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# "Volatility Transmission between the stock and Currency Markets in Emerging Asia: the Impact of the Global Financial Crisis"

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## *Abstract*

This paper examines volatility spillovers between the stock and currency markets of ten Asian economies in the period 2003 to 2014. To carry out this analysis, a multivariate asymmetric GARCH model is used. In general, our results present evidence of bidirectional volatility spillovers between both markets, independently of the individual country's level of development. Additionally, our findings show that the global financial crisis has had mixed effects on the volatility transmission patterns. Overall, our results suggest that exchange rate policies and investment decisions should not be implemented without first taking into consideration the links between the stock and currency markets.

***JEL classification:*** C32, G01, G15

***Keywords:*** Volatility Spillovers, GARCH, International financial markets, Exchange rates

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## 1. Introduction

A causal link is expected, in theory, between stock prices and exchange rate movements. However, there is little consensus on the nature, or even the direction, of this connection. According to the portfolio balance model (see Branson and Henderson, 1985, and Frankel, 1983, among others] a negative correlation exists because, at the macro level, as stock prices fall, domestic wealth also falls, leading to a reduction in domestic money demand that causes interest rates to drop. With investment in the domestic market no longer being attractive, capital outflows to foreign markets and the domestic currency depreciates (leading to a rise in the exchange rate). From the perspective of foreign investors with internationally diversified portfolios, when domestic stock prices fall, they are likely to revise their portfolio asset allocation. The resulting decline in demand for local assets brings about a similar fall in demand for domestic currency as investors seek foreign currency to buy international assets, which leads to a depreciation of the national currency.

In the opposite direction, the influence of the currency market on the stock market should a priori depend on the country's exposure to the exchange risk, that is, whether the country is a net exporter or importer (see Dornbusch and Fischer, 1980). If we assume that changes in the exchange rate affect a country's international competitiveness and trade balance, then if that country is chiefly an exporter, when the domestic currency depreciates its firms will become more competitive as their exports are cheaper. As a result, domestic firms increase their profit levels causing domestic stock prices to rise. However, if the country is chiefly an importer, a depreciation of the domestic currency reduces the competitiveness of its firms. The rise in price of imports in turn causes the profits of the domestic firms to fall and hence their stock prices tumble. Given this dependence on the level of exposure to the exchange rate risk, a country's exchange rate policies need to take this fact into careful consideration and remain aware of the consequences for the stock markets.

The interdependence of stock price returns and exchange rate changes has been extensively examined in the empirical literature with mixed findings on the directional causality (see Adler and Dumas, 1984; Booth and Rotenberg, 1990; Jorion, 1990; Sercu and Vanhulle, 1992; Smith 1992; Bodnar and Gentry, 1993; and Amihud, 1994; among others). Likewise, empirical evidence on the dynamic linkage between stock and currency market volatilities also provides conflicting findings. Early studies, such as Jorion (1990), suggested that exchange rate fluctuations do not affect stock return volatility, while others (see, for example, Dumas and Solnik, 1995; Roll, 1992) identified the existence of a strong linkage. More recently, Kanas (2000) has analysed volatility transmission between stock and currency markets in the USA, the UK, Japan, Germany, France and Canada finding evidence of spillovers between stock returns and exchange rate changes for five of the six countries analyzed (with Germany being the exception). These results present evidence in favour of the portfolio balance model when formulated in terms of the second moments. Caporale *et al. (*2002) analysed the causal relationship in four East Asian countries using daily data from 1987 to 2000. Their results suggest that the causal structure is more complex than implied by the portfolio balance model. Yang and Doong (2004) investigated volatility spillovers between stock prices and exchange rates for the G-7 countries finding that stock markets play a relatively more important role than foreign exchange markets in the second moment interactions and spillovers. Mishra (2007) finds evidence of bidirectional volatility spillover between stock and foreign exchange markets in India. Finally, Walid *et al.* (2011) investigate the impact of exchange rate changes on stock market volatility in four emerging markets (Hong Kong, Singapore, Malaysia and

Mexico) between 1994 and 2009 and find that an increase in currency market volatility leads to an increase in stock market volatility.

Motivated by the impact of the recent crisis, which has renewed interest in understanding the nature of information transmission across markets, our study explores volatility linkages between stock and exchange rate markets in ten, primarily emerging, Asian economies. This analysis has important implications for both market participants and policymakers. For the former, not only is it important to know the nature of the assets and the characteristics of the different geographical areas in which they might invest, it is also essential to identify the factors that influence the behaviour of these assets. Given that interactions might exist between the equity and currency markets, it is vital to analyse them to make effective investment decisions. For policymakers, the understanding of the linkages between stock and currency markets is crucial for maintaining financial stability.

The Asian markets included are Japan, representative of the mature Asian market; the emerging economies of Southeast Asia divided into two groups – the Asian Tigers (hereinafter *tigers*) of Taiwan, Singapore, Hong Kong and South Korea (hereinafter Korea), and the Tiger Cub countries (hereinafter *cubs*), comprising the Philippines, Indonesia, Malaysia and Thailand; and, China, a growing economy with a great influence worldwide and Asia's engine of growth.

Southeast Asia is characterized by its high population growth rate, political instability and the fact that it is enjoying a marked economic boom (of the countries analysed here, Indonesia and Singapore show the greatest development potential). However, the Southeast Asian economies remain vulnerable to economic decisions taken abroad, given that their domestic markets are small and they are heavily dependent on their exports and on foreign energy and technology. The *tigers* emerged between 1945 and 1990, and they present a broad range of characteristics that are similar to those found in the economies of China and Japan. The *tigers'* economies underwent great growth, not only in quantitative terms, but also in terms of the quality of the low price products they were able to introduce into international markets. The *cubs* achieved industrialization at a later date, following a similar path to that taken by the *tigers*. Subsequently, all these countries have managed to maintain high rates of industrialization and development, becoming attractive destinations for foreign investment.

The Southeast Asian region makes for an interesting case study because *tigers* and *cubs* alike present great opportunities for international industry. Following the lead taken by China, these developing countries are gaining increasingly strong positions in international industrialization.

This study contributes to the literature in two ways. First, exploring volatility transmission between the equity and currency markets of these Asian economies provides a more complete picture of the links between these two markets and allows us to determine if any differences depend on the level of a country's development. Second, as the sample period covers that of the global financial crisis, we are able to examine if the volatility transmission patterns between the stock and currency markets have increased during the period of crisis.

The analysis conducted here, using a multivariate asymmetric generalized autoregressive conditional heteroskedasticity (GARCH) model, provides several important findings. First, we find more evidence of an asymmetric response of the volatility in stock markets than in currency markets. Second, we find bidirectional volatility spillovers between the stock and currency markets independently of the country's level of development. Third, asymmetric volatility transmission is only observed in a few economies. Finally, we find a mixed effect of the global financial crisis on volatility transmission patterns. Thus, while in some countries there is an increase in volatility spillovers from the stock to the currency markets, in others the increase is observed from the currency to the stock markets. China is found to be an exception in this global analysis.

The rest of the paper is organised as follows. Section 2 presents the data employed in the analysis. The econometric method used to estimate volatility spillovers is outlined in Section 3. Section 4 examines the results. The paper ends with some concluding remarks.

## 2. Data

The data, obtained from Bloomberg, consist of daily closing stock prices and exchange rates for the ten Asian markets (see Table 1) between 1 January 2003 and 31 January 2014 (2,893 observations). The exchange rates are expressed in US dollars per local currency (direct quotation system), so that an increase (decrease) in the rate indicates a depreciation (appreciation) of the domestic currency. The stock market returns and the rate of change in exchange rates are computed as log differences of the daily closing prices and currency exchange rates, respectively.[1] A dummy variable – equal to 1 from 15 August 2007 until the end of the sample period and 0 otherwise – is introduced in the model to control for the global financial crisis.

[1] The Augmented Dickey and Fuller (1981) (ADF), Phillips and Perron (1988) (PP) and Kwiatkowski *et al.* (1992) (KPSS) tests (not reported) show that both stock prices and exchange rates are integrated of order one (I(1)).

Many financial analysts date the onset of the global financial to August 2007 since it was in this month that various governments and central banks responded to the economic collapse with unprecedented fiscal stimuli, monetary policy expansions and institutional bailouts. At the beginning of that month, the bursting of the global housing bubble rapidly developed into a global economic shock, resulting in a number of European bank failures, declines in various stock indexes and sharp falls in the market value of equities and commodities. On August 10, the central banks took coordinated actions to increase liquidity for first time since the aftermath of the terrorist attacks of 11 September 2001. In the days that followed, stock indexes continue to fall and the US Federal Reserve (Fed), the European Central Bank (ECB), the Bank of Japan and the central banks of Australia and Canada continued injecting liquidity into the system. For these reasons, the onset of the crisis is fixed at 15 August 2007 (see Valls and Chuliá, 2012).

[Insert Table 1 about here]

Table 2 shows the descriptive statistics for the stock index returns and exchange rate changes. The mean returns are positive for all stock markets; however, the less developed countries (the *cubs*) present higher returns than those presented by the more developed markets (the *tigers*). Japan and China present the lowest returns. The mean returns of all the exchange rates are either very low or negative. All the return series (both the stocks and exchange rates) are leptokurtic and the Bera-Jarque test rejects the normality of all the series, as expected. These characteristics are well documented in the financial literature. Finally, note that almost all the return series exhibit serial correlation and heteroskedasticity.

[Insert Table 2 about here]

## 3. Methodology

To analyse the volatility spillovers between stock and currency markets in the ten Asian countries considered, a bivariate VAR-GARCH process was used. Hence, 10 bivariate models were estimated.

The conditional mean equations are defined as a vector autoregressive process of order 1 [VAR(1)] process:

$$R_{1,t} = \mu_1 + x_1 D_t + d_{11,1} R_{1,t-1} + d_{12,1} R_{2,t-1} + \varepsilon_{1,t}$$

$$R_{2,t} = \mu_2 + x_2 D_t + d_{21,1} R_{1,t-1} + d_{22,1} R_{2,t-1} + \varepsilon_{2,t} \qquad (1)$$

where $R_{1,t}$ and $R_{2,t}$ are the stock and the exchange rate returns, respectively, $\mu_i, x_i$ and $d_{ij,p}$ for $i,j$=1,2 are the parameters to be estimated and $D_t$ is the dummy series for the global financial crisis. Finally, $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are the innovations. The VAR lag was chosen by applying the Schwarz criterion.

To model the conditional variance-covariance matrix we used an asymmetric version of the BEKK model [Baba *et al.* (1989), Engle and Kroner (1995) and Kroner and Ng (1998)][2]. As in the mean equations, we introduced a dummy series to capture the global financial crisis.

The compact form of the model is:

$$H_t = C'C + B'H_{t-1}B + A'\varepsilon_{t-1}\varepsilon_{t-1}'A + G'\eta_{t-1}\eta_{t-1}'G + V'\varepsilon_{t-1}\varepsilon_{t-1}'VD_t \qquad (2)$$

[2]Asymmetric volatility refers to the empirical evidence according to which a negative shock increases volatility more than a positive shock of the same size. In the financial literature, two explanations of the asymmetries in equity markets have been put forward: The *leverage* effect and the volatility *feedback* effect. Which of the two effects is the main determinant of asymmetric volatility remains an open question.

where *C, B, A, G* and *V* are matrices of parameters to be estimated, *C* being an upper-triangular and positive definite matrix, $H_t$ the conditional variance-covariance matrix in *t*, $\eta_t = \max(\varepsilon_t, 0)$ the Glosten *et al.* (1993) dummy series collecting the stylized negative asymmetry from the shocks and *Dt* the dummy variable taking into account the crisis. It takes a value of 0 until 15 August 2007 and 1 otherwise. Matrix *B* depicts the extent to which current levels of conditional variances are related to past conditional variances, matrix *A* captures the effects of lagged shocks or events on volatility, matrix *G* shows the asymmetric volatility effect and matrix *V* captures the effect of the crisis.

Equation (2) allows for both own-market and cross-market influences in the conditional variance, thus allowing us to analyse the volatility spillovers between the two markets. Moreover, the BEKK model guarantees by construction that the variance-covariance matrix will be positive definite. The conditional variance for each market can be expanded for the bivariate BEKK as follows:

$$\begin{aligned}\sigma_{1,t}^2 &= c_{11}^2 + b_{11}^2\sigma_{1,t-1}^2 + b_{21}^2\sigma_{2,t-1}^2 + 2b_{11}b_{21}\sigma_{12,t-1} + a_{11}^2\varepsilon_{1,t-1}^2 + \\ &+ a_{21}^2\varepsilon_{2,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + g_{11}^2\eta_{1,t-1}^2 + g_{21}^2\eta_{2,t-1}^2 + 2g_{11}g_{21}\eta_{1,t-1}\eta_{2,t-1} + \\ &+ v_{11}^2\varepsilon_{1,t-1}^2 D_t + v_{21}^2\varepsilon_{2,t-1}^2 D_t + 2v_{11}v_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1}D_t\end{aligned} \qquad (3)$$

$$\begin{aligned}\sigma_{2,t}^2 &= c_{12}^2 + c_{22}^2 + b_{12}^2\sigma_{1,t-1}^2 + b_{22}^2\sigma_{2,t-1}^2 + 2b_{12}b_{22}\sigma_{12,t-1} + a_{12}^2\varepsilon_{1,t-1}^2 + \\ &+ a_{22}^2\varepsilon_{2,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + + g_{12}^2\eta_{1,t-1}^2 + g_{22}^2\eta_{2,t-1}^2 + 2g_{12}g_{22}\eta_{1,t-1}\eta_{2,t-1} + \\ &+ v_{12}^2\varepsilon_{1,t-1}^2 D_t + v_{22}^2\varepsilon_{2,t-1}^2 D_t + 2v_{12}v_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1}D_t\end{aligned} \qquad (4)$$

Equations (3) and (4) reveal how shocks and volatility are transmitted across time and across markets. In equation (2), the elements in *C*, *B*, *A*, *G* and *V* matrices cannot be interpreted individually. Instead, we have to interpret the non-linear functions of the parameters which form the intercept terms and the coefficients of the lagged variances, covariances, error terms and dummy variables. We follow Kearney and Patton (2000) and calculate the expected value and the standard error of those non-linear functions. The expected value of a non-linear function of random variables is calculated as the function of the expected value of the variables. In order to calculate the standard errors of the function, a first-order Taylor approximation is used. This linearizes the function by using the variance-covariance matrix of the parameters as well as the mean and standard error vectors.

The parameters of the bivariate BEKK system are estimated by maximizing the conditional log-likelihood function:

$$L(\theta) = -\frac{TN}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\left(\ln\left|H_t(\theta)\right| + \varepsilon_t^{'} H_t^{-1}(\theta)\varepsilon_t\right) \tag{5}$$

where $T$ is the number of observations, $N$ is the number of variables in the system and $\theta$ denotes the vector of all the parameters to be estimated. Numerical maximization techniques were used to maximize this non-linear log likelihood function based on the BFGS algorithm. [3]

In order to estimate the model in equations (1) and (2), it is assumed that the vector of innovations is conditionally normal and a quasi-maximum likelihood method is applied. Bollerslev and Wooldridge (1992) show that the standard errors calculated using this method are robust even when the normality assumption is violated.

[3] A range of starting values was used to ensure that the estimation procedure converged to a global maximum. The estimations were repeated with random restarts of the starting values. None of the estimation results indicated any local maximum. The results also seem robust to alternating convergence criteria and optimizing methods. Consequently we are confident that we have found a global maximum.

## 4. Empirical results

Table 3 shows the results of estimating the BEKK model[4]. An interpretation of these results requires that we distinguish between own-market and cross-market effects.

[Insert Table 3 about here]

### *4.1. Own-market effects*

In the case of the stock markets, coefficients on $\varepsilon_{1,t-1}^2$ and $\eta_{1,t-1}^2$ are statistically significant in all countries except Hong Kong, indicating that the volatilities of almost all the Asian equity markets analysed are affected by their own past shocks and that they exhibit an asymmetric volatility response. The coefficient on $\sigma_{1,t-1}^2$ is significant for all the economies analysed, indicating that the volatility of the Asian equity markets is influenced by their own past volatility. Finally, the coefficient on $\varepsilon_{1,t-1}^2 D_t$ is significant only for Japan, Singapore and Indonesia, suggesting that in these equity markets the effects of their own shocks on volatility are higher since the onset of the current financial crisis.

In the case of the currency markets, the estimated own-market coefficients on $\varepsilon_{2,t-1}^2$ and $\sigma_{2,t-1}^2$ are statistically significant for almost all the Asian markets. Therefore, we find evidence that in general the Asian currency markets are affected by their own past shocks and volatility. However, the coefficient on $\eta_{2,t-1}^2$, measuring the asymmetric response of volatility, is statistically significant only for Japan, Hong Kong, Philippines and Thailand. Finally, the coefficient on $\varepsilon_{2,t-1}^2 D_t$ indicates that the volatility of the

[4] In order to keep an appropriate length of the paper the results of the estimated VAR model are not reported, although they are available upon request.

currency markets of Japan, Hong Kong, Korea, Singapore, Philippines, Malaysia and China has been more strongly affected by their own shocks since the onset of the crisis.

### *4.2. Cross-market effects*

If we focus on volatility spillovers from the stock markets to the currency markets, we find that the coefficient on $\varepsilon_{1,t-1}^{2}$ is significant for most of the Asian markets (Japan, the *tigers* and Indonesia), whereas the coefficient on $\sigma_{1,t-1}^{2}$ is only significant in the case of just three economies (Hong Kong, Singapore and Indonesia). As for the asymmetric volatility response, the coefficient on $\eta_{1,t-1}^{2}$ is significant for Singapore, Philippines, Indonesia and Thailand indicating that in these countries negative shocks from the stock market generate greater volatility in their exchange rate markets than do positive shocks of a similar magnitude. Thus, overall, with the exception of China, we find statistically significant evidence of volatility transmission from the stock market to the currency market in one mature market, four *tigers* and three *cubs*, suggesting that volatility spillovers are independent of the country's level of development. Finally, half the Asian economies analysed (Singapore, Taiwan, Philippines, Indonesia and Malaysia) exhibit significant coefficients on $\varepsilon_{1,t-1}^{2}D_t$, indicating that in these countries the equity market has had a greater influence on the currency market following the onset of the global financial crisis.

In the case of volatility spillovers from the currency market to the stock market the coefficient on $\varepsilon_{2,t-1}^{2}$ is statistically significant in practically all the economies considered (Japan, three of the *tigers* and three of the *cubs*). As for the coefficient on $\sigma_{2,t-1}^{2}$, the past volatility of the exchange rate of most of the countries (three *tigers* and three *cubs*) affects the volatility of the stock prices. The asymmetric reaction of the volatility (coefficient on $\eta_{2,t-1}^{2}$) can be perceived in some economies (Japan, Hong Kong, Malaysia and Thailand), indicating that negative shocks from the currency market increase the volatility of equity markets more than positive shocks of the same magnitude. All in all, again with the exception of China, we find that the currency market has a clear influence on the equity market of the Asian countries analysed, independently of the degree of development of the economy. Finally, the coefficient on $\varepsilon_{2,t-1}^{2}D_t$ indicates that volatility transmission patterns have changed since the onset of the crisis in Hong Kong, Philippines and Malaysia.

Overall, there are noticeable bidirectional volatility spillovers between the stock and currency markets. However, the asymmetric response of the volatility is only apparent in some of the economies analysed. Our results paint a complex picture of the effects of the global financial crisis on the volatility transmission patterns. Thus, while in some countries there is an increase in volatility spillovers from the stock to the currency markets, in others the increase is observed from the currency to the stock markets. In this respect, China emerges as an exception. As expected, given the country’s fixed exchange rate, together with the changes to its monetary system and the currency devaluations that have been implemented, we find no evidence of volatility spillovers from the stock prices to the exchange rates. Interestingly, our results show that cross-market effects are not statistically significant in either direction, indicating that the devaluations of the Chinese currency have had no effect on the volatility of the stock market either.

## 5. Conclusions

This paper has examined the causal relationship between stock price and exchange rate volatilities in ten, primarily emerging, Asian economies, drawing on daily data from January 2003 to January 2014. In so doing, we employed a methodology based on a bivariate VAR-GARCH process, using an asymmetric version of the BEKK model. Additionally, our approach has taken into account the effect of the onset of the global financial crisis.

The empirical results can be summarized as follows. As regards own-market effects, the volatilities of both the stock and the currency markets were, in general, affected by their own past shocks and past episodes of volatility. In the case of the stock markets, we find some evidence for an asymmetric response of the volatility; hence, a negative shock had a greater influence on volatility than a positive shock of a similar magnitude. However, this asymmetric effect was much less apparent in the exchange rate market. Our examination of the impact of the financial crisis revealed that the pattern of behaviour found in the stock markets only changed in a few countries after the onset of the crisis, whereas in the currency markets the earlier pattern changed in a greater number of economies.

As regards cross-market effects, our analysis has identified several important trends. First, we find empirical evidence for bidirectional volatility transmission between the stock and the currency markets, independently of the country's level of development. Second, China emerges as an exception as it does not show any significant volatility transmission in either direction. The explanation for this would seem to lie in the fact that China operates a fixed exchange-rate system, which in recent years has been switched from the US Dollar to a basket of foreign currencies, and as a consequence it has experienced a number of devaluations. Third, in some cases we have found that the volatility transmission patterns are asymmetric. Finally, we find a mixed effect of the global financial crisis on volatility transmission patterns.

The results of this study should be valuable for analysts, traders and practitioners that seek to diversify their portfolios and to invest in different assets, i.e., both stocks and exchange rates. When investing in the emerging economies of Asia, before constructing a portfolio it would clearly be beneficial to take into account volatility spillovers between stocks and currencies, as we have found empirical evidence of a bidirectional connection between these two markets. Likewise, policy makers could usefully take into account the relationship between stock prices and exchange rates before implementing their exchange rate policies.

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## 7. Tables

**Table 1. Stock market indexes and exchange rates for each market covered**

<table>
<tr><th colspan="3">Type of market</th><th>Economy</th><th>Equity Index</th><th>Exchange Rate</th></tr>
<tr><td colspan="3">Mature market</td><td>JAPAN</td><td>Nikkei 225 Index</td><td>Japanese Yen/US Dollar</td></tr>
<tr><td rowspan="9">Emerging markets</td><td rowspan="8">Southeast Asia</td><td rowspan="4">Asian Tigers</td><td>HONG-KONG</td><td>Hang Seng Index</td><td>Hong Kong Dollar/US</td></tr>
<tr><td>SOUTH KOREA</td><td>Kospi Index</td><td>South Korean Won/US Dollar</td></tr>
<tr><td>SINGAPORE</td><td>Straits Time Index Exchange Index</td><td>Singapore Dollar/US Dollar</td></tr>
<tr><td>TAIWAN</td><td>Taiwan Stock Exchange Index</td><td>Taiwanese Dollar/US Dollar</td></tr>
<tr><td rowspan="4">Asian Tiger Cubs</td><td>PHILIPPINES</td><td>Philippine Stock Exchange Index</td><td>Philippine Peso/US Dollar</td></tr>
<tr><td>INDONESIA</td><td>Jakarta Composite Index</td><td>Indonesian Rupiah/US Dollar</td></tr>
<tr><td>MALAYSIA</td><td>FTSE Bursa Malaysia Kuala Lumpur Composite Index</td><td>Malaysian Ringgit/US Dollar</td></tr>
<tr><td>THAILAND</td><td>FTSE SET Shariah Index</td><td>Thai Baht/US Dollar</td></tr>
<tr><td colspan="2">Other</td><td>CHINA</td><td>Shanghai A-Share Stock Price Index</td><td>Chinese Renminbi/US Dollar</td></tr>
</table>

*Note*: We differentiate Hong Kong from China, as the former, being a British colony until 1997, retains to this day independent economic, administrative and judicial systems.

**Table 2. Summary statistics of the return series of stock markets and exchange rates**

| | Mean | Std. Dev. | Skewness | Kurtosis | Bera-Jarque test | Q(12) | ARCH(12) |
|---|---|---|---|---|---|---|---|
| **Japan** | | | | | | | |
| *Stock markets* | 0.0002 | 0.0151 | -0.5901 | 11.573 | 2,076.667 | 20.055 | 247.682 |
| | | | | | (0.0000) | (0.0661) | (0.0000) |
| *Exchange rates* | -0.0001 | 0.0066 | 0.0789 | 7.148 | 3,853.452 | 14.164 | 930.351 |
| | | | | | (0.0000) | (0.2904) | (0.0000) |
| **Hong-Kong** | | | | | | | |
| *Stock markets* | 0.0003 | 0.0152 | 0.0364 | 13.164 | 12,448.070 | 46.552 | 164.223 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| *Exchange rates* | 0.0000 | 0.0004 | -2.6175 | 44.743 | 213,268.300 | 20.093 | 815.474 |
| | | | | | (0.0000) | (0.0653) | (0.0000) |
| **Korea** | | | | | | | |
| *Stock markets* | 0.0004 | 0.0141 | -0.4952 | 9.398 | 5,051.144 | 82.935 | 676.967 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| *Exchange rates* | 0.0000 | 0.0075 | -0.7935 | 56.608 | 346,603.000 | 10.455 | 696.995 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| **Singapore** | | | | | | | |
| *Stock markets* | 0.0003 | 0.0117 | -0.1970 | 8.800 | 4,072.163 | 35.943 | 227.906 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| *Exchange rates* | -0.0001 | 0.0034 | 0.0120 | 8.118 | 3,156.308 | 31.796 | 781.723 |
| | | | | | (0.0000) | (0.0015) | (0.0000) |
| **Taiwan** | | | | | | | |
| *Stock markets* | 0.0003 | 0.0128 | -0.3741 | 6.440 | 1,493.681 | 38.956 | 167.925 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| *Exchange rates* | 0.0000 | 0.0026 | -0.2521 | 7.958 | 2,993.230 | 23.991 | 325.358 |
| | | | | | (0.0000) | (0.0204) | (0.0000) |
| **Philippines** | | | | | | | |
| *Stock markets* | 0.0006 | 0.0131 | -0.6430 | 10.755 | 7,445.578 | 13.719 | 333.121 |
| | | | | | (0.0000) | (0.3190) | (0.0000) |
| *Exchange rates* | -0.0001 | 0.0036 | 0.1370 | 4.536 | 293.432 | 70.120 | 368.139 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| **Indonesia** | | | | | | | |
| *Stock markets* | 0.0008 | 0.0142 | -0.6515 | 9.880 | 5,907.782 | 128.678 | 367.096 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| *Exchange rates* | 0.0001 | 0.0060 | 0.0525 | 17.886 | 26,702.100 | 55.999 | 333.629 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| **Malasya** | | | | | | | |
| *Stock markets* | 0.0004 | 0.0075 | -1.0415 | 17.407 | 25,533.320 | 15.737 | 338.645 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| *Exchange rates* | 0.0000 | 0.0035 | -0.2554 | 8.799 | 4,083.054 | 60.322 | 161.812 |
| | | | | | (0.0000) | (0.0000) | (0.0000) |
| **Thailand** | | | | | | | |
| *Stock markets* | 0.0004 | 0.0136 | -0.8677 | 15.656 | 19,663.460 | 35.554 | 436.725 |
| | | | | | (0.0000) | (0.0004) | (0.0000) |
| *Exchange rates* | -0.0001 | 0.0032 | 0.2113 | 17.373 | 24,916.190 | 28.218 | 334.353 |
| | | | | | (0.0000) | (0.0051) | (0.0000) |
| **China** | | | | | | | |
| *Stock markets* | 0.0001 | 0.0158 | -0.2469 | 7.057 | 2,012.999 | 30.710 | 359.457 |
| | | | | | (0.0000) | (0.0022) | (0.0000) |
| *Exchange rates* | -0.0001 | 0.0009 | -3.9514 | 92.560 | 974,053.900 | 24.912 | 474.573 |
| | | | | | (0.0000) | (0.0152) | (0.0000) |

*Note*: The Bera-Jarque statistic tests for the normal distribution hypothesis and has an asymptotic distribution $X^2(2)$. Q(12) is the Ljung-Box tests for twelfth order serial correlation in the returns. ARCH(12) is Engle's test for twelfth order ARCH, distributed as $X^2(12)$. P-values displayed as (.).

## Table 3. Results of the linearized multivariate BEKK model

| | Japan | Hong Kong | Korea | Singapore | Taiwan | Philippines | Indonesia | Malaysia | Thailand | China |
|---|---|---|---|---|---|---|---|---|---|---|
| *Stock markets* | | | | | | | | | | |
| $\sigma^2_{1,t-1}$ | 0.4918*** | 0.0798** | 0.0024** | 0.2369* | 0.1285** | 0.2153** | 0.1625*** | 0.1982* | 0.1254*** | 0.0952** |
| | (2.90) | (2.37) | (2.48) | (1.88) | (1.99) | (2.01) | (3.01) | (1.79) | (2.59) | (2.11) |
| $\sigma^2_{2,t-1}$ | 0.0030 | 0.1163*** | 0.0731** | 0.0456** | 0.1563 | 0.1168** | 0.1232*** | 0.1056** | 0.0952 | 0.0063 |
| | (0.27) | (3.71) | (2.42) | (1.96) | (1.62) | (2.25) | (2.95) | (1.97) | (0.97) | (0.51) |
| $\varepsilon^2_{1,t-1}$ | 0.0275*** | 0.0021 | 0.0762*** | 0.0964*** | 0.0691** | 0.0835*** | 0.0982** | 0.0863** | 0.0852*** | 0.1021** |
| | (3.65) | (0.26) | (2.66) | (2.99) | (2.36) | (3.04) | (2.13) | (2.11) | (3.62) | (2.36) |
| $\varepsilon^2_{2,t-1}$ | 0.0515*** | 0.1565 | 0.0824** | 0.0047*** | 0.0962*** | 0.1641** | 0.0963** | 0.0095*** | 0.00952 | 0.0085 |
| | (4.27) | (0.97) | (2.40) | (4.95) | (3.04) | (1.97) | (2.11) | (2.91) | (1.61) | (0.62) |
| $\eta^2_{1,t-1}$ | 0.1287** | 0.0749 | 0.3426*** | 0.3676*** | 0.2967*** | 0.2412*** | 0.2942** | 0.0562** | 0.2621** | 0.1241* |
| | (2.42) | (1.62) | (3.48) | (3.61) | (2.74) | (3.15) | (2.11) | (2.25) | (2.52) | (1.75) |
| $\eta^2_{2,t-1}$ | 0.1941*** | 0.3409* | 0.0049 | 0.1910 | 0.1536 | 0.0952 | 0.0752 | 0.0382* | 0.0812** | 0.0742 |
| | (3.49) | (1.85) | (0.58) | (1.10) | (1.32) | (1.34) | (0.92) | (1.86) | (2.01) | (0.82) |
| $\varepsilon^2_{1,t-1}D_t$ | 0.0082*** | 0.0013 | 0.0001 | 0.017** | 0.0086 | 0.0123 | 0.0082*** | 0.0063 | 0.0672 | 0.0074 |
| | (3.51) | (1.39) | (0.31) | (2.02) | (0.68) | (0.98) | (3.42) | (1.15) | (0.92) | (1.60) |
| $\varepsilon^2_{2,t-1}D_t$ | 0.0002 | 0.0016** | 0.0001 | 0.0145 | 0.0052 | 0.0215*** | 0.0362 | 0.0095** | 0.0125 | 0.0092 |
| | (0.26) | (2.01) | (0.42) | (0.50) | (0.94) | (2.96) | (0.26) | (1.98) | (0.84) | (1.17) |

## Table 3. Results of the linearized multivariate BEKK model (continued)

| | Japan | Hong Kong | Korea | Singapore | Taiwan | Philippines | Indonesia | Malaysia | Thailand | China |
|---|---|---|---|---|---|---|---|---|---|---|
| *Exchange rates* | | | | | | | | | | |
| $\sigma^2_{1,t-1}$ | 0.0451 | 0.0412*** | 0.0152 | 0.0212*** | 0.0543 | 0.0095 | 0.0621*** | 0.0821 | 0.0751 | 0.0039 |
| | (0.11) | (3.05) | (0.21) | (2.68) | (1.32) | (1.26) | (2.68) | (0.53) | (0.81) | (1.13) |
| $\sigma^2_{2,t-1}$ | 0.1672 | 0.0596** | 0.7844*** | 0.0126*** | 0.1632*** | 0.1452** | 0.2153** | 0.1284*** | 0.1821** | 0.1092*** |
| | (0.53) | (2.24) | (2.62) | (2.86) | (2.67) | (2.12) | (2.18) | (2.96) | (2.09) | (3.61) |
| $\varepsilon^2_{1,t-1}$ | 0.0092*** | 0.0014** | 0.0035*** | 0.0031* | 0.0026*** | 0.0125 | 0.0086** | 0.0263 | 0.00921 | 0.0362 |
| | (4.17) | (2.37) | (3.82) | (1.75) | (3.14) | (1.09) | (2.21) | (0.43) | (1.60) | (0.74) |
| $\varepsilon^2_{2,t-1}$ | 0.0033 | 0.3258* | 0.1035** | 0.0404** | 0.0982** | 0.1162*** | 0.1096** | 0.1281** | 0.1962 | 0.1521** |
| | (0.54) | (1.71) | (2.05) | (2.07) | (2.39) | (2.62) | (1.97) | (2.05) | (1.43) | (2.42) |
| $\eta^2_{1,t-1}$ | 0.0041 | 0.0002 | 0.0003 | 0.0029** | 0.0007 | 0.0046** | 0.0062** | 0.0032 | 0.0052* | 0.0042 |
| | (0.62) | (0.14) | (0.17) | (2.41) | (1.12) | (2.51) | (2.14) | (0.63) | (1.91) | (1.24) |
| $\eta^2_{2,t-1}$ | 0.0693*** | 0.2345*** | 0.0023 | 0.0038 | 0.1582 | 0.0895** | 0.1231 | 0.0962 | 0.1042** | 0.0852 |
| | (2.69) | (3.11) | (0.41) | (0.52) | (1.29) | (2.01) | (0.91) | (1.11) | (1.98) | (1.08) |
| $\varepsilon^2_{1,t-1}D_t$ | 0.0039 | 0.0435 | 0.0006 | 0.0752** | 0.0201*** | 0.0523* | 0.0625** | 0.0852*** | 0.0584 | 0.0451 |
| | (0.26) | (0.89) | (0.10) | (2.45) | (3.05) | (1.75) | (2.12) | (2.63) | (1.10) | (1.00) |
| $\varepsilon^2_{2,t-1}D_t$ | 0.2622*** | 0.8224*** | 0.0663*** | 0.0942** | 0.1562 | 0.0863*** | 0.1021 | 0.0952*** | 0.0932 | 0.0821*** |
| | (4.91) | (4.92) | (2.72) | (2.44) | (0.78) | (2.91) | (0.84) | (3.06) | (0.10) | (2.95) |

Note: We only report the estimated coefficients for the "direct effects". Coefficients on covariances and cross-error terms are available upon request. Below the estimated coefficients are the corresponding t-values given in parentheses. *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively. The expected value is obtained by taking expectations to the non-linear functions, therefore involving the estimated variance-covariance matrix of the parameters. To calculate the standard errors, the function must be linearised using first order Taylor series expansion. This is sometimes called the 'delta method'. When a variable Y is a function of a variable X, i.e., Y =F(X), the delta method enables us to obtain approximate formulation of the variance of Y if: (1) Y is differentiable with respect to X and (2) the variance of X is known. Therefore: $V(Y) \approx (\Delta Y)^2 \approx \left(\frac{\partial Y}{\partial X}\right)^2 (\Delta X)^2 \approx \left(\frac{\partial Y}{\partial X}\right)^2 V(X)$

When a variable Y is a function of variables X and Z in the form of Y = F(X, Z), we can obtain approximate formulation of the variance of Y if: (1) Y is differentiable with respect to X and Z and (2) the variance of X and Z and the covariance between X and Z are known. This is: $V(Y) \approx \left(\frac{\partial Y}{\partial X}\right)^2 V(X) + \left(\frac{\partial Y}{\partial Z}\right)^2 V(Z) + 2\left(\frac{\partial Y}{\partial X}\right)\left(\frac{\partial Y}{\partial Z}\right) Cov(X, Z)$

Once the variances are calculated it is straightforward to calculate the standard errors.

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