THE RELATIONSHIP BETWEEN STOCK MARKET AND EXCHANGE RATE WITH DYNAMIC VOLATILITY SPILLOVER: EVIDENCE FROM ASIA-PACIFIC REGION

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Abstract

This study investigates the dynamic relationship between the stock market and exchange rates, using daily data from 1994 to 2018. Johansen's cointegration analysis shows significant long-run relationships for Hong Kong. The Granger causality tests show a significant bi-directional and uni-directional causality in the Asia-Pacific region, except for China. Results also show volatility spillovers in the UK, Germany, and the USA, which persistently influence the stock market and exchange rates in the Asia-Pacific region. During crisis, the stock market is better in capturing total volatility spillovers than the exchange rate.

Keywords: Volatility spillover, connectedness, causality, cointegration

INTRODUCTION

The relationship between exchange rates and stock price is applied frequently in finances and economic literature. A healthy relationship implicates a piece of essential information for policy-makers, investors, and practitioners. This relationship research can provide some insightful directions for decision-makers to better comprehend their decisions. For instance, the application of a change of exchange rate presented a flow-oriented model in which changes in the exchange rate can provide guidance of stock price, which could inform decisions on policy frameworks or portfolios per-spectives. From an academic point of view, previous theoretical studies suggest two models for the relation-ship between exchange rates and the stock market. First, Dornbusch and

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Fischer (1980) have a direct effect on a country's international competitiveness in firms, exports, and asset value, all of which refer to the stock market. Second, Branson (1981); and Frankel (1984) suggested a stock-oriented model where changes in stock prices, through the balancing of supply and demand in international and domestic assets, affect the asset values and currency values, thus driving exchange rate.

In these theoretical studies, the relationship analysis is interpreted mostly without concerning volatility spillover. This might have led to a lack of investigation between the linkages in financial markets. To fill this gap in the literature, this study further investigates the connectedness among all Asia-Pacific countries compared with other continents.

LITERATURE REVIEW

In a financial scheme, the co-movement between the exchange rate and the stock price plays a crucial role in analysis during a financial crisis. Lin (2012); and Sui and Sun (2016) found strong effects on both currency and stock markets. Pan, Fok, and Liu (2007) found that in the Asian Crisis from 1997 to 1998, the exchange rates and stock markets of the seven Asian countries studied, had a causal relationship, except for Malaysia. Tsagkanos and Siriopoulos (2013), showed a short-term causal relationship between stock prices and exchange rates in the USA, and long-run effects in the EU during the financial crisis period from 2008 to 2012.

Regarding further events, Granger, Huangb, and Yang (2000) proposed evidence from the Asian flu of 1997 and 1998, looking at stock prices and exchange rates through nine Asian markets. The results showed significant relationships in all markets, except Indonesia and Japan. However, Smyth and Nandha (2003); and Zhao (2010) argued that during the specific period of crisis no relationship is shown between the exchange rate and the stock market. Although, it seems plausible that the investigations of the price or return can capture the interaction between the exchange rate and the stock market, an additional measure of volatility shows more evidence on the interaction. As proposed by Fang (2002), under the Asian crisis, domestic currency depreciation had the effect of decreased stock returns and increased stock market volatility.

Analysis of the connectedness of measurements was implemented to explore the volatility spillover between different variables. One of the methods proposed by Diebold and Yilmaz (2009) described forecast error variance decompositions from vector autoregressions. This method reported evidence between the market price and volatility in global emerging markets.

Moreover, Diebold and Yilmaz (2012) found that during the crisis, volatility showed significant fluctuations in four different financial markets, including the stock market and exchange market. Following on from this, this study aims to investigate a long-run volatility analysis based on the framework of the variance decompositions connectedness. To specify the impact of the shocks during each crisis, emphasis is placed on the use of different frequencies, following the method of Baruník and Krehlík (2018).

This study focused on the relationship between the stock market and the exchange rate, and investigated the relationship by using the Granger causality test, the Johansen cointegration tests, and volatility spillover via the generalized variance decompositions method. The results might be helpful for practitioners, and asset allocation investors to assess the situation regarding financial distress in markets throughout the Asia-Pacific region.

Table 1: Previous studies of the relationships between exchange rate and stock price in Asia.

Relation	Author	Year	Observation	Data Period	Techniques
Flow-oriented	Chiang, Yang, and Wang	2000	Asian-9, U.S.	Daily, 01/01/1990 to 10/02/1998	GARCH(1,1)
	Wu	2000	Singapore, Malaysia, Indonesia, Japan, the U.S.	Weekly, 04/03/1991 to 05/31/2000	Johansen
	Wongbangpo and Sharma	2002	Indonesia, Malaysia, the Philippines, Singapore, Thailand	Monthly, 1985 to 1996	Johansen
	Pan, Fok, and Liu	2007	Hong Kong, Japan, Malaysia, Thailand	Daily, 12/06/1997 to 31/08/1998	Johansen
	Yau and Nieh	2009	Taiwan, Japan	Monthly, 01/1991 to 03/2008	TAR
Stock-oriented	Kwon and Shin	1999	Korea	Monthly, 01/1980 to 12/1992	EG two-step
	Maysami and Koh	2000	Singapore	Monthly, 01/1988 to 01/1995	Johansen
	Ibrahim and Aziz	2003	Malaysia	Monthly, 01/1977 to 08/1998	Johansen
	Tai	2007	India, Korea, Malaysia, the Philippines, Taiwan, Thailand	Monthly, 01/1980 to 03/2001	MGARCH(1,1)-in-Mean
	Tsai	2012	Singapore, Thailand, Malaysia, the Philippines, Korea, Taiwan	Monthly, 01/1992 to 12/2009	Quantile regression
	Chkili and Nguyen	2014	Brazil, Russia, India, China	Weekly, 03/1997 to 02/2013	Markov switching VAR
No relationship	Smyth and Nandha	2003	Bangladesh, India, Pakistan, Sri Lanka	Daily, 02/01/1995 to 23/11/2001	EG two-step, Johansen
	Zhao	2010	China	Monthly, 01/1991 to 06/2009	Johansen

(Table 1 Continued)

Mixed	Granger, Huangb, and Yang	2000	Asian-9	Daily, 03/01/1986 to 16/06/1998	Gregory and Hansen
	Phylaktis and Ravazzolo	2005	Hong Kong, Malaysia, The Philippines, Singapore, Thailand	Monthly, 01/1980 to 12/1998	Johansen
	Bahmani-Oskooee and Saha	2016	Brazil, Canada, Chile, Indonesia, Japan, Korea, Malaysia, Mexico, the U.K	Monthly, 08/1980 to 03/2014	ARDL
	Yang	2017	Hong Kong, Singapore, South Korea, Taiwan	Monthly, 01/1999 to 12/2016	Geweke's linear feedback measures

Notes: All exchange rates are in relation to the U.S. dollar. GARCH (1,1) stands for Generalized Autoregressive Conditional Heteroskedasticity by order of the GARCH terms, when the order of the ARCH terms is 1. The Johansen, EG two-step (Engle-Granger Two-Step Method), of Granger, Gregory and Hansen, is used to test the cointegration between the stock market(s) and the exchange rate(s). The abbreviated models are described as follows; TAR is the Threshold Auto-regressive Regression model, MGARCH (1,1)-in-Mean is the Multivariate Generalized Autoregressive Conditional Heteroskedasticity in the Mean by order of the GARCH terms, and the order of the ARCH terms; Markov switching VAR stands for Markov switching Vector Auto Regressive model, OLS is Ordinary Least Squares, and ARDL is Autoregressive Distributed Lag. These categorize the relation section into four types; flow-oriented, stock-oriented, no relationship, and mixed. In the data period section, the terms daily, weekly, and monthly describe the frequency of data collection. Lastly, the techniques section describes the long-run techniques in each article.

METHODOLOGY

1. Research Question

How do the volatility spillovers of the stock market (the exchange rate) explain the connectedness between the Asia-Pacific region and other continents?

2. Annualized Realized Volatility

The return is calculated first,

$$R_t = ln(P_t) - ln(P_{t-1}), \qquad (1)$$

then,

$$vol_t = \sqrt{\frac{252}{n}\sum_{t=1}^{n}(R_m - R_t)^2}, \qquad (2)$$

where R_m is the mean return, R_t is the return at time t, P_t is the price at time t, and vol_t is annualized realized volatility. Computation occurs by using a rolling window of set n to 252.

3. Unit Root Test

In this study, the Augmented Dickey-Fuller (ADF) test devised by Dickey and Fuller (1981) is employed to test for stationarity in each price and exchange rate of the samples. The drift model of ADF is shown as follows:

$$\Delta P_t = \alpha + \gamma P_{t-1} + \sum_{j=1}^{l} \psi_j \, \Delta P_{t-j} + \varepsilon_t, \quad (3)$$

where P_t is the stock market price (exchange rate) at time t, α is a constant, Δ is the first difference, l is the lag order term of the autoregressive process, ε_t is the error term. Akaike's information criterion (AIC) is applied to avoid a biased estimation of the optimal lag length.

4. Cointegration Test

In the cointegration test, the estimation list consists of canonical correlations, the maximum likelihood in an error correction model, nonlinear least squares, ordinary least square, and the principal component. Gonzalo (1994) found that the maximum likelihood of error correction model, applied in Johansen's approach, provides the best estimator. For this reason, Johansen's method was chosen for analysis in this study. According to Johansen (1988, 1991), a multivariate maximum likelihood cointegration test should be performed following the vector autoregression (VAR) models with ECM:

$$P_t = \Gamma_1 \Delta P_{t-1} + \cdots + \Gamma_{l-1} \Delta P_{t-l+1} + \Pi X_{t-l} + \Psi D_t + \eta_t, \quad (4)$$

where P_t is ($K \times 1$) the vector of the stock market price (exchange rate) at time t, Γ_1,..., Γ_{l-1}, Π are ($K \times K$) matrices of unknown parameters, D_t is a nonstochastic variable, η_t is ($K \times 1$) a vector of the error term that is normally distributed with a mean of zero and constant variance. For this study, the nonstochastic variables, seasonal dummy variables, and a matrix of dummy variables are excluded.

5. Granger Causality Test

The Granger causality test (Granger, 1969) was used to test the causal relationship between the exchange rate and the stock market. The analysis implements the bivariate VAR as follows:

$$P_t = \sum_{i=1}^{l} B_{11} P_{t-i} + \sum_{j=1}^{l} B_{12} X_{t-j} + \epsilon_t \quad (5)$$

$$X_t = \sum_{i=1}^{l} B_{21} P_{t-i} + \sum_{j=1}^{l} B_{22} X_{t-j} + \upsilon_t \quad (6)$$

where P_t is the stock market price at time t, X_t is the exchange rate at time t, l is the lag length, B is the matrix of coefficients, and ϵ_t and υ_t are the error terms of P_t and X_t, respectively.

6. Variance Decompositions Connectedness

According to Koop, Pesaran, and Potter (1996); Pesaran and Shin (1998) introduced the generalized variance decompositions method. Cholesky factorization is used to compute the shocks to each variable orthogonally. Thereby, the variance decompositions remain unchanged in order. Following Koop et al. (1996), the H-step-ahead error variance decompositions are given by:

$$\theta_{ij}(H) = \frac{\sigma_{ii}{}^{-1} \sum_{h=0}^{n} \left(e_i' A_h \Sigma e_j\right)^2}{\sum_{h=0}^{n} \left(e_i' A_h \Sigma A_h' e_i\right)}, \quad (7)$$

where i and j are 1, 2, 3, … , N , with $i \neq j$, Σ denotes the variance matrix for the error vector from the VAR(l) process, A_h denotes a matrix of the coefficients at lag h of the VAR process by following the moving average, σ_{ii} is the standard deviation of the error term, e_j is defined as a vector of unity when it is the i th element and zero otherwise, and $\theta_{ij}(H)$ provides the variance decomposition matrix of spillover. As $\sum_{j=1}^{N} \theta_{ij}(H) \neq 1$, the normalized variance decomposition matrix is calculated by the row sum on each entry as given:

$$\breve{\theta}_{ij}(H) = \frac{\theta_{ij}(H)}{\sum_{j=1}^{N} \theta_{ij}(H)}, \quad (8)$$

where each row is a sum up to 1, $\sum_{j=1}^{N} \breve{\theta}_{ij}(H) = 1$, and the sum of all elements is N, $\sum_{i,j=1}^{N} \breve{\theta}_{ij}(H) = N$ by the normalized construction. The contributions of the total volatility spillover index can be provided by:

$$S_H = \frac{\sum_{j \neq k}^{N} \breve{\theta}_{ij}(H)}{\text{N}} \times 100, \quad (9)$$

where N is denoted by the sum of all elements, or $\sum_{i,j=1}^{N} \breve{\theta}_{ij}(H)$.

RESULTS

1. Data

This study observed the daily price of stock markets and exchange rates as compared to the US dollar. All data were retrieved from December 31, 1993, through December 19, 2018, a total of 6514 days, with the exception of the Ho Chi Minh Stock Exchange and the Jakarta Stock Exchange, for which less data were retrieved. The State Security Commission of Vietnam was founded in HSX in July 2000, thereby data collection started on July 28, 2000, and carried through to December 19, 2018, a total of 4799 days. The Surabaya Stock Exchange merged with the Jakarta Stock Exchange in October 2007, thus data collection started on November 30, 2007, and carried through to December 19, 2018, providing a total of 2883 days.

From the Asia-Pacific region, China (SHCOMP/CNY), Japan (Nikkei225/JPY), Korea (KOSPI/KRW), Hong Kong (HSI/HKD), India (SENSEX/ INR), Taiwan (TWSE/TWD), Australia (AOI/AUD), Pakistan (KSE100/ PKR), Sri Lanka (SL20/LKR), Malaysia (KLCI/MYR), Indonesia (JSX/RP), Singapore (STI/SGD), Thailand (SET/THB), Philippines (PSEi/PHP), Vietnam (HSX/VND), New Zealand (NZX/NZD), and Bangladesh (DSE/BDT) were selected. To analyze the connectedness interactions, the UK (FTSE100/GBP), Germany (DAX/EUR), and the USA (S&P500/USD) were also included.

Regarding volatility spillover analysis, volatility was calculated using equation 2. As a result of the calculation, the total number of data points reduced from 6514 to 6262, as the first 252 data points were preserved as observations for the annualized rolling windows.

Table 2 presents the descriptive statistics of the price of stock markets. The results of skewness show that all markets are relatively symmetrical, except the Karachi Stock Exchange, which is highly skewed at 1.23; the Straits Times Index shows this market to be negatively skewed, similar to the London Stock Exchange. Kurtosis of all stock markets shows negative signs, except for the Karachi Stock Exchange and the Ho Chi Minh Stock Exchange which show positive signs at 0.28 and 0.00 respectively, which is enough to describe the equally distributed variances in all stock markets. In the stock markets, the results of the kurtosis analysis show in the range of -2 to 1, illustrating that the variance in price is equally distributed. The Jarque-Bera and Ljung–Box tests show significant values in all series, demonstrating independence in the distributions, and that all data follow a normal distribution.

Table 3 presents the descriptive statistics of exchange rates. The results of skewness show that all currencies are quite symmetric, except the New Zealand Dollar which is shown to be highly skewed. Kurtosis of all currencies shows a. relatively equal distribution of variances. The Jarque-Bera and Ljung–Box tests give statistically

Table 2: Descriptive statistics of the price of stock markets.

Index	Nobs	Mean	SD	Skewness	Kurtosis	Jarque-Bara	Ljung–Box
SHCOMP	6514	2183.06	1062.07	0.76	0.64	747.26 ***	6501.91 ***
NIKKIE225	6514	14873.33	4219.56	0.05	-1.16	369.25 ***	6496.46 ***
KOSPI	6514	1340.37	611.21	0.14	-1.40	552.60 ***	6506.81 ***
HIS	6514	17233.82	6099.31	0.26	-1.03	364.11 ***	6499.72 ***
SENSEX	6514	12905.51	9912.24	0.70	-0.70	672.06 ***	6505.38 ***
TWSE	6514	7382.05	1672.13	0.06	-0.69	133.69 ***	6490.68 ***
AOI	6514	4081.51	1324.23	0.03	-1.27	435.90 ***	6504.74 ***
KSE100	6514	12747.68	13733.05	1.23	0.28	1668.49 ***	6508.82 ***
SL20	6514	3033.67	2520.60	0.51	-1.44	846.63 ***	6511.08 ***
KLCI	6514	1178.84	418.37	0.16	-1.27	462.50 ***	6508.45 ***
JSX	2883	2264.04	1963.90	0.64	-1.15	797.03 ***	6507.69 ***
STI	6514	2452.55	669.88	-0.14	-1.08	339.86 ***	6503.23 ***
SET	6514	921.75	456.79	0.22	-1.32	527.49 ***	6504.86 ***
PSEI	6514	3650.13	2247.32	0.80	-0.78	868.26 ***	6508.10 ***
HSX	4799	490.58	249.99	0.73	0.00	425.98 ***	4788.64 ***
NZX	6514	915.34	232.43	1.18	0.57	1603.75 ***	6501.85 ***
DSE	6514	2484.53	1885.65	0.56	-1.20	739.10 ***	6506.81 ***
FTSE100	6514	5490.76	1182.59	-0.35	-0.74	276.97 ***	6493.91 ***
DAX	6514	6298.47	2938.63	0.60	-0.41	442.66 ***	6504.32 ***
S&P500	6514	1340.09	551.08	0.81	0.35	748.58 ***	6502.62 ***

Notes: *** indicates significance at the 1% level. The nobs is a number of observations. The Jarque-Bera is the test of normality, and Ljung–Box is the test for serial correlation.

significant results for all currencies.

Table 4 presents the descriptive statistics of the annualized realized volatility of the stock markets. The results of skewness show that most markets are highly skewed to the right, with the exception of the Taiwan Stock Exchange Weighted Index, which is quite small at a minimum of 0.27. The results of kurtosis, the Shanghai Composite Index, Nihon Keizai Shinbun, and Kuala Lumpur Composite Index show excess kurtosis, while the Jarque-Bera and Ljung–Box tests give significant results for all stock markets.

Table 5 presents the descriptive statistics of the annualized realized volatility for the exchange rates. The results of skewness show that most exchange rates are highly skewed to the right, with the exception of the Hong Kong Dollar, and Indian Rupee which show skewness at 0.46 and 0.45, respectively. In kurtosis, Chinese Yuan, Korean Won, New Taiwan Dollar, Australian Dollar, Malaysian Ringgit, Indonesian Rupiah, Thai Baht, New Zealand Dollar and Pound sterling, all show excess kurtosis. Specifically, the Chinese Yuan to the U.S. Dollar shows extremely high values in skewness and kurtosis.

Table 3: Descriptive statistics of the exchange rates.

Currency	nobs	Mean	SD	Skewness	Kurtosis	Jarque-Bara	Ljung–Box
CNY	6514	7.49	0.88	-0.29	-1.65	827.85 ***	6498.52 ***
JPY	6514	107.73	13.73	-0.41	-0.12	183.20 ***	6495.36 ***
KRW	6514	1091.15	165.02	0.04	0.79	171.62 ***	6479.12 ***
HKD	6514	7.77	0.03	0.56	-0.33	367.26 ***	6462.52 ***
INR	6514	48.19	10.42	0.52	-0.53	367.32 ***	6504.78 ***
TWD	6514	31.18	2.35	-0.48	-0.52	320.30 ***	6501.88 ***
AUD	6514	1.35	0.25	0.62	0.11	425.59 ***	6500.61 ***
PKR	6514	70.46	25.54	0.27	-0.97	334.60 ***	6503.70 ***
LKR	6514	102.14	31.46	-0.04	-0.79	169.15 ***	6504.57 ***
MYR	6514	3.52	0.58	0.18	0.67	157.93 ***	6493.93 ***
RP	6514	8996.08	3396.65	-0.71	-0.01	543.76 ***	6498.51 ***
SGD	6514	1.50	0.18	0.24	-1.23	471.45 ***	6504.10 ***
THB	6514	34.72	5.69	0.06	-0.46	62.60 ***	6503.07 ***
PHP	6514	44.12	8.83	-0.88	-0.06	845.93 ***	6505.94 ***
VDN	6514	16895.37	3854.98	0.09	-1.20	401.47 ***	6508.10 ***
NZD	6514	1.57	0.32	1.19	0.75	1687.80 ***	6501.90 ***
BDT	6514	63.42	14.04	-0.29	-1.20	480.57 ***	6507.91 ***
GBP	6514	0.63	0.07	0.25	0.27	87.89 ***	6490.10 ***
EUR	6514	0.84	0.12	0.92	0.47	987.97 ***	6501.80 ***

Notes: *** indicates significance at the 1% level.

Table 4: Descriptive statistics of the annualized realized volatility of stock markets.

Index	nobs	Mean	SD	Skewness	Kurtosis	Jarque-Bara	Ljung–Box test
SHCOMP	6262	0.26	0.13	1.77	4.18	7843.37 ***	6245.02 ***
Nikkie225	6262	0.22	0.06	1.68	4.43	8077.46 ***	6257.10 ***
KOSPI	6262	0.23	0.12	0.84	-0.32	767.36 ***	6259.85 ***
HIS	6262	0.23	0.10	1.30	0.94	1989.96 ***	6259.40 ***
SENSEX	6262	0.22	0.08	0.86	0.60	868.41 ***	6258.01 ***
TWSE	6262	0.21	0.07	0.27	-0.85	262.88 ***	6258.74 ***
AOI	6262	0.14	0.05	1.77	3.94	7339.15 ***	6259.48 ***
KSE100	6262	0.22	0.08	0.94	0.81	1090.36 ***	6258.69 ***
SL20	6262	0.15	0.07	1.16	1.28	1828.93 ***	6254.45 ***
KLCI	6262	0.16	0.12	2.37	5.59	14010.60 ***	6258.66 ***
JSX	2883	0.21	0.09	1.29	1.31	2192.38 ***	6258.36 ***
STI	6262	0.17	0.08	1.05	0.34	1175.79 ***	6259.96 ***
SET	6262	0.22	0.09	0.78	0.14	648.30 ***	6257.45 ***
PSEi	6262	0.20	0.07	1.13	0.61	1442.46 ***	6256.07 ***
HSX	4547	0.22	0.09	0.69	-0.42	398.25 ***	4545.54 ***
NZX	6262	0.11	0.04	1.32	0.84	2008.96 ***	6254.62 ***
DSE	6262	0.22	0.12	0.81	-0.25	703.30 ***	6249.00 ***
FTSE100	6262	0.16	0.07	1.28	1.84	2600.47 ***	6259.76 ***
DAX	6262	0.21	0.08	0.98	0.37	1043.89 ***	6259.28 ***
S&P500	6262	0.16	0.07	1.74	3.99	7332.45 ***	6259.48 ***

Notes: *** indicates significance at the 1% level.

Table 5: Descriptive statistics of the annualized realized volatility of exchange rates.

Currency	nobs	Mean	SD	Skewness	Kurtosis	Jarque-Bara	Ljung–Box
CNY	6262	0.01	0.01	9.43	241.95	15376486.10 ***	4890.24 ***
JPY	6262	0.10	0.03	1.04	1.03	1414.65 ***	6254.63 ***
KRW	6262	0.10	0.09	2.91	8.16	26194.65 ***	6258.03 ***
HKD	6262	0.00	0.00	0.46	-0.67	340.94 ***	6249.53 ***
INR	6262	0.05	0.03	0.45	-0.68	330.16 ***	6256.57 ***
TWD	6262	0.04	0.01	1.65	4.11	7245.23 ***	6251.45 ***
AUD	6262	0.12	0.04	2.57	7.87	23088.11 ***	6257.65 ***
PKR	6262	0.04	0.03	0.63	-1.04	698.65 ***	6227.90 ***
LKR	6262	0.03	0.02	1.52	2.45	3986.49 ***	6251.76 ***
MYR	6262	0.07	0.09	2.56	6.80	18933.75 ***	6249.76 ***
RP	6262	0.13	0.16	3.13	9.83	35451.19 ***	6260.04 ***
SGD	6262	0.07	0.02	1.72	3.56	6409.85 ***	6257.94 ***
THB	6262	0.06	0.05	2.70	7.29	21485.70 ***	6257.14 ***
PHP	6262	0.07	0.05	2.00	3.93	8217.69 ***	6249.64 ***
VDN	6262	0.03	0.03	1.08	-0.32	1241.98 ***	6245.99 ***
NZD	6262	0.13	0.04	1.57	4.20	7177.45 ***	6256.21 ***
BDT	6262	0.03	0.02	1.31	1.74	2592.13 ***	6245.45 ***
GBP	6262	0.09	0.03	1.99	4.20	8750.92 ***	6256.75 ***
EUR	6262	0.09	0.02	0.79	1.50	1239.17 ***	6256.64 ***

Notes: *** indicates significance at the 1% level.

2. Results

The test statistics of the ADF test, shown in Table 6 indicate that non-stationarity shows in the levels or $I(0)$ processes for all series, but there is stationarity in the first differences or $I(1)$ processes. As a result, cointegration tests were enabled to test for long-run relationships between the exchange rate and the stock market.

The results of the cointegration test provided by Johansen's trace tests and the maximum eigenvalue test, are reported in Table 7. Only Hong Kong showed significant results in the rank of matrix $r > 1$. Thus, the existence of cointegration relationships between the exchange rate and the stock market was identified.

As shown in Table 8, almost all countries showed significant results for uni-directional and bi-directional causality, with the exception of China, which showed no interference between the exchange rate and the stock market.

Tables 9 and 10 show the volatility spillovers of the 10-day-ahead forecast, produced by following the generalized variance decompositions method. The results separately describe the spillover index of stock markets and exchange rates based on vector autoregressions of order two, and generalized variance decompositions of 10-day-ahead volatility forecast errors. The total spillover index, as derived from equation 9, was performed on stock markets generating a value of 23.81%, which is relatively higher than that of the exchange rates which achieve a value of 8.29%.

On the one hand, the total for the "direction from the other indices" in Table 9 shows that the less active markets have relatively low performance, for example the Karachi Stock Exchange 100 Index, Sri Lanka 20 index, Ho Chi Minh Stock Exchange, and Dhaka Stock Exchange. Analogously, the "direction from the other exchanges" in Table 10 shows a similar result. On the other hand, the "direction to the other indices" in Table 9 performs relatively highly on the active market, for example, Nihon Keizai Shinbun, Korea Composite Stock Price Index, and Hang Seng Index. However, the "direction to the other exchange" in Table 10 shows independent high values for the Japanese Yen and Australian Dollar. By focusing on the Australian Dollar and New Zealand Dollar, a strong linkage was found between these currencies.

Table 6: The test statistic of the price of stock markets and the exchange rates.

Country	Test statistic			
	Index I(0)	*Index* I(1)	*Exchange Rate* I(0)	*Exchange Rate* I(1)
China	-1.79	-45.04 ***	-2.16	-218.16 ***
Japan	-1.62	-59.03 ***	-2.18	-47.40 ***
Korea	-0.97	-56.68 ***	-3.31	-54.05 ***
Hong Kong	-1.49	-57.99 ***	-3.10	-59.71 ***
India	0.82	-55.17 ***	-0.07	-57.10 ***

(Table 6 Continued)

Country	*Test statistic*			
	Index I(0)	*Index* I(1)	*Exchange Rate* I(0)	*Exchange Rate* I(1)
Taiwan	-2.23	-44.60 ***	-2.18	-54.24 ***
Australia	-1.34	-48.32 ***	-1.65	-50.05 ***
Pakistan	0.48	-43.75 ***	2.44	-56.97 ***
Sri Lanka	-0.21	-41.56 ***	1.92	-42.64 ***
Malaysia	-0.88	-53.77 ***	-2.31	-54.20 ***
Indonesia	0.54	-49.53 ***	-1.87	-46.49 ***
Singapore	-1.54	-56.13 ***	-1.20	-51.21 ***
Thailand	-1.34	-54.63 ***	-1.95	-47.07 ***
Philippines	-0.03	-47.02 ***	-1.60	-57.19 ***
Vietnam	-1.24	-36.10 ***	0.19	-50.29 ***
New Zealand	-0.24	-37.90 ***	-1.62	-49.54 ***
Bangladesh	-1.41	-20.25 ***	-0.95	-62.60 ***

Notes: *, **, *** indicates significance at the 10%, 5%, and 1% levels which the test statistic are -3.43, -2.86, and -2.57, respectively. The null hypothesis of the ADF test is that the series is non-stationary or a unit root ($\gamma = 0$) and against the alternative that stationary ($\gamma \neq 0$). All the lag lengths are all set at order 2.

Table 7: Johansen cointegration test between the exchange rate and price of the stock market.

Country	λ_{max}		λ_{trace}	
	r ≤ 1	r=0	r ≤ 1	r=0
China	5.68	61.56 ***	5.68	67.24 ***
Japan	3.44	5.62	3.44	9.06
Korea	8.12	25.08 ***	8.12	33.19 ***
Hong Kong	13.16 **	22.29 **	13.16 **	35.44 ***
India	4.08	7.31	4.08	11.40
Taiwan	5.35	10.56	5.35	15.91
Australia	2.99	6.98	2.99	9.97
Pakistan	3.04	8.31	3.04	11.35
Sri Lanka	0.97	9.50	0.97	10.47
Malaysia	7.33	15.81	7.33	23.14 *
Indonesia	6.88	12.00	6.88	18.89
Singapore	3.11	14.58	3.11	17.69
Thailand	10.45	16.00	10.45	26.46 **
Philippines	2.62	9.96	2.62	12.58
Vietnam	2.30	7.84	2.30	10.14
New Zealand	2.29	6.43	2.29	8.72
Bangladesh	5.18	14.05	5.18	19.23

Notes: *, ** and *** indicate significance at the 10%, 5% and 1% levels for which the maximum eigenvalue statistics of r ≤ 1 are 10.49, 12.25, and 16.26 respectively, and for r < 0, 16.85, 18.96, and 23.65 respectively; the trace statistics of r ≤ 1 are 10.49, 12.25, and 16.26 while those for r < 0 are 22.76, 25.32, and 30.45. The null hypothesis of the trace tests is that there are at most r cointegrating relations and is against the alternative of p cointegrating relations. The null hypothesis of the maximum eigenvalue test is that there are r cointegrating relations and is against the alternative of r+1 cointegrating relations. The lag lengths are all set at order 2.

Table 8: Granger-causality tests between the exchange rate and price of the stock market.

Country	Stock Market ⟹ Exchange Rate	p-value	Exchange Rate ⟹ Stock Market	p-value
China	0.5228	0.5929	0.4889	0.6133
Japan	2.5843	0.0755**	73.3799	0.0000***
Korea	9.6836	0.0001***	8.3652	0.0002***
Hong Kong	6.8950	0.0010***	11.9623	0.0000***
India	2.4921	0.0828**	1.0930	0.3352
Taiwan	1.8486	0.1575	15.3778	0.0000***
Australia	2.2993	0.1004*	22.2997	0.0000***
Pakistan	6.6573	0.0013***	1.4130	0.2435
Sri Lanka	2.4542	0.0860**	0.9620	0.3821
Malaysia	4.4447	0.0118**	9.1787	0.0001***
Indonesia	0.5629	0.5696	2.9692	0.0514*
Singapore	9.1653	0.0001***	17.0098	0.0000***
Thailand	3.6878	0.0251**	1.8035	0.1648
Philippines	0.0310	0.9695	34.7607	0.0000***
Vietnam	4.4410	0.0121**	0.1008	0.9041
New Zealand	2.0262	0.0199**	7.9982	0.0003***
Bangladesh	1.9670	0.7867	3.4492	0.0318**

Notes: *, ** and *** indicate significance at the 10%, 5% and 1% levels respectively. The null hypothesis of Granger causality using an *F*-test is that the exchange rate (stock market) does not Granger-cause the stock market (exchange rate) and is against the alternative that the exchange rate (stock market) does Granger-cause the stock market (exchange rate). All lag lengths are set at 2.

Table 9: Spillover index of the stock markets

From → To ↓	SHCOMP	Nikkie225	KOSPI	HSI	SENSEX	TWSE	AOI	KSE100	SL20	KLCI	JSX	STIx	SET	PSEi	HSX	NZX	DSE	FTSE100	DAX	S&P500	From Others
SHCOMP	99.16	0.00	0.01	0.02	0.16	0.00	0.00	0.00	0.01	0.02	0.00	0.07	0.00	0.00	0.18	0.02	0.01	0.14	0.01	0.18	0.84
Nikkie225	0.46	82.57	0.10	0.59	0.51	0.01	0.01	0.07	0.43	0.01	0.01	0.06	0.38	0.35	0.07	0.51	0.05	6.96	0.60	6.23	17.43
KOSPI	0.39	9.65	75.72	0.60	0.38	0.14	0.46	0.10	0.54	0.05	0.19	0.03	0.32	0.21	0.00	0.72	0.06	6.86	0.08	3.50	24.28
HSI	1.70	5.54	9.98	62.96	0.56	0.00	0.99	0.02	0.09	0.07	0.19	0.10	1.20	1.32	0.04	3.80	0.00	4.06	0.43	6.94	37.04
SENSEX	0.55	4.00	4.50	0.88	88.14	0.05	0.34	0.01	0.20	0.00	0.08	0.09	0.02	0.23	0.02	0.06	0.01	0.26	0.03	0.56	11.86
TWSE	1.23	4.15	7.96	3.11	0.90	75.58	0.06	0.18	0.16	0.02	0.03	0.05	0.06	0.25	0.08	0.14	0.02	3.05	0.02	2.96	24.42
AOI	1.46	8.97	4.22	11.28	1.42	0.77	47.66	0.02	0.02	0.05	0.18	0.04	0.38	0.21	0.08	1.40	0.01	10.67	0.87	10.29	52.34
KSE100	0.04	0.16	0.95	0.52	0.55	0.01	0.17	96.95	0.01	0.04	0.01	0.01	0.03	0.04	0.02	0.06	0.00	0.02	0.01	0.41	3.05
SL20	0.03	0.38	0.01	0.25	0.56	0.44	0.01	0.01	97.56	0.02	0.01	0.01	0.03	0.15	0.02	0.03	0.01	0.03	0.00	0.44	2.44
KLCI	0.02	1.09	0.63	5.33	0.21	0.66	0.05	0.11	0.00	88.59	0.36	1.41	0.18	0.33	0.03	0.09	0.01	0.13	0.19	0.56	11.41

(Table 9 Continued)

From → To ↓	SHCOMP	Nikkie225	KOSPI	HSI	SENSEX	TWSE	AOI	KSE100	SL20	KLCI	JSX	STIx	SET	PSEi	HSX	NZX	DSE	FTSE100	DAX	S&P500	From Others
JSX	0.40	2.34	6.03	9.08	3.87	0.55	0.57	0.02	0.07	0.93	69.65	0.02	0.68	1.11	0.03	0.07	0.00	2.11	0.25	2.21	30.35
STIx	0.70	6.47	12.06	14.98	2.70	0.46	1.00	0.17	0.14	0.83	4.92	46.56	0.74	1.51	0.09	0.04	0.01	2.73	0.03	3.87	53.44
SET	0.47	3.44	4.16	1.27	2.23	0.01	0.01	0.04	0.01	1.37	2.17	1.73	82.26	0.04	0.00	0.01	0.01	0.19	0.00	0.57	17.74
PSEi	0.17	3.39	2.41	3.29	1.10	0.05	0.03	0.04	0.03	0.20	3.11	2.25	2.79	77.51	0.02	0.02	0.00	1.57	0.16	1.86	22.49
HSX	0.11	0.08	0.02	0.07	0.24	0.07	0.04	0.03	0.01	0.03	0.03	0.02	0.03	0.09	98.84	0.01	0.01	0.03	0.00	0.25	1.16
NZX	0.38	0.91	2.55	14.65	0.02	0.15	11.09	0.53	0.01	0.00	0.11	0.01	0.19	0.20	0.00	56.00	0.00	3.28	0.83	9.08	44.00
DSE	0.01	0.01	0.01	0.00	0.14	0.01	0.01	0.28	0.04	0.00	0.04	0.00	0.01	0.03	0.00	0.01	99.32	0.03	0.01	0.04	0.68
FTSE100	0.83	6.15	1.79	1.30	1.49	0.24	1.55	0.04	0.09	0.37	0.40	0.47	0.86	0.13	0.25	0.03	0.02	80.24	0.16	3.60	19.76
DAX	0.77	6.01	2.08	6.34	1.07	0.15	2.16	0.02	0.03	0.58	0.08	0.09	0.81	0.14	0.19	1.10	0.00	40.56	34.54	3.27	65.46
S&P500	0.80	3.32	1.46	2.22	0.51	0.29	0.70	0.03	0.12	0.50	0.07	0.14	1.27	0.26	0.06	0.26	0.01	20.61	3.45	63.94	36.06
To Others	10.53	66.04	60.94	75.79	18.61	4.06	19.25	1.73	2.00	5.10	11.97	6.60	9.98	6.60	1.18	8.36	0.24	103.29	7.12	56.83	476.25
Total	109.69	148.61	136.66	138.75	106.75	79.65	66.91	98.68	99.56	93.69	81.62	53.16	92.25	84.11	100.02	64.36	99.56	183.54	41.66	120.77	**23.81 %**

Spillover Index

Notes: The results are implemented from vector autoregressions of order two and generalized variance decompositions of 10-day-ahead volatility forecast errors.

Table 10: Spillover index of the exchange rates.

From → To ↓	CNY	JPY	KRW	HKD	INR	TWD	AUD	PKR	LKR	MYR	RP	SGD	THB	PHP	VND	NZD	BDT	GBP	EUR	From Others
CNY	95.43	0.05	0.23	0.02	0.07	0.00	0.21	0.87	0.20	0.16	1.00	0.64	0.06	0.35	0.37	0.08	0.08	0.13	0.05	4.57
JPY	0.21	99.28	0.07	0.00	0.01	0.03	0.08	0.02	0.02	0.03	0.01	0.03	0.00	0.00	0.06	0.01	0.11	0.02	0.01	0.72
KRW	0.26	0.25	95.19	0.01	0.01	1.62	0.94	0.17	0.01	0.03	0.44	0.20	0.26	0.01	0.19	0.02	0.29	0.04	0.06	4.81
HKD	0.13	0.43	0.10	99.04	0.00	0.08	0.03	0.01	0.01	0.01	0.04	0.01	0.02	0.02	0.02	0.03	0.00	0.02	0.01	0.96
INR	0.19	1.42	0.16	0.33	96.89	0.01	0.03	0.13	0.01	0.05	0.31	0.21	0.01	0.00	0.05	0.07	0.01	0.09	0.03	3.11
TWD	0.00	0.47	0.20	0.02	0.19	98.06	0.02	0.04	0.01	0.01	0.05	0.49	0.10	0.05	0.00	0.03	0.07	0.00	0.17	1.94
AUD	0.05	14.82	1.01	0.16	0.34	0.04	83.16	0.10	0.01	0.13	0.01	0.03	0.01	0.00	0.01	0.04	0.00	0.05	0.03	16.84
PKR	0.12	0.00	0.01	0.01	0.34	0.00	0.05	99.27	0.00	0.02	0.00	0.00	0.00	0.09	0.00	0.01	0.00	0.02	0.04	0.73
LKR	0.07	0.11	0.14	0.02	0.66	0.10	0.02	0.02	98.49	0.01	0.00	0.00	0.01	0.04	0.00	0.05	0.08	0.13	0.05	1.51
MYR	0.00	0.01	0.09	0.00	0.00	0.11	0.02	0.01	0.00	99.38	0.02	0.08	0.00	0.19	0.01	0.04	0.00	0.03	0.00	0.62
RP	0.79	0.39	0.74	0.15	0.03	0.77	0.53	0.02	0.02	0.65	94.66	0.48	0.23	0.17	0.15	0.04	0.05	0.11	0.05	5.34
SGD	0.08	7.65	0.15	0.09	0.50	1.21	1.28	0.03	0.05	0.10	2.62	85.93	0.06	0.04	0.00	0.00	0.16	0.02	0.02	14.07
THB	0.22	0.40	0.19	0.01	0.01	0.04	0.03	0.01	0.00	0.32	0.30	1.60	96.80	0.01	0.00	0.02	0.01	0.02	0.02	3.20
PHP	0.02	0.02	0.03	0.00	0.00	0.01	0.00	0.03	0.02	0.01	0.06	0.36	0.57	98.74	0.01	0.01	0.01	0.00	0.08	1.26
VND	0.00	0.00	0.14	0.01	0.10	0.01	0.01	0.05	0.00	0.02	0.01	0.00	0.06	0.03	99.49	0.04	0.01	0.00	0.02	0.51

(Table 10 Continued)

From → To ↓	CNY	JPY	KRW	HKD	INR	TWD	AUD	PKR	LKR	MYR	RP	SGD	THB	PHP	VND	NZD	BDT	GBP	EUR	From Others
NZD	0.43	17.69	0.59	0.03	0.91	0.03	37.84	0.02	0.01	0.05	0.01	0.74	0.01	0.06	0.06	41.48	0.02	0.02	0.01	58.52
BDT	0.04	0.00	0.02	0.02	0.06	0.62	0.00	0.00	0.01	0.00	0.06	0.04	0.02	0.00	0.00	0.06	99.04	0.00	0.01	0.96
GBP	0.47	7.32	0.03	0.01	0.14	0.22	1.31	0.03	0.03	0.00	0.03	0.01	0.02	0.00	0.00	0.87	0.11	89.29	0.10	10.71
EUR	0.11	12.87	0.07	0.08	0.12	0.10	2.72	0.08	0.13	0.00	0.08	1.36	0.06	0.16	0.03	2.09	0.05	7.04	72.83	27.17
To Others	3.19	63.91	3.97	0.98	3.51	5.01	45.11	1.63	0.54	1.59	5.06	6.28	1.49	1.23	0.98	3.51	1.07	7.75	0.75	157.55
Total	98.62	163.19	99.16	100.02	100.39	103.07	128.27	100.91	99.03	100.97	99.72	92.22	98.29	99.97	100.46	44.99	100.11	97.04	73.58	**8.29 %**

Total Spillover

*Note*s: The results are implemented from vector autoregressions of order two and generalized variance decompositions of 10-day-ahead volatility forecast errors.

DISCUSSION

From the results of the Johansen cointegration test, with a linear trend, it was found that the only significant result comes from the Hong Kong pair. The test results show that the eigenvalues of cointegration between index, exchange rate, and the trend are 0.0034, 0.0020, and 0.0000, respectively. The eigenvector of the Hang Seng Index was selected as it presented the highest eigenvalue. Following this, the linear combination equation of the Hong Kong Dollar, Hang Seng Index, and the trend from the best-selected eigenvector allowed formation of a stationary series,

$$s = 1.0000 \times in - 99806.5850 \times ex - 2.2879,$$

where s is a stationary series, in is the Hang Seng Index series, ex is the Hong Kong Dollar series, and the value –2.2879 is the trend component. To assure the stationary series, the Hang Seng Index and the Hong Kong Dollar series were applied into the stationary series equation above and tested via a unit root test. The ADF test of stationary series s was -3.8282 at a p-value of 0.0175. As a result, the linear combination equation above is stationary. Consequently, the stationary series equation with the trend describes that the Hang Seng Index and the Hong Kong Dollar interact with the negative impact between each other. For instance, to form the stationary series s at 0 without the trend component; a change of 1 unit in the Hong Kong Dollar needs negative 99806.5850 units to compensate the Hang Seng Index.

Regarding causality, there is no Granger-cause of the Chinese Yuan to

U.S. Dollar exchange rate on the Shanghai Composite Index; this might be due to the SHCOMP analysis - a share, which is a restriction of foreign trade on stock markets. As a result, the Chinese Yuan would not greatly affect the Shanghai Composite Index.

The uni-directional relationship of Vietnam and Indonesia should be interpreted differently because of the change in trading systems. Thus, analysis began from July 2000 and November 2007, respectively. To illustrate a uni-directional relationship, the Philippines was selected as an example.

The VAR selection of Akaike Information Criteria (AIC), Hannan-Quinn Criteria (HQ), Schwarz Criterion (SC) and Forecast Prediction Error (FPE) was selected to determine the optimal lag length. On the one hand, the Philippine Peso shows the optimal lag numbers of AIC, HQ, and FPE at l = 10, and SC at l = 5. On the other hand, the Philippine Stock Exchange Composite Index shows the optimal lag numbers of both AIC and FPE at l = 10, and both HQ and SC at l = 2. Therefore, the optimal lag length of the Philippine Stock Exchange Composite Index was chosen as it provides the lowest value of l = 2. By conducting the estimation of VAR, the lag value of 2 was applied for a restricted model:

$$Y_t = 6.09 \times 10^6 \cdot in_{t-1} + 1.0712 \cdot ex_{t-1} \\ -5.45 \times 10^6 \cdot in_{t-2} - 7.12 \times 10^2 \cdot ex_{t-2},$$

where in is the Philippine Stock Exchange Composite Index, and ex is the Philippine Peso. After testing, the result showed an F-Test value of 33.73, with a p-value at 2.442×10^{-15}. This means that the addition of the past values of Philippine Peso (ex_{t-1} , ex_{t-2}) influence change in the prediction of the Philippine Stock Exchange Composite Index (Y_t).

Since the relationships from the Granger-causality tests were found, to ascertain the dynamic change across the countries, the spillover from variance decomposition was applied. Diebold and Yilmaz (2012) have shown that return spillovers show no bursts but are slightly increased in the trend, while volatility spillovers show the other way around. From this point, volatility spillovers can provide useful associated effects when crisis events occurr.

To explain the volatility spillovers among the Asia-Pacific region, the analysis of the exchange rates and the stock markets were separated individually. Moreover, contagions from different sources were also investigated by including the UK, Germany, and the U.S. to access the impact of a dynamic volatility spillover between the Asia-Pacific region and other continents. From Table 9, the Deutscher Aktienindex has the highest influence among other stock markets at 65.46 from the total spillovers index of 23.81%. Table 10 shows the New Zealand Dollar as having the highest influence among other exchange rates at 58.52 from the total spillovers index of 8.29%. However, the results shown in Tables 9 and 10 are implemented from a single period of data. Thus, results can provide only a static result. This leads to a lag of information during the time series period. Therefore, the total volatility indexes using rolling windows of 252 days with a 10-day-ahead forecast were used to overcome this problem.

The rolling window analysis of Figure 1 (above) shows the dynamic total spillovers of the Asia-Pacific region. The dynamic total spillover plot shows a relatively high vaue at approximately 60% during economic crisis periods, e.g., the Asian financial crisis (from 1997 to 1998), the dot-com bubble (from 2003), financial crisis (from 2007 to 2008) and the European sovereign debt crisis (from 2010). Figure 1 (below) shows the dynamic total spillovers of the stock market over the Asia-Pacific region including the UK, Germany, and the U.S. The results show a similar pattern from the above figure but are slightly better at capturing the dynamic total spillovers. This means that the stock market of the Asia-Pacific region has close connectedness to Europe and the U.S. In Figure 2, the dynamic total spillovers of the exchange rate show lower overall values than the stock market and that it is quite difficult to react during crisis periods. However, the dynamic total spillovers of the Asia-Pacific region including the UK, Germany, and the U.S., show a higher amount than the Asia-Pacific region alone.

Consequently, first, during the economic crisis, the dynamic total volatility spillover of the stock market is better to react compared to the exchange rate. Second, the dynamic total volatility spillovers of both the stock market and exchange rate are increasing when the UK, Germany, and the U.S. are included in the samples. The findings from this evidence are that the better results of capturing the dynamic total volatility spillovers can explain the close connectedness of the Asia-Pacific region and other continents.

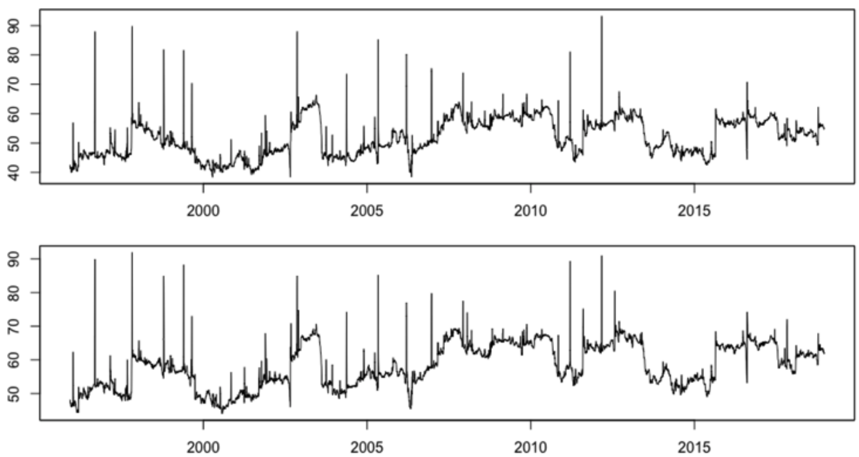

Figure 1: The comparison of the dynamic total spillovers of stock markets between the Asia-Pacific and other continents (the UK, Germany, and the US).

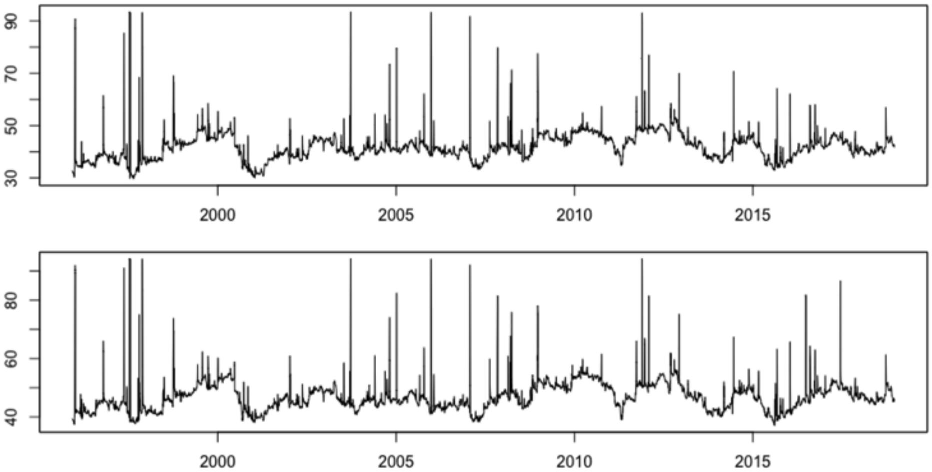

Figure 2: The comparison of the dynamic total spillovers of exchange rates between the Asia-Pacific and other continents (the UK, Germany, and the US).

CONCLUSION

In this study, the stock markets and exchange rates of the Asia-Pacific region were investigated and analyzed over a long-term period from 1994 to 2018. The cointegration analysis shows cointegration only in Hong Kong. Besides this, Granger causality tests showed significant bi-directional and uni-directional causality in all countries, except China. According to the previous theoretical studies, a flow-oriented model was found in Taiwan, Indonesia, the Philippines, and Bangladesh, while a stock-oriented model was found in India, Pakistan, Sri Lanka, Thailand, and Vietnam. In particular, the results of both the stock market and the exchange rate show better results in capturing the dynamic total volatility spillovers when the UK, Germany, and the U.S. are included in the samples. Hence, the results explain the close connectedness between the Asia-Pacific region and other continents. During crisis, moreover, the stock market is better in capturing the dynamic total volatility spillovers than the exchange rate. For future research, a multivariate volatility model can provide further improvement, making an allowance for forecast volatility.

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