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VOLATILITY SPILLOVERS BETWEEN STOCK PRICES AND EXCHANGE RATES: EMPIRICAL EVIDENCE FROM APEC ECONOMIES

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Abstract

This paper set out to examine the volatility linkages between stock returns and exchange rates in a number of East Asian markets. Overall, our main results indicate that since the Asian financial crises, there exists significant scope for investors and portfolio managers to diversify their assets between stocks and currencies in these markets. In particular, the lack of volatility spillovers between stock markets and exchange rates, and between exchange rates and stock markets in all countries, except Taiwan in the post crises period indicates that there is scope for investors to diversify their investments and to benefit from potential gains in the long run in this region.

1. Introduction

Several theoretical models have demonstrated theoretically the exchange rate between two currencies is affected by stock price changes in the respective countries; for example, Zapatero (1995) shows that in fully integrated financial markets, there is an explicit linkage between the volatility of stock prices and the volatility of the exchange rate. More recently, Yang and Doong (2002) note that given the rapid integration and deregulation of international financial markets in recent years, exchange rates have become more sensitive to stock market innovations. Existing empirical evidence on volatility spillovers between stock markets and exchange rates have tended to focus on the G-7 countries (see for example, Yang and Doong, 2004; Kanas, 2000, 2002). Empirical evidence to date that has examined the interaction between stock markets and exchange rates for the Asian markets has focused on the effect of currency depreciation on stock market returns and volatility (Fang, 2002). The only study that has examined the relationship between the volatility of stock prices and the volatility of exchange rates in a number of East Asian markets is Wu (2005) who examines volatility spillovers between the two markets for the period of the Asian financial crises and the period after the crises; however his sample only runs until the end of 2000. Thus there is no up to date recent evidence on volatility spillovers between stock markets and exchange rates for Asian countries. We address the gap in the literature in this area by investigating this issue using daily data for the period 1997 and 2006[1] for Hong Kong, South Korea, Singapore, Taiwan and Thailand. The layout of the paper is as follows. Section 1 sets out the theoretical and empirical evidence on the nature of linkages between stock markets and exchange rates in the next section. Section 2 describes of the methodology we use to assess the nature of volatility spillovers between the two markets, and we discuss our data. Section 3 sets out the results from our estimation. We finish by summarising our main results and drawing some conclusions from our analysis.

[1] Our sample runs from 1/1/1997 to 31/7/2006 and the data are sourced from Datastream.

2. Literature Review

Several theoretical models have analysed the link between stock markets and currency markets. The asset market approach to exchange rate determination (Branson, 1983; Frankel, 1983) posits that causality will run from stock prices to exchange rate changes as expectations of financial asset price movements affect the dynamics of exchange rates. Smith (1992) derives an estimable equation for the exchange rate where the stock price is included as an explanatory variable. The goods market approach suggests causality runs in the opposite direction, from exchange rates to stock prices (Mundell, 1963, 1964; Dornbusch and Fisher, 1980). In these models, movements in exchange rates affect the international competitiveness of firms which affects real income and output and eventually stock prices. In Hekman's (1984) model the exchange rate is an explanatory variable for stock prices.

Much of the available empirical evidence on the linkages between stock markets and exchange rates has concentrated on the first moments[2]. Yang and Doong (2004) note that there is a dearth of empirical evidence that concentrates on the linkages between the second moments of the distribution of the variables. A number of studies however have examined the extent to which volatility from one stock market spills over into other stock markets or between different assets[3]. Kanas (2000) was one of the first studies which analysed volatility spillovers from stock returns to exchange rate changes in the USA, the UK, Japan, Germany, France and Canada. He found evidence of spillovers from stock returns to exchange rate changes for all countries except Germany, suggesting that the asset approach to exchange rate determination is valid when formulated in terms of the second moments of the exchange rate distribution for the countries included in his analysis. Volatility spillovers from exchange rate changes to stock returns were insignificant for all countries. Yang and Doong (2004) explored the nature of the mean and volatility transmission mechanism between stock and foreign exchange markets for the G-7 countries. The results point to significant volatility spillovers and an asymmetric effect from the stock market to the foreign exchange market for France, Italy, Japan and the US, suggesting integration between stock and foreign exchange markets in these countries. Verma, Jackson and Swisher (2005), examined price and

[2] See for example Nieh and Lee (2001), Yau and Nieh (2006) for recent evidence on this topic.
[3] See also for example, Nelson (1991), Koutmos and Booth (1995), Laopodis (1998).

volatility spillovers from interest rates and exchange rates to American Depository Receipts (ADRs), originating from Mexico, Brazil and Chile. In terms of volatility spillovers, their results indicated that both interest rates and exchange rates spillover to Brazilian and Chilean ADRs, whereas only exchange rates spillover to Mexican ADRs. In relation to asymmetry, the interest rates of Mexico, Brazil and Chile as well as the exchange rates of Chile, indicate that negative innovations increase volatility more than positive innovations. The only existing evidence on this issue for Asian countries is Wu (2005) who examines volatility spillovers between stock prices and exchange rates for Japan, South Korea, Indonesia, Philippines, Singapore, Thailand and Taiwan for the period 1997-2000, splitting the sample into crises and recovery periods. He found a bi-directional relationship between the volatility of stock returns and exchange rate changes during the recovery period in all countries except South Korea, as well as significant contemporaneous relationships between the two markets for most of the countries. Furthermore, he found volatility spillovers increased in the recovery period.

3. Methodology and Data

The analysis will be conducted with the purpose of investigating volatility spillovers between stock returns and exchange rate changes for five Asian Markets, Hong Kong, South Korea, Singapore, Taiwan and Thailand, for the period 1 January 1997 to 7 July 2006. The data set consists of daily closing values for the Hang Seng, Strait Times, Korea SE Composite, Taiwan Se Weighted and Thailand SE TISCO stock market indices, and the Hong Kong$, Singapore$, South Korea Won, Taiwan New and Thai Bhat foreign exchange rates against the US$. Our sample has a total of 2485 observations. All data are taken from DataStream. Following Kanas (2000) we use continuously compounded stock returns and exchange rate changes calculated as the first differences of the natural log. That is, S= Stock Prices; $S_t = \ln\left(P_t^s\right) - \ln\left(P_{t-1}^s\right)$ and E= Exchange Rates; $E_t = \ln\left(P_t^e\right) - \ln\left(P_{t-1}^e\right)$.

As an initial step we perform a stationarity test on each of the relevant variables that are included in our analysis to ensure that the results from the analysis are not spurious. We apply the Dickey Fuller (DF) test, or Augmented Dickey-Fuller test (ADF) procedure if serial correlation is present. We also apply the Lagrange Multiplier (LMF) test, to ensure that a sufficient number of lags have been added in the ADF test to ensure that there is no serial correlation present and the results of the ADF test are valid. The LMF test is applied given that it is valid in the presence of lagged dependent variables as well as having the advantage of testing for first and higher orders of serial correlation. If we found that our variables are an I(0) process, meaning that they are stationary in levels, we will proceed to perform our EGARCH (p,q) analysis, otherwise if we found that our variables are not an I(0) process, what it means that they are stationary in levels then we will need to proceed and perform unit root test in our variables, applying to them first differences, if we found that our variables are an I(d) process, it will means that they have to be integrated at the same order then we will be able to proceed with the cointegration test on our variables as is stated in the cointegration test methodology (Enders, 2004). Using the Johansen Cointegration test to investigate the long-run relationship between Stock Prices and Exchange Rates, as Enders (2004) notes given that the results of the test can be quite sensitive to the lag length, the most common procedure is to estimate a Vector Autoregression (VAR) model on the undifferenced data in order to determine the lag length for the Johansen test. We estimate the lag selection tests up 20 lags. In terms of choosing between the various lag length selection criteria we follow Johansen *et al*. (2000) who suggest that when different information criteria suggest different lag lengths, it is common practice to prefer Hannan-Quinn (HQ) criteria. Again, we ensure that the lag length selected for the VAR model is free from serial after performing by applying the LMF test to test for serial correlation up to the number of lags in the VAR model. There are five possible models to choose from for the Johansen test as follows.

$$H_2(r) : \Pi y_{t-1} + B x_t = \alpha B' y_{t-1} \quad (1)$$

$$H^*_1(r) : \Pi y_{t-1} + B x_t = \alpha (B' y_{t-1} + p_0) \quad (2)$$

$$H_1(r) : \Pi y_{t-1} + B x_t = \alpha (B' y_{t-1} + p_0) + \alpha_\perp \gamma_0 \quad (3)$$

$$H^*(r) : \Pi y_{t-1} + B x_t = \alpha (B' y_{t-1} + p_0 + p_1 t) + \alpha_\perp \gamma_0 \quad (4)$$

$$H(r) : \Pi y_{t-1} + B x_t = \alpha (B' y_{t-1} + p_0 + p_1 t) + \alpha_\perp (\gamma_0 + \gamma_1 t) \quad (5)$$

Equation 1 has no deterministic trends in the level data and no intercepts in the cointegrating equations. Equation 2 has no deterministic trends in the level data and the cointegrating equations have intercepts. Equation 3 has linear trends in the level data but the cointegrating equations only have intercepts. Equation 4 has linear trends in both the level data and the cointegrating equations, and equation 5 has quadratic trends in the level data and linear trends in the cointegrating equations. Harris and Sollis (2003) note that model 1 i.e. with no deterministic components in the data or cointegration relations, is unlikely to occur in practice, as generally an intercept is needed to take account of the units of measurement of the variables; they also note that model 5 with quadratic trends, is economically hard to justify, as if the variables are entered in logs, as they are in our model, as this would imply an every increasing or decreasing rate of change. This leaves a choice between models 2-4. Johansen (1992) suggests choosing the appropriate model according to the Pantula principle; all three models are estimated; the Pantula principle involves moving through each model for the null hypothesis of *r=0,* then *r=1* etc., and picking the model where the null hypothesis is rejected for the first time. Chang and Caudill (2005) note that the λ_{trace} test statistic is more robustness to both skewness and excess kurtosis than the λ_{max} test statistic; for comparative purposes, we show both the results of the λ_{trace} and the λ_{max} test statistics.

We then proceed with our volatility analysis and apply a bivariate extension of the EGARCH (*p,q*) model in order to examine whether the volatility of stock returns affects and is affected by the volatility of exchange rate changes within each economy. The EGARCH specification (Nelson, 1991) is used in order to test whether the volatility spillover effects are asymmetric. For example, an asymmetric spillover from stock returns to exchange rate changes would suggest that the effect of “bad” stock market news on the exchange rate change is greater than the effect of “good” news. The model is specified as follows:

$$S_t = a_{s,0} + \sum_{i=1}^{r} a_{s,i} S_{t-i} + \sum_{i=1}^{r} a_{e,i} E_{t-i} + \beta_s \lambda_{s,t-1} + e_{S,t} \qquad \textbf{(6)}$$

$$E_t = a_{E,0} + \sum_{i=1}^{r} a_{E,i} E_{t-i} + \sum_{i=1}^{r} a_{S,i} S_{t-i} + \beta_E \lambda_{E,t-1} + e_{E,t} \qquad \textbf{(7)}$$

$$e_{S,t} / \Omega_{t-1} \approx N(0, \sigma^2_{S,t})$$
$$e_{E,t} / \Omega_{t-1} \approx N(0, \sigma^2_{E,t})$$

The conditional variances of stock returns and exchange rates changes are specified as follows:

$$\sigma_{S,t}^2 = \exp\left\{c_{S,0} + \sum_{j=1}^{ps} b_{S,j}\log(\sigma_{S,t-j}^2) + \delta_{S,S}\left[\left(\left|z_{S,t-1}\right| - E\left|z_{S,t-1}\right| + \theta_{S,Sz_{s,T-1}}\right) + \delta_{S,E}\left[\left(\left|z_{E,t-1}\right| - E\left|z_{E,t-1}\right| + \theta_{S,EzE,t-1}\right)\right]\right]\right.$$

(8)

$$\sigma_{E,t}^2 = \exp\left\{c_{E,0} + \sum_{j=1}^{ps} b_{E,j}\log(\sigma_{E,t-j}^2) + \delta_{E,E}\left[\left(\left|z_{E,t-1}\right| - E\left|z_{E,t-1}\right| + \theta_{E,Ez_{s,T-1}}\right) + \delta_{E,S}\left[\left(\left|z_{S,t-1}\right| - E\left|z_{S,t-1}\right| + \theta_{E,SzE,t-1}\right)\right]\right]\right.$$

(9)

$$\sigma_{S,E,T} = \rho_{S,E}\sigma_{S,t}\sigma_{E,t}$$

We summarise each of the relevant terms in equations (6-9) in Table 1.

Table 1 **Description of Parameters Equations (6)-(9)**

	Stock Returns	**Exchange Rate Returns**
Error correction terms (lagged residuals from the cointegrating regression of S_t, E_t)	$\lambda_{S,t-1}$	$\lambda_{E,t-1}$
Stochastic error terms	$e_{S,t}$	$e_{E,t}$
Information set at time *t-1*	Ω_{t-1}	Ω_{t-1}
Conditional (time varying) variances	$\sigma_{S,t}^2$	$\sigma_{E,t}^2$
Standardised residuals assumed to be normally distributed with 0 mean and variances of $\sigma_{S,t}^2, \sigma_{E,t}^2$	$z_{S,t} = e_{S,t} / \sigma_{S,t}$ $e_{S,t} / \Omega_{t-1} \sim \mathrm{N}(0,\ \sigma_{S,t}^2)$	$z_{E,t} = e_{E,t} / \sigma_{E,t}$ $e_{E,t} / \Omega_{t-1} \sim \mathrm{N}(0,\ \sigma_{E,t}^2)$
Persistence of Volatility	$\sum_{j=1}^{ps} b_{S,j}$	$\sum_{j=1}^{pE} b_{E,j}$
ARCH effect where the parameters $\theta_{S,S}, \theta_{E,E}$ allow this effect to be asymmetric	$\left[\left|z_{S,t}\right| - E\left|z_{S,t}\right| + \theta_{S,Sz_{S,t}}\right]$	$\left[\left|z_{E,t}\right| - E\left|z_{E,t}\right| + \theta_{E,Ez_{E,t}}\right]$
Volatility Spillover	$\delta_{S,E}\left[\left|z_{E,t-1}\right| - E\left|z_{E,t-1}\right| + \theta_{S,Ez_{E,t-1}}\right]$	$\delta_{E,S}\left[\left|z_{S,t-1}\right| - E\left|z_{S,t-1}\right| + \theta_{E,Sz_{SSt-1}}\right]$
Measures of spillovers	$\delta_{S,E}$	$\delta_{E,S}$
Asymmetry of Spillovers	[4] $\theta_{S,E}$	$\theta_{E,S}$
Correlation Coefficient for Standardised Residuals	$\rho_{S,E}$	$\rho_{E,S}$

[4] $\theta_{S,E} < 0, \theta_{S,E} < 0$, implies that negative exchange rate shocks increase the volatility of stock returns more than positive shocks

The lag truncation length p in the EGARCH model is determined using the Likelihood Ratio (LR) test on alternative specifications. Hamilton (1994) defines the LR test as follows: $2\left[L(\hat{\theta}) - L(\tilde{\theta})\right] \approx \chi^2(m)$, where $L(\hat{\theta})$ denotes the value of the log likelihood function at the unrestricted estimate and $L(\tilde{\theta})$ denotes the value of the log likelihood function of the restricted estimate. Bollerslev-Woolridge robust t-statistics are derived to take into account possible non-normality of the residuals.

Given that our sample period includes the Asian financial crises, in addition to examining volatility spillovers between stock returns and exchange rates for the entire period, we also split our sample in order to compare the effect of volatility spillovers during and after the crises. Wu (2005) notes that the financial crises were triggered by Thailand's request for assistance from the IMF the 2nd of July 1997 and that most countries had recovered from the crises by late 1998. Thus our split samples comprise the crises period of 2 July 1997 to31 December 1998 and the post crises period of 1 January 1999-7 July 2006.[5] All results are generated using the EVIEWS statistical program.

4. Empirical Results

We begin by providing descriptive statistics for stock returns and exchange rates, in order to summarise the statistical characteristics of our sample which are set out in Table 3. For the entire period, the sample means of stock returns are positive for all countries except Taiwan as well as being positive for Hong Kong and South Korea during the crises period and negative for the other countries in the crises period. In the post crises period, the mean of all stock returns were positive. The highest mean returns were for South Korea at 2.78% followed by Thailand at 1% for the entire sample; for the crises period they were highest for Hong Kong and Korea for the post crises period they were highest for Singapore, followed by Korea and Hong Kong, with Taiwan having the lowest mean returns in the post crises period.

[5] Wu (2005) examines the extent of volatility spillover before and after the crises but our results differ from his in that he defines the crises period from 2 July 1997 to 30 September 1998 and his sample for the post crises period runs from 1 October 1998 to 31 December 2000; thus our post crises sample is considerably longer and more up to date.

The standard deviations of the stock returns range from 0.7% to 2.7% for the entire period and from 0.5% to 3.2% in the crises period and 0.03% to 1.9% in the post crises period, indicating that the volatility of stock returns in general were lower in the post crises period than during the financial crises. Both the skewness and kurtosis coefficients indicate that stock returns are leptokurtic relative to the normal distribution, which Caporale et al. (2002) note is a common finding for stock returns. The Jarque-Bera test also rejects the hypothesis that stock returns are normally distributed in all countries.

Table 3 Descriptive Statistics

Stock Returns						
		Mean (x10^3)	**SD**	**Skewness**	**Kurtosis**	**JB**
Hong Kong	Total sample	0.082	0.0169	0.17	14.63	14002
	Crises	0.369	0.0075	-0.88	8.09	474
	Post-crises	2.52	0.0135	-0.26	6.47	1008
South Korea	Total sample	0.278	0.0217	-0.13	6.15	1035
	Crises	0.400	0.0050	1.88	15.99	2988
	Post-crises	2.81	0.0118	-0.36	7.69	1841
Singapore	Total sample	0.078	0.0140	0.36	13.95	12467
	Crises	-1.10	0.0290	0.44	9.10	620
	Post-crises	4.27	0.0194	-0.39	6.08	825
Taiwan	Total sample	-0.018	0.0160	-0.06	5.59	698
	Crises	-0.800	0.0316	0.27	4.19	28
	Post-crises	0.002	0.0003	-3.06	229.43	4194538
Thailand	Total sample	0.099	0.0071	-0.54	419.26	17933710
	Crises	-0.900	0.0162	-0.09	4.58	41
	Post-crises	0.017	0.0040	0.13	17.74	17774
Exchange Rates						
		Mean (x10^3)	**SD**	**Skewness**	**Kurtosis**	**JB**
Hong Kong	Total sample	0.002	0.0004	-3.16	171.70	2949788
	Crises	0.009	0.0005	-3.15	71.79	77932
	Post-crises	0.002	0.0003	-3.06	229.43	4194538
South Korea	Total sample	0.044	0.0106	0.01	139.86	1938493
	Crises	0.800	0.0251	-0.08	28.20	10371
	Post-crises	-0.023	0.0027	-0.22	6.18	844
Singapore	Total sample	0.048	0.0039	-0.94	18.86	26410
	Crises	1.00	0.0175	2.01	26.39	9197
	Post-crises	-0.126	0.0039	-0.06	6.35	920

Taiwan	Total sample	0.067	0.0034	1.15	33.60	97464
	Crises	-0.800	0.0230	0.85	9.79	801
	Post-crises	0.017	0.0161	-0.04	5.78	631
Thailand	Total sample	0.155	0.0082	3.31	90.14	790400
	Crises	-0.300	0.0124	-0.40	154.14	373107
	Post-crises	0.237	0.0023	-0.51	7.66	1859

The descriptive statistics for the exchange rate returns show that the sample means are positive for all countries for the entire period except for Taiwan and Korea; for the crises period the means were negative only for Taiwan and Thailand, and for the post crises period were negative only for Korea and Singapore. The volatility of exchange rate returns ranged from 0.04% in Hong Kong to 1.06% in South Korea for the entire period; volatility was higher during the crises period than the post crises period for all countries. Again the skewness and kurtosis statistics indicate that the distribution of exchange rate returns are non-normal and the Jarque-Bera test also rejects the hypothesis of normally distributed returns for all periods for all countries.

Table 2 Augmented Dickey Fuller Test Results

	Variables	Total Sample	Crises	Post crises
Hong Kong	E	-14.4	-10.9	-12.0
	S	-24.4	-21.0	-42.8
South Korea	E	-7.1	-0.4	-15.2
	S	-35.2	-13.5	-20.7
Singapore	E	-9.9	-9.8	-13.3
	S	-44.3	-20.9	-42.9
Taiwan	E	-9.5	-17.5	-19.2
	S	-22.1	-16.6	-12.0
Thailand	E	-9.4	-15.8	-11.9
	S	-11.1	-10.7	-15.6

1% critical values

The results from the ADF tests are given in Table 2. The values of the test statistics indicate that we can reject the null hypothesis of the existence of unit root in levels for all variables in all periods indicating that all series are *I(0)*.[6] Given that all variables are integrated of the same order, and also given that they are an I(0) process is no need to process

[6] The LMF test results indicated that the ADF tests were free from serial correlation; for brevity we do not show the test results here.

we the Cointegration tests, we will proceed directly to perform our volatility analysis using EGARCH (p,q) modelling.

Table 3 Likelihood Ratio Test for EGARCH Model Selection for Conditional Variance Equations

	Stock Returns			Exchange Rates		
Country	**Total Sample**	**Crises**	**Post Crises**	**Total Sample**	**Crises**	**Post Crises**
Hong Kong	12.6*	12.0*	17.3*	895.8*	7.4*	3.7
South Korea	0.4	19.8*	4.9	41.0*	0.6	0.7
Singapore	1.1	0.0	1.1	1.0	12.5*	18.9*
Taiwan	8.0*	0.04	800.9*	84.2*	0.0	18.3*
Thailand	159.1*	0.0	9.7*	22.1*	2.1	17.6*

Note: H_0: EGARCH (1,1), H_1: EGARCH(2,1) The 5% critical value for the LR test distributed as χ^2 with 2 degrees of freedom is 5.99. * indicates rejection of the null hypothesis at 5% significance.

The results in Table 3 indicate that for the entire period we select the EGARCH (*2,1*) in the case Hong Kong, Taiwan and Thailand for stock prices, and for Hong Kong, South Korea, Taiwan and Thailand in the case of exchange rate changes. The EGARCH (*1,1*) model is selected for South Korea and Singapore for stock prices and for Singapore for exchange rate changes. For the crises period, we select the EGARCH (*2,1*) model for stock prices for Hong Kong and Singapore and the EGARCH (*1,1*) for Singapore, Taiwan and Thailand. For exchange rates for the crises period, we select the EGARCH (*2,1*) model for Korea and Thailand, and the EGARCH (*1,1*) for Hong Kong, Singapore and Taiwan. For the post crises period, the EGARCH (*2,1*) is selected for stock prices for Hong Kong and Taiwan, and for exchange rates for Hong Kong, Singapore, Taiwan and Thailand; the EGARCH (*1,1*) is selected for stock prices for the post crises period for Korea, Singapore and Thailand, and for exchange rates for Korea.

The estimated parameters from the EGARCH estimation are set out in Tables 7-9, for the total sample, the crises period and the post crises period respectively. Firstly, in relation to the coefficients on the volatility persistence term, the results indicate that there is significant persistence in stock returns volatility for all countries for the entire period and the post crises period, with the exception of Hong Kong. For the crises period, the persistence of volatility is significant for all countries except Thailand. For the exchange rate equation, for the total sample the coefficients are significant for all countries; for the crises period volatility persistence is significant for all countries except Thailand and for the post crises period for all countries except Taiwan. Wu (2005) notes that a necessary condition for the volatility persistence terms to be stable is that the value of the estimated coefficients should be less than one; for our results, this applies in all cases except for Hong Kong for the total sample, although we note that the coefficients are less than one in each of the sub-samples.

In terms of the coefficients for the volatility spillover effects from stock returns to exchange rate changes, we find that there are some significant differences between the results for the three time periods. All coefficients are significant for the entire sample. For the crises period, coefficients are significant for Korea, Singapore and Thailand while for the post crises period, volatility spillovers from stock markets to exchange rates were only significant for Hong Kong. The significant coefficients indicate that the volatility of stock returns was a determinant of the volatility of the exchange rate as well as indicative of integration between stock markets and exchange rate markets. Furthermore, where significant, the results indicate that volatility information contained in stock prices impacted on the behaviour of exchange rates in these markets. The lack of significant spillovers in the post crises period in all markets at 1% level indicates that there is potential for diversification between stock markets and currency markets in these countries.

In terms of volatility spillovers from exchange rates to stock markets, we found that again for the entire period, the estimated coefficients were significant for all countries; however for the crises period, coefficients for Hong Kong, Singapore and Taiwan were significant, while in the post crises period, significant volatility spillovers from exchange rates to stock markets were only found for Taiwan. The lack of significant spillovers from exchange rate changes to stock returns found here for some countries is consistent with results from Jorion (1990) as well as with Yang and Doong (2005). Jorion (1990) explained the lack of spillovers as possibly due to positive exchange rate volatility on stock returns for some firms offsetting negative exchange rate volatility on stock returns for other firms to give an insignificant or weak effect overall. In addition to this, the use of instruments to hedge exchange rate risk, may reduce the impact of exchange rate volatility on stock markets; Grant and Marshall, 1997, and Bodnar *et al.* (1995) both note that the use of hedging instruments to ameliorate exchange rate risk is pervasive amongst larger companies which are the main components of national stock market indices. The lack of significant spillovers from exchange rates to stock markets in the post crises period may thus be indicative of wider use of hedging by firms listed on the stock markets in these countries than during the crises; it is also likely that the crises itself may have contributed to more extensive use of hedging against foreign exchange rate risk.

A positive sign on the spillover coefficient indicates that an increase in volatility in one market is associated with increased volatility in the other market while a negative coefficient indicates that increase volatility in one market is associated with decreased volatility in the other market. In our results, we found a mixture of positive and negative significant coefficients for the two spillover terms; this indicates that the impact of volatility from exchange rate markets to stock markets or *vice versa* is not constant either over time for the same country, or across countries for the same period of time. Different significant results for the entire sample and subsamples were also found for some Asian markets by Caporale et al (2002) when testing for causal relationships between stock prices and exchange rate volatility.

For the asymmetric spillover effects from stock returns to exchange rates, we find significant coefficients for all countries for all time periods, with the exception of Hong Kong during the crises period where the coefficient was insignificant. Similarly, the asymmetric spillover effects from exchange rates to stock prices are significant for all countries for all time periods, with the exception of Thailand during the crises period. The insignificant coefficients indicate that the spillover effects in these instances are symmetric, that is that positive and negative shocks have the same impact on volatility, or that a decrease in stock returns has the same impact on exchange rate volatility as an increase in stock returns. The positive sign on all significant coefficients indicates that unexpected good news has a greater impact on volatility than unexpected bad news. One possible explanation for this is that good news on stock prices may have a greater impact on demand for currency so increasing volatility as foreign investors want to increase holdings of rising stocks; good news on exchange rates may have a greater impact on demand for stocks as investors switch between holdings of stocks and currency, so impacting on stock market volatility. The correlation coefficients for the standardised residuals from the stock and exchange rate equations are significant for Korea, Taiwan and Singapore for the entire period and the crises period indicating significant contemporaneous relationships between the two markets in these countries for these periods. The only significant correlation for the post crises period is for Thailand.

The diagnostic tests on the standardised residuals are listed in part B of the respective tables. The Jarque-Bera test indicates that we reject the hypothesis that they are normally distributed, hence justifying the use of the Bollerslev-Woolridge robust *t*-statistics. The Ljung-Box statistics for all three periods for all countries indicate that there are no residual linear or non linear dependencies; the one exception to this is for linear dependency in the exchange rate equation for Hong Kong for the total sample, although for the crises and post crises periods separately, the linear dependencies are absent[7].

Table 7a Volatility Spillovers Between Stock Returns and Exchange Rate Changes: Total Sample

Estimated Parameters	Hong Kong	South Korea	Singapore	Taiwan	Thailand
Volatility Persistence (Stock Returns) ($\sum b_S$)	-0.0088 (0.7880)	0.1167 (0.0000)	0.1927 (0.0000)	0.6989 (0.0000)	1.2553 (0.000)
Spillover: from Stock Returns to Exchange Rates ($\sum \delta_{S,E}$)	-0.0759 (0.0000)	-0.0382 (0.0000)	-0.0650 (0.0000)	-0.0224 (0.0167)	-0.1851 (0.0000)
Asymmetric Spillover effect:From Stock Returns to Exchange Rates ($\sum \theta_{S,E}$)	0.9875 (0.0000)	0.9927 (0.0000)	0.9870 (0.0000)	0.9277 (0.000)	0.9684 (0.0000)
Volatility Persistence (Exchange Rates) ($\sum b_E$)	1.6202 (0.0000)	0.3075 (0.0000)	0.1249 (0.0000)	0.6940 (0.0000)	0.4938 (0.0000)
Spillover: from Exchange Rates to Stock Returns ($\sum \delta_{S,E}$)	-0.0480 (0.0000)	0.0414 (0.0000)	0.0217 (0.0000)	-0.0219 (0.0000)	-0.0304 (0.0000)
Asymmetric Spillover effect:From: Exchange Rates to Stock Returns ($\sum \theta_{S,E}$)	1.0064 (0.0000)	0.9780 (0.0000)	0.9911 (0.0000)	0.9257 (0.0217)	0.9861 (0.0000)
Correlation Coefficient ($\rho_{S,E}$)	-0.022	-0.047*	-0.068*	0.999*	-0.039

Table 7b Diagnostics on Standardised Residuals: Residuals: Total Sample

	Hong Kong	South Korea	Singapore	Taiwan	Thailand
Stock return equation					
Jarque-Bera	167.99	477.31	981.08	423144	4136.70
LB(20)	20.5270 (0.425)	12.4860 (0.898)	13.3470 (0.862)	36.4330 (0.014)	25.6320 (0.178)

[7] Kanas (2000) found similar linear dependencies for the UK in the stock return equation.

$LB^2(20)$	22.3480 (0.322)	15.6310 (0.739)	9.3331 (0.979)	2.0531 (1.000)	6.6433 (0.998)
Exchange rate equation					
Jarque-Bera	228663	1970	1132	420905	247021
LB(20)	85.532 (0.000)	28.5330 (0.097)	22.7200 (0.0303)	35.4130 (0.018)	26.3690 (0.154)
$LB^2(20)$	3.404 (1.000)	60.8450 (0.000)	20.4030 (0.0433)	2.1156 (1.000)	5.3958 (1.000)

Table 8a Volatility Spillovers Between Stock Returns and Exchange Rates: Crises period

Estimated Parameters	Hong Kong	South Korea	Singapore	Taiwan	Thailand
Volatility Persistence (Stock Returns) ($\sum b_S$)	0.3760 (0.007)	0.4340 (0.015)	0.1635 (0.015)	0.1246 (0.005)	0.1714 (0.0584)
Spillover: from Stock Returns to Exchange Rates ($\sum \delta_{S,E}$)	-0.1609 (0.139)	0.1225 (0.017)	-0.1709 (0.000)	-0.0282 (0.400)	-0.1903 (0.001)
Asymmetric Spillover effect:From Stock Returns to Exchange Rates ($\sum \theta_{S,E}$)	0.1096 (0.671)	0.9859 (0.000)	0.9587 (0.000)	0.9838 (0.000)	0.8468 (0.000)
Volatility Persistence (Exchange Rates) ($\sum b_E$)	0.691 (0.000)	0.576 (0.000)	0.288 (0.004)	0.200 (0.038)	0.514 (0.511)
Spillover: from Exchange Rates to Stock Returns ($\sum \delta_{S,E}$)	0.272 (0.019)	0.013 (0.817)	0.067 (0.022)	-0.167 (0.005)	-0.012 (0.950)
Asymmetric Spillover effect:From: Exchange Rates to Stock Returns ($\sum \theta_{S,E}$)	0.815 (0.000)	0.984 (0.000)	0.998 (0.000)	0.984 (0.000)	0.462 (0.094)
Correlation Coefficient ($\rho_{S,E}$)	0.0004	0.2225*	-0.2121*	0.2138*	0.0407

Table 8b Diagnostics on Standardised Residuals: Residuals

	Hong Kong	South Korea	Singapore	Taiwan	Thailand
Stock return equation					
Jarque-Bera	204.8681	3687.1710	47.0391	13.8639	23.3531
LB(20)	32.52 (0.038)	17.95 (0.591)	17.95 (0.669)	17.65 (0.611)	9.68 (0.974)
LB²(20)	18.02 (0.586)	2.21 (1.000)	2.21 (0.641)	19.72 (0.476)	10.78 (0.958)
Exchange rate equation					
Jarque-Bera	2022.90	86.39	54.38	99.05	111852.00
LB(20)	10.38 (0.961)	15.03 (0.775)	16.12 (0.709)	22.42 (0.318)	31.45 (0.05)
LB²(20)	5.18 (1.000)	10.90 (0.949)	6.98 (0.997)	12.08 (0.913)	0.34 (1.000)

Table 9a Volatility Spillovers Between Stock Returns and Exchange Rates: Post crises period

Estimated Parameters	Hong Kong	South Korea	Singapore*	Taiwan	Thailand
Volatility Persistence (Stock Returns) ($\sum b_S$)	-0.097 (0.2085)	0.192 (0.000)	0.098 (0.000)	0.216 (0.000)	0.261 (0.000)
Spillover: from Stock Returns to Exchange Rates ($\sum \delta_{S,E}$)	-0.033 (0.021)	-0.046 (0.1073)	-0.038 (0.0575)	0.002 (0.8612)	-0.036 (0.525)
Asymmetric Spillover effect:From Stock Returns to Exchange Rates ($\sum \theta_{S,E}$)	0.991 (0.000)	0.980 (0.000)	0.991 (0.000)	0.969 (0.000)	0.939 (0.000)
Volatility Persistence (Exchange Rates) ($\sum b_E$)	0.215 (0.000)	0.100 (0.000)	0.406 (0.000)	-0.062 (0.3526)	0.538 (0.000)
Spillover: from Exchange Rates to Stock Returns ($\sum \delta_{S,E}$)	0.002 (0.8573)	-0.008 (0.5959)	0.036 (0.1679)	-0.072 (0.000)	-0.020 (0.4162)
Asymmetric Spillover effect:From: Exchange Rates to Stock Returns ($\sum \theta_{S,E}$)	0.969 (0.000)	0.961 (0.000)	0.935 (0.000)	0.981 (0.000)	0.933 (0.000)
Correlation Coefficient ($\rho_{S,E}$)	-0.006	-0.045	-0.023	0.004	-0.073*

*Hong Kong Exchange Rates Returns follows a t-distribution, standardised residuals, EGARCH(1,1) is the specification that is working for this model. Thailand Exchange Rates follows a t-distribution, standardised residuals, EGARCH (1,1) and lags (2,3). *Singapore Stock Returns standardised residuals follows a t-distribution, EGARCH (1,1)

Table 9b Diagnostics on Standardised Residuals: Residuals

	Hong Kong	South Korea	Singapore	Taiwan	Thailand
Stock return equation					
Jarque-Bera	149.32	886.63	531.85	4659373	20797.72
LB(20)	19.17 (0.511)	18.34 (0.565)	12.36 (0.903)	3.07 (1.000)	30.37 (0.064)
LB²(20)	22.41 (0.319)	9.59 (0.975)	14.91 (0.781)	0.05 (1.000)	4.01 (1.000)
Exchange rate equation					
Jarque-Bera	4715625	662	427	140	1934
LB(20)	3.16 (1.000)	24.19 (0.234)	24.91 (0.205)	18.07 (0.583)	32.70 (0.036)
LB²(20)	0.0482 (1.000)	9.4796 (0.977)	32.013 (0.043)	17.679 (0.609)	33.218 (0.032)

5. Summary and Conclusions

This paper set out to examine the volatility linkages between stock returns and exchange rates in a number of East Asian markets. While there is a significant body of evidence which investigates the relationship between the first moments of exchange rates and stock returns, the evidence on volatility linkages between the two markets is scarce and has generally been confined to investigation of the relationship for developed country markets. Thus our analysis make a clear contribution in providing more up to date information of the volatility linkages between stock prices and exchange rates which serves as a basis for increasing our understanding of the nature of integration of stock and exchange rate markets in the countries we have examined.

We examined the period 1997-2006, as well as splitting our sample to compare and contrast the volatility linkages between the two markets during the Asian financial crises, as well as after the crises. Our results indicated that for most markets, there exists significant persistence in the volatility of both exchange rates and stock returns in all periods. In addition to this, we found significant volatility spillovers between stock returns and exchange rates during the crises period for Korea, Singapore and Thailand. While Wu (2005) investigates this relationship for a number of East Asian countries, his sample ends in 2000; our results are broadly consistent with those for the crises period even though our crises sample period is slightly different than Wu's. However, there are some difference in our results for the post crises period; in particular in contrast to Wu we found no volatility spillovers between the stock and currency markets in Korea and Taiwan, and no volatility spillovers from currency markets to stock markets in Singapore and Thailand. The reduced volatility transmission from currency markets to stock returns in most markets since the Asian financial crises may be indicative of increased use of hedging instruments by firms; the lack of volatility spillovers from stock to currency markets in the post crises period may be indicative of the changes in the financial structure which have taken place since the crises.

Our results overall indicate that since the Asian financial crises, there exists significant scope for investors and portfolio managers to diversify their assets between stocks and currencies in these markets. In particular, the lack of volatility spillovers between stock markets and exchange rates in all countries, and between exchange rates and stock markets in all countries except Taiwan in the post crises period indicates that there is scope for investors to diversify their investments in these markets. From the point of view of policy, linkages between the two markets in Taiwan indicates that policymakers should take into account the impact of any exchange rate policy on stock markets, and the impact of policies relating to the stock market in terms of their impact on the exchange rate.

6. References

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