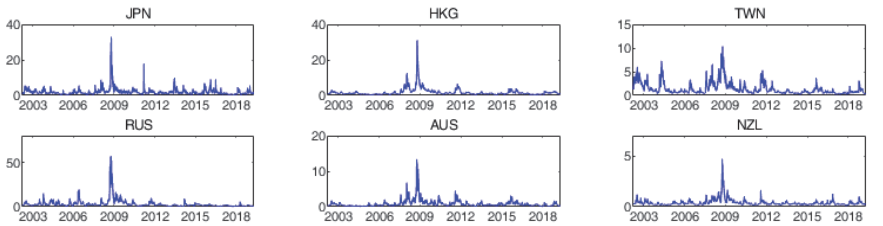


Figure 2. Countined

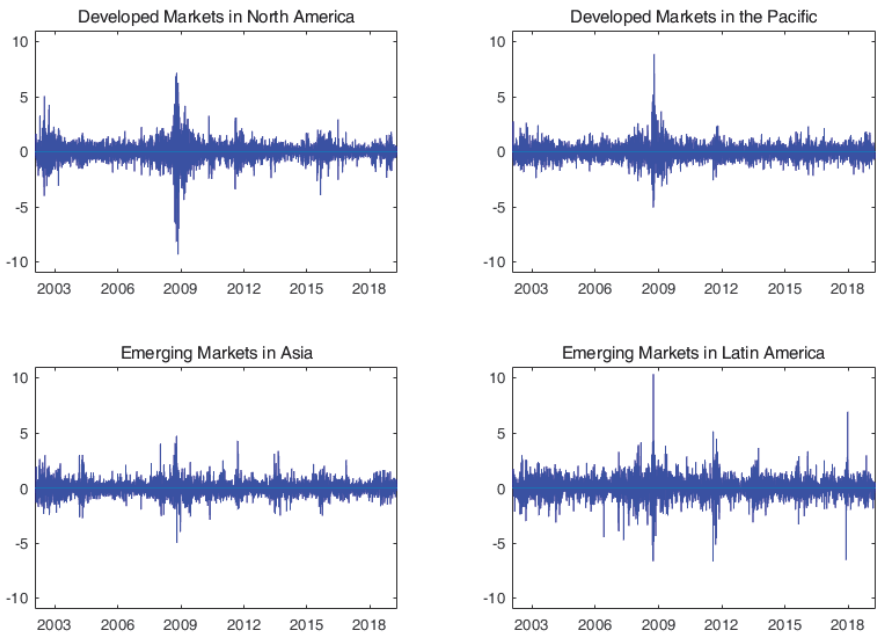


Source: Author's calculation.

A dynamic factor model is estimated on the basis of the stock market categories by MSCI global market classification. Four groups of stock markets are classified as follows: (i) 'developed markets in North America' of CAN and USA, (ii) 'developed markets in the Pacific' of AUS, HKG, JPN, NZL, and SGP, (iii) 'emerging markets in Asia' of TWN, IDN, MYS, CHN, KOR, PHL, and THA, (iv) 'emerging markets in Latin America' of CHL and MEX. In estimating the factor model, Russia is not considered because her stock market is the only emerging one in Europe, and Viet Nam is also excluded due to its classification as the frontier emerging market.

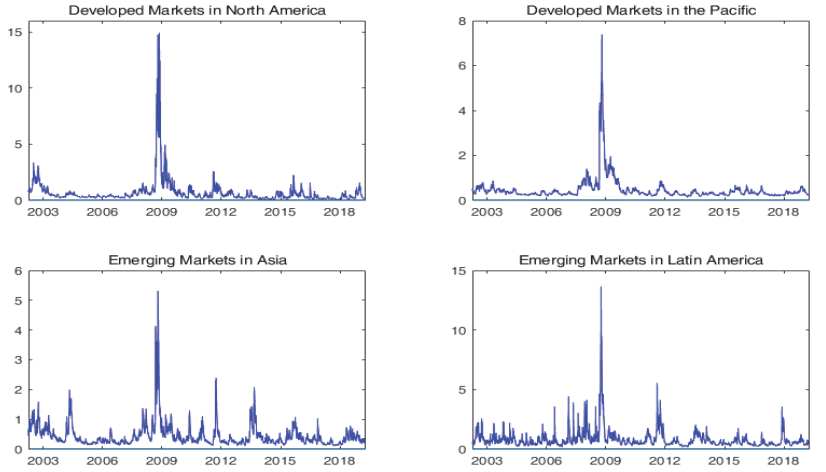
Figure 3 displays the estimated latent group-specific components of daily stock returns. These estimated group-specific factors will be used in the following section to analyze connectedness among the MSCI-classified groups. Figure 3 shows the GFC impact for the developed markets in North America, and the emerging markets in Latin America seem to be directly affected by the GFC shock at that time. On the other hand, the developed markets in the Pacific and the emerging markets in Asia are affected relatively less in 2008, compared to other two groups. Figure 4 plots four group-specific volatilities, taken from EGARCH(1,1) estimation, corresponding to each group-specific factor of returns. The volatility dynamics display high volatility during the recent crises - the global financial crisis, European sovereign debt crisis - with volatility clustering.

Figure 3. MSCI-Group-Specific Factors of Stock Returns



Source: Author's calculation.

Figure 4. MSCI-Group-Specific Volatilities



Source: Author's calculation.

III. Stock Return Connectedness

3.1. Connectedness of Individual Markets

We examine two subsamples of the pre- and post-GFC periods by taking the break point of Lehman's collapse on September 15, 2008. Tables 1 and 2 are the connectedness tables to summarize the generalized forecast error variances with 10-day-ahead forecast horizon.[5] For parsimonious estimations, the lag lengths are determined with Schwartz Criterion. The ijth entry in the connectedness table is the contribution to the forecast error variance of market i coming from innovations to market j. In the table, the off-diagonal column sums (i.e. contributions to others) and row sums (i.e. contributions from others) are the 'To' and 'From' directional spillovers, and the differences of 'From minus To' are the net spillovers. The total spillover index is presented in the lower right corner of the connectedness table.

Table 1 for the pre-GFC period reveals the following findings. From the 'contribution to others' row, we can see that gross directional return spillovers to others from each of the markets are different. Singapore (108.80), Hong Kong (109.92), and Australia (106.07) shows large values to reflect efficient stock market information transmitters. In fact, Singapore and Hong Kong play the role of the international financial hub in global financial markets. Singapore, Hong Kong and Australia share large portion of APEC common factor of stock returns, as confirmed in Figures 7 and 8. Allen et al. (2014) also highlight that Hong Kong market has the greatest influence on the Australia stock market. According to the 2009 Capital Access Index (CAI) released by Milken Institute, Australia was ranked fifth in the Asia-Pacific region.[6] High level of capital market openness and the government's efforts

5 This is because ten-day horizon is commonly used to calculate financial Value at Risk. See Diebold and Yilmaz (2014).

6 The CAI ranking of the APEC members is Canada (8.25), Hong Kong (7.99), Singapore (7.92), USA (7.88), Australia (7.52) in order.

for Australia financial center brought about Australian role of information mediator in stock markets. We can also see from the 'contribution from others' column that the gross directional return spillovers from others to Viet Nam is very small, explaining 8.86% of the forecast error variance.

As for the net directional return spillovers, the net transmitters, having positive value of net spillover index, are the United States (7.22), Singapore (33.46), Korea (13.56), Japan (9.17), Hong Kong (33.54), Taiwan (0.50), and Australia (29.91). Similarly, other stock markets are the net receivers of return shocks. In addition, the total return spillover index indicates that, on average, 60.53% of the return forecast error variance in all markets comes from spillovers.

Table 2 for the post-GFC period reveals different results from Table 1. We see that gross directional spillovers from others of the eighteen markets are not very different. The net information transmitters are Indonesia (7.03%), Thailand (5.56%), Singapore (41.76%), Malaysia (2.81%), Korea (22.90%), Japan (6.15%), Hong Kong (44.13%), Taiwan (12.15%), Russia (13.04%), and Australia (22.09%). The difference in return connectedness before and after the GFC is that the United States (-1.16) has changed from a net transmitter to a net receiver and several emerging markets - Indonesia (7.03), Thailand (5.56), Malaysia (2.81), and Russia (13.04) - have become net return transmitters with small magnitudes of net spillovers. The total return spillover index of 71.35%, which is greater than that of the pre-GFC period in Table 1. This change implies that there have been increasing information spillovers after the global financial crisis in the Asia-Pacific stock markets.

Table 1. Return Connectedness Table: Individual Markets (Pre-GFC Period)

	From																		
To	USA	CAN	MEX	CHL	IDN	THA	VNM	SGP	PHL	MYS	KOR	CHN	JPN	HKG	TWN	RUS	AUS	NZL	Contribution from others
USA	27.95	11.18	10.44	4.52	1.63	1.74	0.10	4.77	2.98	2.67	4.00	0.15	4.99	5.09	3.70	2.17	8.07	3.85	72.05
CAN	12.32	30.79	8.29	4.07	2.89	2.17	0.10	4.65	2.29	2.78	3.53	0.25	4.02	5.22	2.44	3.71	8.08	2.39	69.21
MEX	11.04	7.82	29.27	5.31	2.98	2.48	0.24	5.50	3.75	2.71	3.87	0.26	4.14	5.40	2.68	3.84	6.61	2.11	70.73
CHL	6.97	5.23	7.47	39.82	3.09	2.51	0.05	4.82	2.75	3.23	2.87	0.36	3.84	4.58	2.27	2.64	5.16	2.32	60.18
IDN	1.87	2.46	2.61	1.45	35.62	4.77	0.03	8.48	2.56	6.15	5.52	0.73	4.51	8.69	4.95	2.49	6.09	1.03	64.38
THA	2.54	2.14	2.16	1.60	5.55	42.26	0.21	7.19	1.89	4.85	5.87	0.37	4.14	6.49	5.20	2.14	4.38	1.02	57.74
VNM	0.36	0.24	0.47	0.20	0.69	0.06	91.14	0.80	0.43	0.76	0.39	0.28	0.94	0.83	0.49	0.42	1.31	0.18	8.86
SGP	3.70	2.35	3.14	1.45	5.75	4.20	0.05	24.66	2.40	6.00	7.82	0.79	7.30	11.94	6.50	2.59	7.72	1.67	75.34
PHL	4.29	2.56	5.01	2.40	4.62	2.68	0.22	5.69	39.92	4.70	4.18	0.44	4.13	5.24	3.52	2.19	6.01	2.18	60.08
MYS	3.28	2.62	2.68	2.08	6.50	4.01	0.08	9.11	3.39	34.40	5.42	1.13	4.48	6.99	4.38	2.21	5.82	1.43	65.60
KOR	3.58	2.03	2.36	0.95	4.34	3.85	0.07	8.96	2.42	4.27	27.49	0.56	9.29	9.25	9.85	1.91	7.07	1.74	72.51
CHN	0.55	0.45	0.51	0.49	1.74	0.66	0.03	2.62	0.47	2.55	1.55	75.34	1.66	6.14	1.34	0.57	2.16	1.19	24.66
JPN	4.64	2.63	3.26	1.83	3.77	2.79	0.24	8.78	2.41	3.58	9.55	0.67	28.19	8.52	6.62	2.59	8.11	1.82	71.81
HKG	4.08	3.14	3.43	1.93	5.79	3.65	0.03	11.62	2.38	4.52	7.89	1.94	7.04	23.61	6.09	2.28	8.86	1.72	76.39
TWN	3.81	1.53	2.29	1.01	4.44	4.03	0.13	8.42	2.41	4.09	11.28	0.55	7.34	8.18	31.27	1.61	6.29	1.32	68.73
RUS	2.90	2.66	2.62	0.54	2.84	2.39	0.05	5.60	1.46	2.42	3.00	0.34	3.21	4.71	2.37	57.44	4.22	1.24	42.56
AUS	6.81	5.63	4.85	2.43	4.17	2.51	0.21	7.72	3.27	3.84	6.12	0.62	6.78	8.95	4.81	2.60	23.84	4.82	76.16
NZL	6.53	3.40	3.25	2.33	1.66	1.50	0.12	4.09	2.79	2.20	3.22	0.51	3.17	3.71	2.11	1.78	10.12	47.50	52.50
Contribution to others	79.27	58.08	64.84	34.62	62.44	46.00	1.94	108.80	40.06	61.34	86.07	9.96	80.98	109.92	69.33	37.73	106.07	32.02	Total Spillover index
T	7.22	−11.13	−5.89	−25.56	−1.94	−11.74	−6.91	33.46	−20.02	−4.25	13.56	−14.69	9.17	33.54	0.59	−4.83	29.91	−20.48	= 60.53%

Source: Author's calculation.

Table 2. Return Connectedness Table: Individual Markets (Post-GFC Period)

	From																		
To	USA	CAN	MEX	CHL	IDN	THA	VNM	SGP	PHL	MYS	KOR	CHN	JPN	HKG	TWN	RUS	AUS	NZL	Contribution from others
USA	20.28	10.27	7.85	3.69	2.95	3.55	1.22	5.61	3.46	3.18	4.57	1.24	5.94	5.67	3.87	4.54	7.12	5.00	79.72
CAN	11.50	22.43	6.00	3.33	3.24	3.86	1.15	5.46	2.61	3.23	4.24	1.14	4.74	5.53	3.87	6.55	6.93	4.17	77.57
MEX	9.13	5.84	23.09	4.40	4.08	3.84	0.97	6.43	3.25	3.82	4.98	1.28	3.98	6.87	3.60	5.89	5.16	3.40	76.91
CHL	5.98	4.32	5.87	27.83	4.78	4.78	0.79	5.89	3.36	4.44	4.71	1.47	3.47	5.76	3.37	5.19	5.20	2.82	72.17
IDN	2.89	1.99	2.56	1.16	27.21	7.20	0.64	8.96	5.07	6.74	6.11	1.51	3.54	7.22	6.14	3.99	4.76	2.30	72.79
THA	2.35	1.17	1.78	1.26	7.86	30.22	0.89	9.04	4.42	5.47	5.37	1.92	4.00	8.74	4.65	4.19	4.51	2.15	69.78
VNM	2.89	1.72	1.79	0.79	1.96	2.73	55.27	3.59	2.12	3.38	3.09	1.26	3.46	3.21	2.90	4.16	3.50	2.19	44.73
SGP	3.21	1.68	2.51	0.95	6.73	6.27	0.71	21.31	3.05	6.22	7.89	2.41	5.56	11.03	6.59	4.11	6.85	2.91	78.69
PHL	4.65	2.29	3.23	1.75	6.71	5.89	1.05	6.13	29.15	5.67	4.97	1.35	4.06	6.25	4.95	4.05	4.65	3.19	70.85
MYS	3.24	2.13	2.53	1.15	7.30	5.25	0.98	8.47	4.72	27.26	6.08	1.35	4.28	6.73	6.37	3.74	5.57	2.84	72.74
KOR	3.05	1.68	2.18	1.11	5.22	4.10	0.71	8.81	2.88	4.87	22.72	2.29	7.16	9.39	9.60	4.42	7.25	2.57	77.28
CHN	1.44	0.75	0.55	0.45	2.76	3.03	0.99	5.47	1.91	2.38	4.79	47.91	3.43	12.35	4.89	2.30	3.26	1.31	52.09
JPN	6.18	3.04	3.04	1.71	3.37	3.62	1.18	7.19	3.17	3.94	7.82	1.76	24.47	7.35	5.94	3.82	8.23	4.16	75.53
HKG	3.30	1.77	2.76	1.18	5.34	5.83	0.69	10.77	3.37	4.77	8.39	5.33	5.89	20.37	7.11	4.21	6.73	2.20	79.63
TWN	3.20	2.02	2.28	1.08	5.54	4.07	0.79	8.30	3.59	5.51	10.01	2.39	5.68	8.66	23.26	4.12	6.86	2.64	76.74
RUS	1.93	1.30	1.95	0.64	4.93	4.75	1.01	7.33	2.01	4.05	6.33	1.37	3.85	7.22	4.80	40.87	3.98	1.69	59.13
AUS	6.36	4.41	3.36	1.65	3.92	3.41	1.09	7.33	3.07	4.36	6.85	1.48	7.17	7.29	6.22	3.93	21.63	6.46	78.37
NZL	7.25	4.48	3.85	1.99	3.14	3.14	1.32	5.68	3.41	3.52	3.99	1.07	5.46	4.48	3.99	2.98	9.88	30.38	69.62
Contribution to others	78.55	50.85	54.09	28.29	79.81	75.34	16.18	120.45	55.47	75.55	100.18	30.61	81.68	123.76	88.88	72.18	100.45	52.00	Total Spillover index
ET	−1.16	−26.72	−22.83	−43.88	7.03	5.56	−28.54	41.76	−15.38	2.81	22.90	−21.49	6.15	44.13	12.15	13.04	22.09	−17.62	= 71.35%

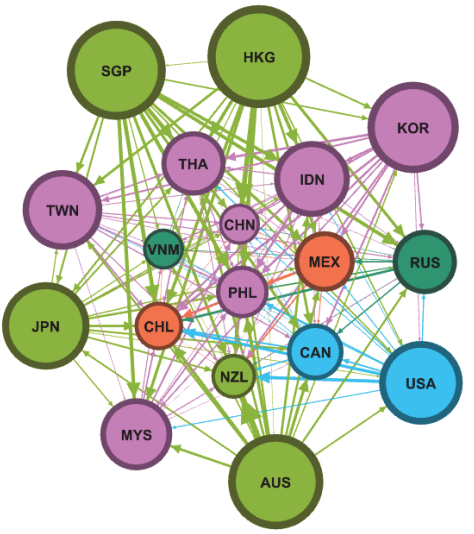
Source: Author's calculation.

We next perform a network analysis of net pairwise connectedness. A network analysis consists of two ingredients: a list of the entities (called nodes) composing the network, and a list of the interactions (called edges) between them. In the following analysis, an attribute of the nodes refers to the MSCI stock market category: developed North America, developed the Pacific, emerging Asia, Emerging Latin America, and others that are not included in the four categories. The color of the nodes and arrows are determined based on the attribute of MSCI classification: cyan for developed markets in North America, dark green for developed markets in the Pacific, red violet for emerging markets in Asia, and magenta for emerging markets in Latin America. The size of a node accounts for the number of directed *net* pairwise connections, and the thickness of an arrowed line reflects the intensity of *net* pairwise spillovers.[7]

We start with comparisons of network graphs based on net pairwise return spillovers between the pre- and post-GFC periods. Figure 5, based on the size of the nodes, Singapore, Hong Kong, Australia, Korea, the United States, and Japan are strong return information transmitters to other markets. In contrast, in Figure 6, the United States (to New Zealand and Chile) and Japan have reduced net pairwise connections and Russia has increased connections after the GFC. In addition, the intensity of information transmission, based on the circle size and thickness of an arrowed line, from Hong Kong to China got stronger after the GFC.

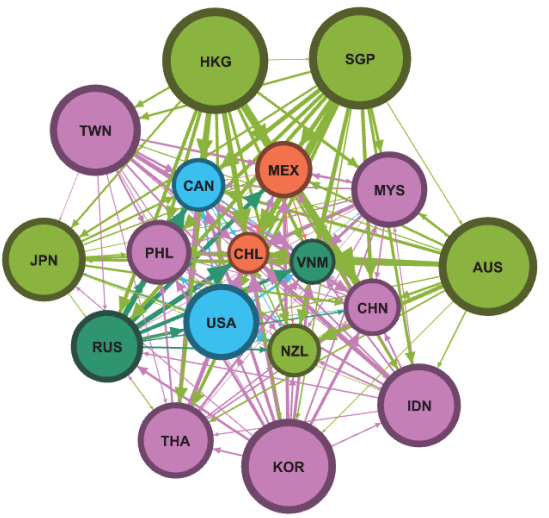
7 We note that the network graphs in this study illustrate the relations of net bilateral spillovers, not gross directional spillovers between markets.

Figure 5. Network of Return Connectedness: Individual Markets (Pre-GFC Period)



Source: Author's calculation.

Figure 6. Network of Return Connectedness: Individual Markets (Post-GFC Period)



Source: Author's calculation.

3.2. Connectedness of MSCI-Classified Groups

In this section, we examine stock return connectedness by grouping the markets according to MSCI classification over two subsamples. We classify the Asia-Pacific stock markets into four categories by MSCI global market classification: developed markets in North America (USA, CAN), developed markets in the Pacific (AUS, NZL, JPN, HKG, SGP), emerging markets in Asia (KOR, CHN, TWN, IND, MYS, PHL, THA), and emerging Latin America (Chile, Mexico).

In the pre-GFC subsample, Table 3 presents the following empirical results. From the 'contribution to others' row, we see that the group of developed markets in North America (24.96%) shows relatively large gross directional return spillovers to others. We also see from the 'contribution from others' column that the gross directional return spillovers from others to developed markets in North America is small, explaining 1.75% of the forecast error variance. Another finding is that the developed group in the Pacific, which includes Singapore, Hong Kong, and Australia, has relatively larger portion (12.12) among them but has small contribution to others (2.22). Therefore, the developed group in North America is the net information transmitter and other three groups are net information recipients.

For the post-GFC period, the group of developed markets in North America, having the outflow spillover index (i.e. contribution to others) of 36.08, remains the strongest information transmitter as ever. However, the group shows much smaller inflow spillover index (i.e. contribution from others) of 0.68. Therefore, the developed group in North America is still the net information transmitter after the GFC. A different change occurs with the emerging group in Asia in the sense that it turned into a net information transmitter after the GFC. As for the other two groups of net information recipients, the degrees of net receivers have been reinforced (-9.90→ -15.00 and -10.42→-20.51, respectively) after the GFC. In addition, the total spillover index has increased from 7.77% before the GFC to 10.50% after the GFC.

Unlike the results for individual markets, the significance of Singapore, Hong Kong, and Australia, being included in the developed markets in the Pacific,

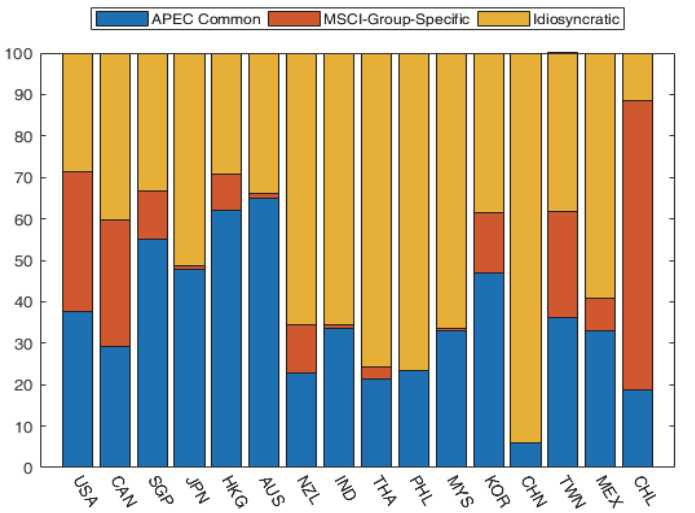
disappears here. Instead, the group of developed markets in North America manifests the strong intensity of return transmission. The reason for these results in the MSCI-group analysis can be sought by the absence of the APEC common factor of returns as follows. In order to quantify the relative contributions of the respective estimated factors in return variations, I calculate a variance decomposition of Eq. (11). That is, the variance of a return variable is decomposed into the proportion that is attributable to the relevant factors. To this end, taking the variance operator to Eq. (10), variance of market i's return is represented by:

$$Var(y_{i,t}) = \hat{\beta}_i^2 Var(F_t) + \hat{\gamma}_i^2 Var(f_{j,t}) + Var(v_{i,t}). \quad (11)$$

For example, the fraction of the total variation of market i's return attributable to the common factor is calculated by $\frac{\hat{\beta}_i^2 Var(F_t)}{Var(y_{i,t})}$.

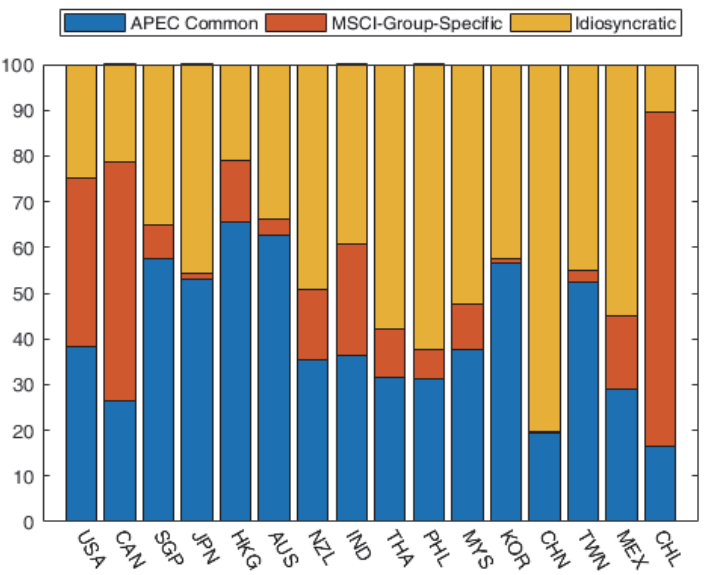
Figures 7 and 8 show the relative contribution of market i's return variability before and after the GFC. Stock markets of the developed group in the Pacific contain high fraction of the APEC common factor and relatively small portion of the group-specific factor. As for Singapore, Hong Kong, and Australia, the APEC common factor dominates other two components. That is, the role of global financial hubs in these economies plays together with the Asia-Pacific-wide common component of returns. Then this effect disappears after removing the APEC common factor as presented above.

Figure 7. Relative Contribution for Return Factors (Pre-GFC Period)



Source: Author's calculation.

Figure 8. Relative Contribution for Return Factors (Post-GFC Period)



Source: Author's calculation.

Table 3. Return Connectedness Table: MSCI-Classified Stock Market Groups (Pre-GFC Period)

	From				
To	Developed Markets in North America	Developed Markets in the Pacific	Emerging Markets in Asia	Emerging Markets in Latin America	Contribution from others
Developed Markets in North America	98.25	0.33	1.40	0.02	1.75
Developed Markets in the Pacific	11.99	87.88	0.12	0.01	12.12
Emerging Markets in Asia and Europe	6.04	0.59	93.30	0.06	6.70
Emerging Markets in Latin America	6.93	1.29	2.30	89.48	10.52
Contribution to others	24.96	2.22	3.81	0.10	Total Spillover index = 7.77%
NET	23.21	−9.90	−2.89	−10.42	

Source: Author's calculation.

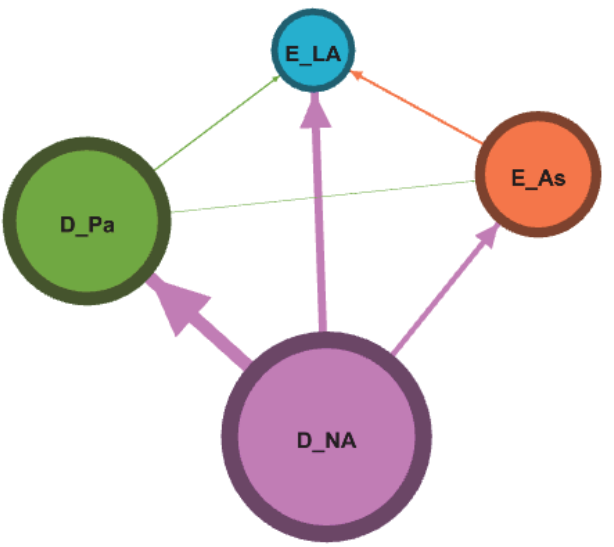
Table 4. Return Connectedness Table: MSCI-Classified Stock Market Groups (Post-GFC Period)

	From				
To	Developed Markets in North America	Developed Markets in the Pacific	Emerging Markets in Asia	Emerging Markets in Latin America	Contribution from others
Developed Markets in North America	99.32	0.44	0.13	0.11	0.68
Developed Markets in the Pacific	17.29	82.47	0.24	0.00	17.53
Emerging Markets in Asia and Europe	1.93	1.21	96.85	0.02	3.15
Emerging Markets in Latin America	16.87	0.89	2.88	79.36	20.64
Contribution to others	36.08	2.54	3.25	0.13	Total Spillover index = 10.50%
NET	35.41	−15.00	0.10	−20.51	

Source: Author's calculation.

As for network connectedness of *net* pairwise spillovers, Figures 9 and 10 illustrate their relations.[8] Based on the size of the nodes, the developed group in North America is the strongest information transmitter to other markets. However, the intensity of transmission from the developed group in North America to other markets was languished after the GFC.

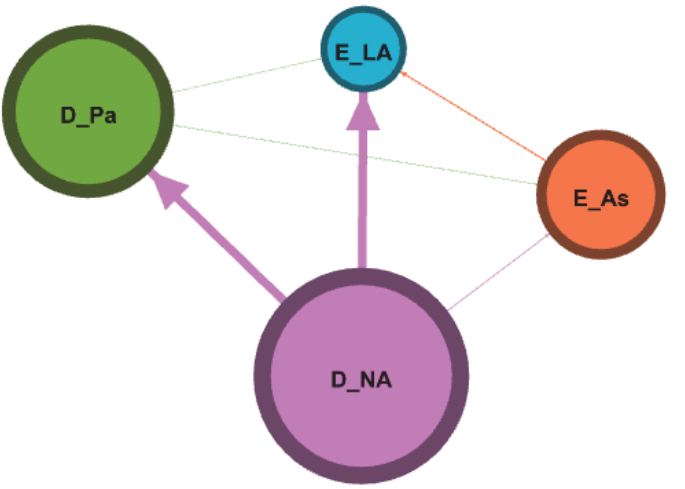
Figure 9. Network of Return Connectedness: MSCI-Classified Groups (Pre-GFC Period)



Source: Author's calculation.

8 In Figures, D_NA, D_Pa, E_As, and E_LA stand for the developed markets in North America, the developed markets in the Pacific, the emerging markets in Asia, and the emerging markets in Latin America, respectively.

Figure 10. Network of Return Connectedness: MSCI-Classified Groups (Post-GFC Period)



Source: Author's calculation.

IV. Market Volatility Connectedness

4.1. Connectedness of Individual Markets

From the viewpoint of financial risk vulnerability in terms of systemic risk management, market volatility spillovers receive more attention of policy makers and financial investors. From the 'contribution to others' row in Table 5, we see that gross directional return spillovers to others from each of the markets are different. The United States (245.03), Canada (57.78), Indonesia (71.00), and Singapore (64.59) show large volatility outflows to other markets. It seems natural to consider the outbreak of the subprime mortgage crisis in the United States and the subsequent financial crisis contagion over the world. However, other stock markets manifest low degree of volatility transmissions to others.

On the other hand, from the 'contribution from others' column, the gross directional spillovers from others to Canada (54.26), Mexico (44.33), Singapore (38.27), the Philippines (39.23), Malaysia (34.03), Korea (38.65), Japan (54.60), Hong Kong (61.71), Taiwan (46.24), Australia (64.18), and New Zealand (31.10) account for large fraction of the forecast error variance. As for the net directional volatility spillovers, the highly influential net volatility transmitter is the United States (241.81), followed by Indonesia (71.00) and Singapore (64.59). Indonesia stands out as being significant, because considerably-increased international capital flows have expanded stock market volatilities and she experienced currency crisis, stock market crisis, and banking crisis as pointed out in Reinhart and Rogoff (2009) and Huh et al. (2011). Russia and most markets in Asia and Oceania are the net receivers of volatility shocks. Finally, the total volatility spillover index addresses that, on average, 32.93% of the forecast error variance in all markets comes from spillovers.

For the post-GFC period, Table 6 shows different aspects from Table 5. From gross directional spillovers to others, USA (253.82), Mexico (55.41), Indonesia (84.12), and Singapore (106.57) are strong volatility transmitters. On the other hand,

gross directional spillovers from others imply that Canada (76.44), Mexico (41.89), Singapore (46.29), Korea (59.26), Japan (51.93), Hong Kong (74.64), and Australia (59.06) are major volatility shock recipients. Canada and Mexico manifest the stronger role of volatility mediator, in combination with synchronization with the USA economy. Kim (2012) shows that market volatility in Mexico converged to the level of that in the USA after the financial crisis. As in Figures 11 and 12, the circle size of Canada and Mexico became larger after the GFC which means the number of bilateral markets that Canada and Mexico affect have been greater. It reflects their geopolitical factors and economic synchronization based on NAFTA. Therefore, the influential net volatility transmitters are USA (238.86), Mexico (13.51), Indonesia (61.35), and Singapore (60.28). In addition, the total spillover index of 38.50% is greater than that of pre-GFC period. This implies that volatility connectedness has been reinforced since the global financial crisis. This provides the necessity of APEC financial cooperation since the net volatility transmitters have been spreading the shocks around the Asia-Pacific region. This result also supports the view that the United States is a major volatility transmitter, causing a trigger event of the 2008 financial crisis.

Table 5. Volatility Connectedness Table: Individual Markets (Pre-GFC Period)

	From																		
To	USA	CAN	MEX	CHL	IDN	THA	VNM	SGP	PHL	MYS	KOR	CHN	JPN	HKG	TWN	RUS	AUS	NZL	Contribution from others
USA	96.78	0.50	0.00	0.05	0.14	0.02	0.02	0.26	0.05	0.48	0.89	0.09	0.08	0.01	0.44	0.03	0.02	0.15	3.22
CAN	49.44	45.74	0.16	0.16	0.15	0.02	0.77	0.28	0.00	0.66	0.01	0.37	0.07	0.00	0.98	0.89	0.30	0.00	54.26
MEX	33.78	6.43	55.67	0.00	1.16	0.05	0.17	0.17	0.14	0.11	0.03	0.07	0.20	0.11	0.02	1.67	0.02	0.21	44.33
CHL	13.36	5.26	5.87	72.85	0.32	0.00	0.10	0.61	0.02	0.31	0.38	0.00	0.42	0.02	0.14	0.10	0.00	0.24	27.15
IDN	9.08	8.35	0.54	1.36	77.92	0.01	1.31	0.14	0.18	0.07	0.01	0.01	0.04	0.55	0.06	0.01	0.03	0.32	22.08
THA	0.01	0.12	0.02	0.02	0.51	98.50	0.50	0.00	0.06	0.02	0.02	0.00	0.11	0.01	0.05	0.02	0.02	0.01	1.50
VNM	0.01	0.78	0.33	0.08	0.20	1.21	94.33	0.44	0.03	0.36	0.13	0.04	0.56	0.03	0.07	0.00	1.38	0.02	5.67
SGP	19.57	2.22	0.71	3.48	9.78	0.10	0.88	61.73	0.39	0.00	0.05	0.02	0.48	0.01	0.22	0.28	0.04	0.04	38.27
PHL	7.73	1.43	9.10	7.40	7.40	0.01	0.78	2.62	60.77	0.10	0.26	0.17	0.79	0.72	0.00	0.00	0.33	0.39	39.23
MYS	6.33	0.22	1.96	4.74	5.45	0.05	2.88	4.49	4.28	65.97	0.24	0.28	0.08	0.01	0.35	0.11	1.70	0.85	34.03
KOR	19.18	0.51	0.01	0.09	8.33	0.01	0.03	7.84	0.41	0.47	61.35	0.00	0.08	0.02	1.08	0.37	0.00	0.21	38.65
CHN	0.06	0.45	0.05	1.13	2.45	0.00	2.22	0.78	0.08	0.58	0.06	91.49	0.04	0.04	0.04	0.04	0.01	0.47	8.51
JPN	18.34	0.95	2.86	0.99	7.39	0.08	0.80	15.26	0.04	1.61	3.89	0.08	45.40	0.01	0.75	1.39	0.07	0.08	54.60
HKG	13.79	7.77	1.45	7.48	10.72	0.03	1.61	16.74	0.05	0.05	0.33	0.63	0.80	38.29	0.14	0.02	0.02	0.07	61.71
TWN	13.63	4.89	0.18	0.24	4.26	0.01	0.18	4.33	1.11	1.34	12.96	0.61	0.17	0.89	53.76	0.41	0.91	0.12	46.24
RUS	2.18	4.24	0.33	0.11	5.25	0.01	0.74	1.82	0.07	1.19	0.12	0.01	1.08	0.09	0.61	81.92	0.01	0.21	18.08
AUS	20.42	12.85	2.19	2.36	5.83	0.09	1.45	7.79	0.23	0.87	0.32	0.16	0.93	6.66	0.24	0.66	35.82	1.14	64.18
NZL	18.11	0.83	0.08	0.00	1.64	0.03	0.15	1.03	1.88	0.17	0.43	0.33	0.30	0.11	0.17	0.35	5.48	68.90	31.10
Contribution to others	245.03	57.78	25.86	29.70	71.00	1.73	14.61	64.59	9.00	8.40	20.12	2.87	6.24	9.29	5.36	6.35	10.33	4.53	Total Spillover index = 32.93%
NET	241.81	3.52	−18.47	2.55	48.92	0.23	8.94	26.33	−30.24	−25.63	−18.53	−5.64	−48.36	−52.42	−40.89	−11.73	−53.84	−26.56	

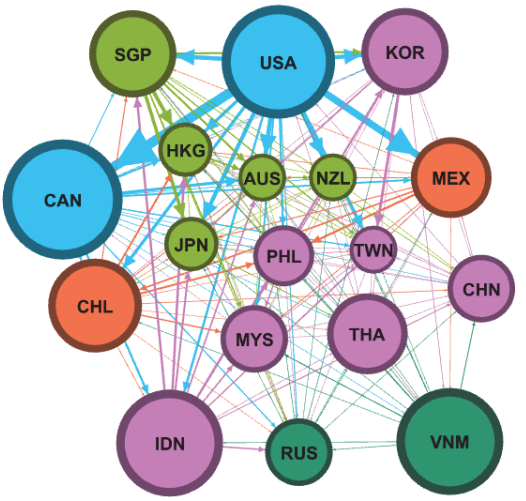
Source: Author's calculation.

Table 6. Volatility Connectedness Table: Individual Markets (Post-GFC Period)

	From																		
To	USA	CAN	MEX	CHL	IDN	THA	VNM	SGP	PHL	MYS	KOR	CHN	JPN	HKG	TWN	RUS	AUS	NZL	Contribution from others
USA	85.04	0.04	0.30	0.69	0.76	0.00	0.03	1.46	3.27	0.01	0.05	0.14	0.07	0.09	1.80	4.85	1.00	0.40	14.96
CAN	59.84	23.56	0.20	0.11	1.36	0.17	0.01	2.39	0.30	0.38	0.10	0.16	0.02	0.30	1.36	6.51	3.22	0.01	76.44
MEX	22.89	1.07	58.11	0.21	0.45	0.02	0.01	3.70	4.14	0.04	0.11	0.00	0.56	1.87	0.63	2.48	1.30	2.41	41.89
CHL	11.39	0.60	9.49	69.47	2.61	0.01	0.02	0.06	1.01	0.12	1.32	0.00	0.12	0.09	1.82	0.90	0.95	0.03	30.53
IDN	5.92	1.91	7.20	1.34	77.23	0.01	0.62	0.78	0.46	0.10	0.03	0.03	0.29	2.74	0.38	0.06	0.54	0.36	22.77
THA	0.46	0.23	0.37	0.32	1.92	95.28	0.36	0.10	0.34	0.00	0.01	0.00	0.04	0.47	0.02	0.05	0.01	0.00	4.72
VNM	0.30	0.04	0.31	0.09	0.03	0.63	95.06	1.01	0.30	0.01	0.24	0.00	0.56	0.05	0.16	0.65	0.52	0.03	4.94
SGP	18.98	1.85	2.70	4.45	9.43	0.07	0.34	53.71	1.06	0.04	2.14	0.03	0.89	0.55	1.23	1.51	0.11	0.90	46.29
PHL	9.60	1.03	8.01	2.97	10.83	0.31	0.79	5.36	50.89	0.05	0.35	0.01	0.25	7.13	0.14	0.60	1.29	0.38	49.11
MYS	3.80	0.00	3.14	2.48	5.69	0.11	2.03	7.91	1.43	71.72	0.07	0.07	0.24	0.34	0.24	0.23	0.34	0.15	28.28
KOR	18.98	1.00	3.08	1.07	5.74	0.01	0.02	22.01	2.25	0.50	40.74	0.07	1.30	1.22	1.00	0.13	0.54	0.33	59.26
CHN	0.05	0.27	0.04	0.06	2.57	0.05	2.28	0.71	0.74	0.74	0.02	92.01	0.08	0.00	0.03	0.11	0.16	0.08	7.99
JPN	20.72	1.56	3.95	2.38	4.20	0.05	0.27	12.40	1.41	0.10	2.00	0.02	48.07	1.06	0.25	1.07	0.01	0.49	51.93
HKG	12.83	0.84	5.73	2.85	13.68	0.12	0.89	30.66	2.00	0.12	0.39	1.17	0.53	25.36	0.08	0.30	1.58	0.87	74.64
TWN	7.45	0.21	3.27	0.64	10.15	0.01	0.35	5.29	0.60	1.11	8.13	0.66	0.88	0.84	60.04	0.03	0.03	0.30	39.96
RUS	3.68	3.22	4.44	0.75	6.83	0.01	1.15	2.49	1.57	0.35	0.86	0.11	0.23	0.12	2.77	71.27	0.02	0.15	28.73
AUS	27.53	0.49	2.83	2.83	6.17	0.03	0.17	7.91	1.79	0.30	1.20	0.37	1.46	0.95	2.41	2.27	40.94	0.35	59.06
NZL	29.40	0.40	0.34	1.99	1.70	0.02	0.64	2.31	0.15	0.10	0.78	0.19	0.25	0.59	2.27	5.17	5.10	48.60	51.40
Contribution to others	253.82	14.77	55.41	25.23	84.12	1.63	10.00	106.57	22.83	4.07	17.80	3.05	7.76	18.42	16.56	26.92	16.71	7.26	Total Spillover index
NET	238.86	−61.67	13.51	−5.30	61.35	−3.09	5.05	60.28	−26.29	−24.21	−41.46	−4.94	−44.17	−56.22	−23.40	−1.81	−42.35	−44.15	= 38.50%

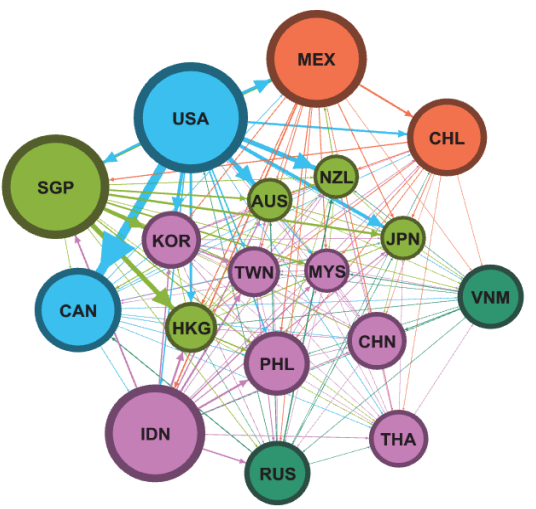
Source: Author's calculation.

Figure 11. Network of Volatility Connectedness: Individual Markets (Pre-GFC Period)



Source: Author's calculation.

Figure 12. Network of Volatility Connectedness: Individual Markets (Post-GFC Period)



Source: Author's calculation.

The network of *net* pairwise volatility spillovers are illustrated in Figure 11. The size of the nodes implies that the United States, Canada, Indonesia, Viet Nam, and Chile are strong volatility transmitters to other markets. In particular, the United States triggers intense volatility transmission to Canada and Mexico. In contrast, in Figure 12, the United States, Singapore, Mexico, Indonesia, Canada, Chile have high degree of pairwise volatility connections after the GFC. We also see that the United States sets off intense volatility spillovers to Canada, Australia, New Zealand, Japan, and Mexico.

4.2. Connectedness of MSCI-Classified Groups

As for the Asia-Pacific stock market categories, we also compare the results between the pre- and post-GFC periods. From the 'contribution to others' row in Table 7, the developed group in North America (14.28) shows the largest gross directional return spillovers to others, followed by the emerging markets in Latin America (7.07). On the other hand, the developed group in the Pacific (10.17) shows the largest volatility inflows from others. Overall, the developed group in North America (13.09) is a major net volatility transmitter and the emerging group in Latin America (0.58) is a weak net volatility transmitter.

For the post-GFC subsample, the developed group in North America, having the outflow spillover index (i.e. contribution to others) of 38.96, still remains the strongest volatility transmitter. However, the group shows the smallest inflow spillover index (i.e. contribution from others) of 7.31 among the four groups. Therefore, the developed group in North America is still the most influential net volatility transmitter after the GFC. Moreover, the intensity of net volatility transmitters has become stronger (13.09→31.66 and 0.58→1.83, respectively). Finally, the total volatility spillover index increased from 6.10% before the GFC to 15.72% after the GFC.

Table 7. Volatility Connectedness Table: MSCI-Classified Stock Market Groups (Pre-GFC Period)

	From				
To	Developed Markets in North America	Developed Markets in the Pacific	Emerging Markets in Asia	Emerging Markets in Latin America	Contribution from others
Developed Markets in North America	98.80	0.01	0.72	0.47	1.20
Developed Markets in the Pacific	5.37	89.83	0.19	4.62	10.17
Emerging Markets in Asia and Europe	3.44	1.15	93.43	1.98	6.57
Emerging Markets in Latin America	5.48	0.93	0.08	93.51	6.49
Contribution to others	14.28	2.08	0.99	7.07	Total Spillover index = 6.10%
NET	13.09	−8.09	−5.58	0.58	

Source: Author's calculation.

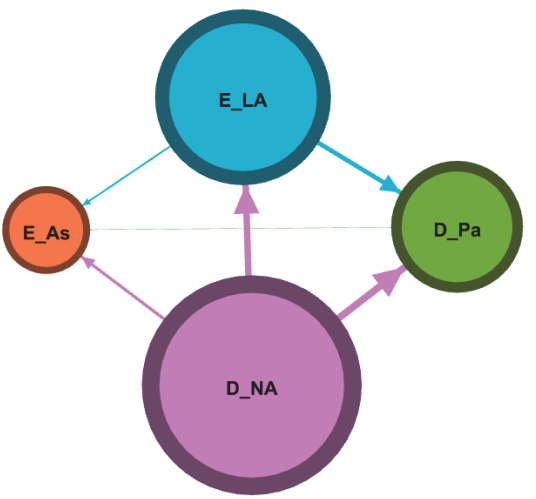
Table 8. Volatility Connectedness Table: MSCI-Classified Stock Market Groups (Post-GFC Period)

	From				
To	Developed Markets in North America	Developed Markets in the Pacific	Emerging Markets in Asia	Emerging Markets in Latin America	Contribution from others
Developed Markets in North America	92.69	4.09	0.45	2.76	7.31
Developed Markets in the Pacific	24.22	68.04	0.12	7.61	31.96
Emerging Markets in Asia and Europe	3.26	3.98	88.84	3.92	11.16
Emerging Markets in Latin America	16.87	0.35	0.63	87.54	12.46
Contribution to others	38.96	8.42	1.21	14.29	Total Spillover index = 15.72%
NET	31.66	−23.53	−9.95	1.83	

Source: Author's calculation.

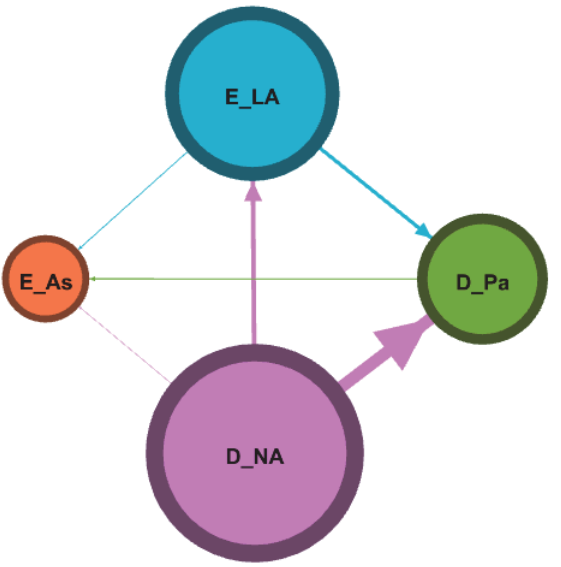
The size of the nodes in Figure 13 implies that the developed group in North America transmits market volatility to other three groups of stock markets. In particular, the developed group in North America transmits intense volatility spillovers to the developed markets in the Pacific and emerging markets in Latin America. For the post-GFC period in Figure 14, the developed group in North America still remains the strongest volatility transmitter to other three groups of markets. However, the spillover intensity from the markets in North America to the emerging markets in Latin America was weakened after the GFC. Overall, the developed group in North America is the most significant volatility transmitter in the Asia-Pacific region.

Figure 13. Network of Volatility Connectedness: MSCI-Classified Groups (Pre-GFC Period)



Source: Author's calculation.

Figure 14. Network of Volatility Connectedness: MSCI-Classified Groups (Post-GFC Period)



Source: Author's calculation.

4.3. Dynamic Volatility Connectedness

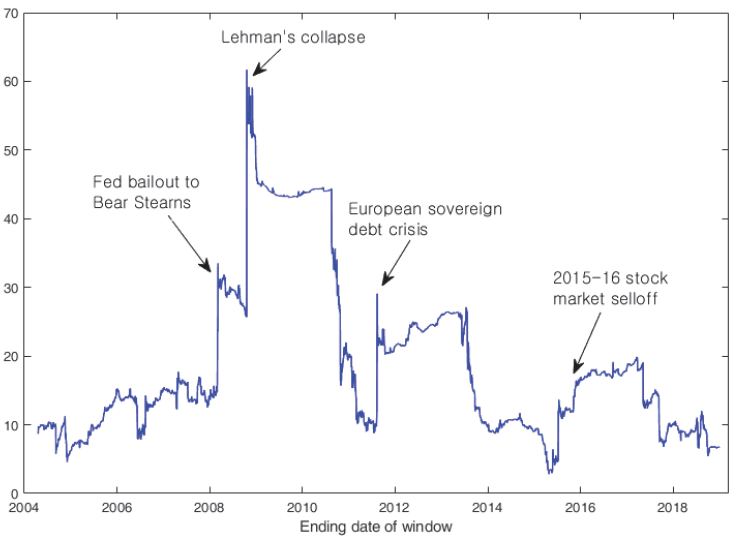
Since various economic events took place during the sample period, the volatility dynamics is not static but dynamic in the sense of time-varying behavior. In view of the results so far, we see that the United States plays a significant role in the Asia-Pacific stock markets. This exhorts us to trace the economic events generating abrupt jumps in volatilities. To this end, we perform rolling-sample analysis using 500-day rolling windows to address the time-varying nature of volatility spillover variation. Figure 15 displays the time-varying total volatility spillovers along with significant economic events. It is uneven on the whole and the GFC is clearly identified in 2008. During the GFC, the connectedness measures peaked with the sizable shock transmission across markets.

Figure 15 displays several abrupt jumps or spikes and we can identify several

important events in the plot. Major economic events generating volatility jumps revalidate the significance of the United States in regard to the GFC. The first event is the Federal Reserve bailout to Bear Stearns. In particular, on March 14, Bear Stearns had to be bailed out by the Fed. as share prices plummeted. The Dow Jones Industrial Average also fell more than 20% from its peak of five months earlier. The Fed. announced the Terms Securities Lending Facility on March 11, 2008, but market participants regarded it as a veiled attempt to bail out Bear Stearns. At that time, Moody's downgraded Bear Stearns' MBS to B and C grades. These events triggered a bank run on Bear Stearns.

Next, in 2008, the total spillovers have jumped to the highest level due to Lehman Brothers collapse, which remains the largest bankruptcy filing in the U.S. history. The bankruptcy recorded one-day drop of 4.5% in the Dow Jones Industrial Average, which was the greatest decline since the 9.11 attack in 2001 and eventually triggered the global financial crisis.

Figure 15. Dynamic Total Volatility Connectedness



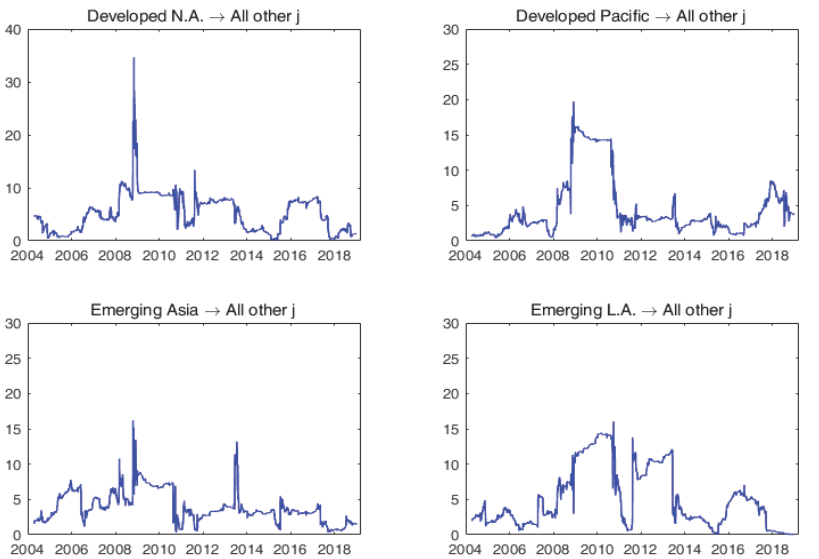
Source: Author's calculation.

The third one is the European debt crisis in 2011. Several Eurozone member states - Greece, Portugal, Ireland, Spain and Cyprus - were unable to repay their government debts or to bail out over-indebted banks without the third parties' emergency assistance. A tripartite committee formed by the European Commission, the European Central Bank and the International Monetary Fund offered Greece a bailout package, worth €130 billion, in October 2011, being conditional on implementation of further austerity measures. Moreover, Standard & Poor's downgraded Greece's sovereign debt rating to a junk grade amid fears of default. Finally, the 2015-16 period was the stock market sell-off occurred between June 2015 to June 2016. Stock market investors sold equities as a result of slowing-down China's economic growth, a fall in oil prices, the Greek debt default in June 2015, the exit plan of the U.S. quantitative easing in 2015, and the Brexit issues in 2016.

The dynamic directional volatility spillover from a group i to all other groups js are illustrated in Figure 16. The plots show that the developed group in North America is a major source of volatility shocks in 2008, and other three groups also maintained as the shock transmitters for a considerable period of time since then. This feature shows that the Asia-Pacific stock markets are vulnerable to financial risk and crisis contagion in the region. In fact, the volatility shock in 2008 was originated in North America but it was not strongly persistent over time. However, each of the other three groups were spreading the crisis shocks to each other. This is where we highlight the necessity of regional financial cooperation for stable financial market environment and sustainable growth in the region.

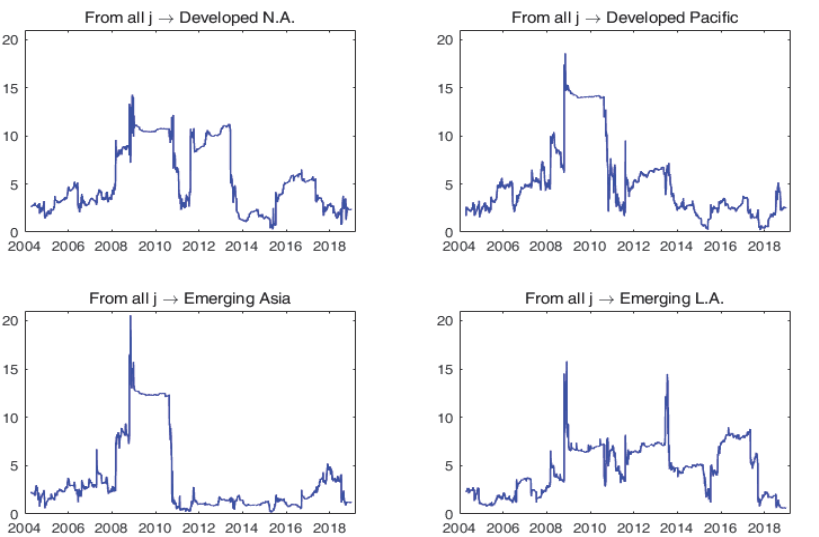
Figure 17 shows that all groups of markets were severely affected in times of the global financial crisis. We also notice the inverse volatility spillover effect from all other markets to the developed markets in North America. This implies the strike-back effect of market risk externalities. That is, although the initial financial crisis shock was triggered by the markets in North America, the subsequent volatilities were transmitted back to them.

Figure 16. Dynamic Directional Volatility Spillovers from i to All Other *j*



Source: Author's calculation.

Figure 17. Dynamic Directional Volatility Spillovers from All Other *j* to *i*



Source: Author's calculation.

V. Concluding Remarks

This study examines the Asia-Pacific stock market connectedness by applying Diebold and Yilmaz (2012) spillover index and network analysis. The empirical findings shed light on the identification of shock transmitters and recipients in the Pacific Rim. Overall, we find that (i) based on the return connectedness measures, global financial hubs - Singapore and Hong Kong - and Australia play an important role as efficient return information transmitters across stock markets, (ii) the United States is an overwhelming volatility transmitter as a net source of shocks during the global financial crisis, and subsequent volatility spillovers spread the crisis shock to each other in the region, (iii) comparing the results between the pre- and post-GFC periods, Canada was a net volatility transmitter before the GFC but has changed to a net volatility receiver after the GFC, and Korea has magnified the role of a net volatility receiver after the GFC, and (iv) in terms of the degree of total spillovers in returns and volatilities at large, stock market connectedness in the Pacific Rim was reinforced after the GFC.

The growing significance of inter- and intra-regional connectedness across the APEC economies validates the significance of APEC-level collective financial cooperation. Financial market connectedness is relevant to the ongoing issues of regional trade issues and financial agendas. The market-driven economic integration and connectedness have deepened in the Asia-Pacific region through international trade. As Chung et al. (2013) pointed out, production network is an important determinant of regional economic integration and the Asia-Pacific is an active region in this regard. In the context of both regional financial connectedness and deepening APEC trade agendas, more detailed commitment of policy cooperation should be made to achieve Bogor Goals and the APEC objectives. The aforementioned connectedness features across the Asia-Pacific stock markets imply the necessity of improving APEC economic cooperation, and thus we exhort the workable plans and a roadmap to achieve higher level of economic connectivity and integration in the region. Accordingly, APEC should conceive specific action plans on the ongoing collective

initiatives.

APEC announced connectivity initiative and regional economic integration in 2008. However, most of the programs focused on the free trade agenda and there has been little progress on the capital markets. After the GFC, the importance of systemic financial crisis stands out and thus we should pay attention to the linkage between the financial and real sectors of the economy. In particular, since APEC has emphasized inclusive and sustainable growth, rather than economic growth itself, financial market stability connotes its significance. Despite APEC's significant performance in the trade-related sectors, there has been little attention on financial cooperation in the Asia-Pacific region. Several financial agendas were discussed but workable action plans have been insufficient so far. For example, Asia Fund Passport and financial infrastructure investment cooperation were suggested, but they were driven by a few countries including Australia. This was because the major APEC member economies were not interested in them.

A recommendation is to invigorate the APEC Financial Forum (APFF). The APFF is an informal, inclusive and advisory public-private platform for collaboration to develop sound and integrated Asia-Pacific financial markets through six work streams.[9] A common agenda across these streams is the promotion of portfolio investment across the region. Aside from foreign direct investment, portfolio investments amongst the APEC economies are yet small in size. The APFF work stream of financial market infrastructure has presented a roadmap on how to develop financial market infrastructure in the region. We should pay attention to beneficial outcomes for both the emerging and developed markets in the Pacific Rim, and accordingly the member economies are building legal and regulatory frameworks to benefit from financial IT development while mitigating various types of risks.

APEC members' efforts have been made to strengthen systemic risk

9 APFF work streams include: insurance and retirement income, lending infrastructure, trade and supply chain finance, financial market infrastructure, cross-border practice, and capital Markets.

management in financial markets since the GFC. Its recent interim report proposes 12 action plans[10] which boil down to two major issues: (i) promoting capital market depth and long-term investments, (ii) expanding financial consumer's access to financial services. Along with these objectives, as an example of policy recommendation, the Know-Your-Customer rules are recently strengthened under the APFF process. Moreover, as the development of Fintech is changing the environment of financial services, the APFF should discuss about the challenges on e-payments and cyber-security problems towards the safe and efficient financial ecosystem.

Another policy recommendation is about strengthening the peer review and information sharing scheme. APEC Individual Action Plans (IAPs) are annual reports that record unilateral steps taken towards the Bogor goals. APEC members report their progress of 15 areas in their respective IAPs, which are subject to peer review. IAPs are aiming to improve the transparency of APEC members' trade and investment regimes, facilitating intra-APEC trade and investment. Even though the IAPs' standardized reporting templates include a Financial Services entry in Chapter 3, the template does not cover cross-border financial investments or capital flows and the like.

In addition, each APEC member is required to submit a full IAP every three to four years and provide an update in intervening years. It generally takes 16 months

10 The action plans are as follows: (1) A pathfinder initiative to develop credit information sharing systems, (2) A pathfinder initiative to improve the legal and institutional architecture for security interest creation, perfection and enforcement and related workshops, (3) Dialogues on regulatory issues in trade and supply chain finance, (4) Workshops on emerging facilitators of trade and supply chain finance, (5) A pathfinder initiative to develop classic repo markets, (6) Workshops to develop strategies to improve legal and documentation infrastructure for the development of OTC derivative market, (7) Self-assessment templates on information for capital market investors, (8) Asian Region Funds Passport support initiative, (9) Workshop series to develop an enabling Asia-Pacific securities investment ecosystem, (10) Dialogue series on regulation and accounting issues impacting the long-term business of the insurance industry in Asia Pacific economies and longevity solutions, (11) Collaboration with APEC Finance Ministers' Process in promoting long-term investment, including infrastructure, (12) Conference and workshop series on linkages on structural issues. (https://www.abaconline.org/v4/download.php?ContentID=226 11 921)

to complete the entire review process. (Hsieh, 2013) However, this procedure makes timely monitoring of financial market and speedy decision making difficult. Consequently, the 'APEC Finance Ministers Meeting' should incorporate more detailed technical reporting requirements along with mutual policy recommendations. Otherwise, a proposal of establishing 'APEC Central Bank Governors' Meeting' or a consultative group is suggested to monitor the Asia-Pacific financial markets and discuss about monetary and financial issues in the region. Though policy coordination and regime setting in financial sector seems to be early at this stage, there is scope for the APEC economies to pursue at least information sharing. These would probably be the most feasible plan for cooperation at present. Given the already strong economic interdependence among the APEC economies, we will benefit from the peer review and information sharing scheme.

The regional economies face several challenges for closer cooperation. The most serious challenge reflects the fact that the regional economies are diverse and heterogeneous in terms of per capita income, stage of economic development, financial market maturity, and institutional capacity. Such diversity and heterogeneity create evident difficulties for attempts to agree on coordinated policies. Poor performance of APEC financial cooperation so far achieved is also attributed to similar diversity and heterogeneity as well as weak governance structure. The heterogeneity yields different market receptivity for a unified collective initiative. Moreover, since many member economies are involved in multiple regional cooperative institutions, some financial agendas could be overlapped and their interests conflict each other. Not all member economies are ready to carry out regionally coordinated policies. It may be difficult for these economies to follow regionally agreed economic policies. If this the case, for a start, APEC is able to start with collective initiatives with several developed and emerging market economies. It might be adequate for regionally coordinated process setting under heterogeneous conditions.

Regional financial cooperation in the Asia-Pacific region is still at the early stage. Institutions and initiatives are not sufficiently developed for significant regional financial integration. Nonetheless, some important steps have been taken, such as

APFF. Based on substantial connectedness of the Asia-Pacific stock markets, APEC economies should carry out feasible and workable action plans and cooperate all together to develop the sustainable Asia-Pacific financial ecosystem.

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Appendix

Table A.1. Sample Stock Market's Indices

	Index	Stock Index Name
United States	S&P500	S&P 500 Index
Canada	TSX	TSX Toronto Stock Exchange 300 Composite Index
Mexico	IPC	Indice de Precios y Cotizaciones
Chile	IPSA	Indice de Precio Selectivo de Acciones
Indonesia	JII	Jakarta Islamic Index
Thailand	SET Index	Thai composite stock market index
Viet Nam	VN Index	Vietnam Index
Singapore	STI	Straits Times Index
Philippines	PSE	The Philippine Stock Exchange, Inc
Malaysia	FBM KLCI	FTSE Bursa Malaysia KLCI
Korea	KOSPI	Korea Composite Stock Price Index
China	SSE Index	Shanghai SE Composite Index
Japan	NIKKEI225	Nikkei Stock Average
Russia	MICEX Index	MOEX Russia Index
Hong Kong	HSI	Hong Kong Hang Seng Index
Taiwan	TAIEX	Taiwan Capitalization Weighted Stock Index
Australia	AOI	All Ordinaries Index (ASX)
New Zealand	NZ50	NZX 50 Index

Source: Thomson Reuters.

국문요약

본 연구는 글로벌 금융위기 전후로 아태지역 주식시장의 수익률과 변동성에 대한 네트워크 연계성을 분석하였다. 실증분석에서는 아태지역의 국가별 연계성 및 MSCI 주식시장 분류에 따른 그룹 특유의 잠재 요인을 추정하여 지역별 선진시장과 신흥시장 간의 연계성을 살펴보았다. 주요 분석 결과로는 (i) 국제금융허브로 기능하고 있는 싱가포르와 홍콩 및 자본시장 개방도가 높은 호주가 효율적인 수익률 정보 전이 시장으로 나타났고, (ii) 글로벌 금융위기 충격의 진원지로서 미국 주식시장이 압도적인 시장 변동성을 유발하는 것으로 나타났으며, (iii) 캐나다는 금융위기 이전에는 변동성 전이의 순유출시장이었으나 위기 이후 순유입시장으로 바뀌었으며, 한국은 금융위기 이후 더욱 강화된 변동성 순유입시장으로 나타났고, (iv) 금융위기 이후로 수익률과 변동성의 총 전이 효과가 커짐에 따라 아태지역 주식시장의 연계성이 더욱 강화된 것으로 나타났다. 이와 같은 결과는 시스템적 위기에 대응하기 위한 APEC 금융협력의 필요성 및 역내 거시금융정책의 잠재적 가능성을 내포하고 있다.

핵심용어: 아시아·태평양 경제협력체(APEC), 주식시장, 모건스탠리 캐피탈 인터내셔널(MSCI), 전이 효과, 네트워크

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