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# Can the traditional Asian US dollar Peg Exchange Rate Regime be extended to include the Japanese yen?

## Abstract

Using daily data for a select set of four Asian exchange rates, namely the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht, from October 1985 to October 2002, we apply principal components analysis and the O-GARCH model to describe the evolution and persistence in the correlations over time. We also estimate 2-, 3- and 4-variable multivariate GARCH models, without imposing the assumption of constant correlations, to investigate volatility interaction amongst the currencies. To allow for fat tails in the distributions of exchange rate changes, we use the multivariate student-t distribution in maximising our log-likelihood functions. Our results indicate the possibility of designing an Asian exchange rate system involving a number of the region's currencies.

## 1. Introduction

The Asian financial crisis 1997-98 (see Au Yong et al. (2004)) raised many questions about the appropriateness of the region's exchange rate systems. Most regional monetary authorities have traditionally managed their exchange rates relative to the US dollar (see Frankel and Wei (1994), McKinnon (2000, 2004) and Kearney and Muckley (2006a, 2006b)). This exchange rate setting practice was motivated by the possibility of achieving price stability alongside the goals of regional financial market and trade integration and the desire to avoid penalising resident investors exposed to foreign exchange rate risk. As the crisis revealed, however, this was not an optimal policy (see Mussa et al. (2000), Kwan (2001) and McKinnon and Schnabl (2003)). Asian investment and trade linkages are increasingly focused beyond the US dollar area, to include Japan and European countries, and, as a result, a volatile Yen/US\$ exchange rate has proven to be harmful for the economies concerned. For example, the US dollar appreciated relative to the Japanese yen by more than 40 percent from May 1995 through August 1998 and it is alleged that this played a central role in precipitating the Asian financial crisis.

It is worthwhile elaborating on this point, many North and Southeast Asian countries, including China and Hong Kong SAR, Indonesia, Malaysia, Singapore and Thailand, already conduct most of their trade within the region, and a significant proportion of this trade occurs with Japan and, moreover, the degree of intra regional trade integration is rising over time (see Shin and Wang (2004), Kearney and Muckley (2005) and Huang and Guo (2006)). Furthermore, a characterising feature of the Asia region is the increasing level of foreign direct investment that originates to a significant extent in Japan or the European economies (see Fukao et al. (2003) and Gao (2005)). Taken together, these emerging features help to explain why the soft dollar peg maintained by many of the North and Southeast Asian countries rendered these countries increasingly uncompetitive and their exchange rate policies increasingly untenable during the late 1990s. Indeed, these emerging trade and investment linkages imply that a future scenario of a strongly appreciating or depreciating US dollar will have an even more profound influence on the region's economies unless better exchange rate arrangements are implemented.

In recognition of this, there is an emerging debate about the need for more cooperative arrangements amongst the region's monetary authorities. Most advocated exchange rate arrangements involve variations on extending the received US dollar pegging regime to a (different) currency specific or a common basket peg arrangement or to an exchange rate system of mutual pegging such as the European Monetary System's Exchange Rate Mechanism. A significant recent development, in this regard, is the extension of the Chiang Mai Initiative in May 2005 from bilateral currency swaps alone to a type of 'multilateralization'. The extended Initiative provides a pool of reserves valued at 40 Billion US dollars which central banks may draw upon if their currencies come under speculative attack. Researchers at key organisations, such as the Institute for International Monetary Affairs and the Asian Development Bank, have advocated the development of this framework to eventually facilitate the coherence of regional foreign exchange rate and related monetary policies (see Madhur (2002) and Shinohara (2006)). Moreover, there exists an impressive array of Asian institutions with related responsibilities, including the ASEAN (+3) (Association of Southeast Asian Nations plus China, Japan and South Korea), the APEC (Asia Pacific Economic Cooperation), the EMEAP (Executives' Meeting of East Asia-Pacific Central Banks) and the six Markets group. These

institutions, with the passing of time, are incessantly extending their remit with respect to supporting and developing regional financial and monetary arrangements. To date, evidence pertaining to informing a more coherent and robust exchange rate arrangement has focused almost exclusively on the determination of the conditional mean of North and Southeast Asian exchange rate returns. Seminal contributions include Frankel and Wei (1994), McKinnon (2000), Hernandez and Montiel (2002) and Bowman (2005). Overall, these articles suggest that while the US dollar continues to be the most influential regional currency, the Japanese yen and the euro exert rising effects on several currencies, especially since the Asian financial crisis. These findings point to the promising possibility of introducing a more co-ordinated basket peg type exchange rate regime in North and Southeast Asia (see Williamson (2001), Kawai (2002) and Ogawa and Ito (2002)). While there is a growing literature advocating the basket peg exchange rate regime, as a solution to the Asia problem, there is a paucity of results regarding the compatibility of the Asian currencies, from a time series perspective, with such an exchange rate arrangement. In this article, we provide preliminary evidence with respect to the possibility of extending the existing basket peg exchange rate regime to include the Japanese yen. Japan is the most important regional economy with respect to trade and also, at least prior to the late 1990s, with respect to foreign direct investment (see Urata (2001) and Kearney and Muckley (2005)). Furthermore, researchers at the Bank of Japan have expressed an interest in deliberately pursuing the possibility of a more co-ordinated regional exchange rate arrangement in the future (see Kamada and Takagawa (2005)).

In this article, we build on this possibility by examining three simple and intuitive statistical pre-conditions for the successful extension of the *quasi* US dollar pegging regime to a common basket peg including the Japanese yen. *First*, the Japanese yen exchange rates should exhibit approximate stability. Evidently, given the Yen/US\$ exchange rate volatility at the crux of the problem, it is expected that the yen rates would not be perfectly stable. Nonetheless, this is an important criterion and should be satisfied to as great an extent as possible. *Second*, to the extent that the first precondition is not satisfied, the Japanese yen exchange rate returns ought to exhibit a high degree of multilateral correlation and, furthermore, the estimated multilateral correlation statistic should be persistent rather than erratic. The presence of this feature in the data would reflect a capacity for the yen to manage its value relative to

the candidate set of currencies in the region. Otherwise, it is likely that different currencies may have significantly different optimal management policies with respect to innovations in the Japanese yen exchange rate. For example, Williamson (2001) reports that the Korean won and the Malaysian ringgit appear to have followed a depreciating Japanese yen and the Singapore dollar appears to have followed an appreciating Japanese yen. *Finally*, periods of relative tranquillity and periods of relative volatility should not coincide across the Japanese yen rate returns. Independent time varying volatilities are tantamount to an intrinsic aversion – within a candidate bloc – to constraints with respect to co- movements between the exchange rate returns. The satisfaction of this precondition would suggest that volatility in the candidate set of currencies is determined by common factors. This is a desirable condition as it indicates that the candidate currencies are sensitive to similar factors, even in periods of relatively intense volatility, thus furthering the possibility of managing these rates together relative to a common currency basket.

The remainder of this article is structured as follows. Section 2 summarises the data studied and identifies the set of four yen rates that demonstrates the greatest degree of stability, the first of the aforementioned preconditions. Section 3 inspects the same set of currency returns with respect to the criterion of multivariate correlation, relative to all currency sets of that size. Also, the degree of persistence in the multilateral correlations in this set of currencies is calibrated. These perspectives address the second precondition. Section 4 estimates the degree of volatility transmission in the set of currencies. This evidence pertains to the third statistical precondition. The final Section summarises the main findings and draws together the main conclusions.

## **2. Stability: Data, Summary Statistics and a candidate Sub-System**

Our data set comprises daily (close of business) bilateral yen exchange rates for the Chinese yuan, the Hong Kong dollar, the Indonesian rupiah, the Korean won, the Malaysian ringgitt, the Philippine peso, the Singapore dollar, the Taiwan dollar and the Thailand baht over the period 1<sup>st</sup> October 1985 to 1<sup>st</sup> October 2002. All data comes from *Datastream International Ltd*. In our econometric analysis, they are log-differenced to convert them to continuously compounded returns, de-meanned, and

multiplied by 100. The summary statistics are provided in Table 1. It first presents the largest daily percentage appreciations and depreciations (which correspond to the minimum and maximum values, respectively). Comparing these two columns, the Indonesian rupiah has the widest range of daily changes in its yen value, followed by the Chinese yuan, the Malaysian ringgit, the Korean won and the Philippine peso. The Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht have the smallest range of daily appreciations and depreciations against the yen. The relative positions are maintained when we look at the variances. This indicates a significant degree of relative stability in the latter set of four yen exchange rate returns. Indeed, the level of instability compares quite favourably to the level of instability in the German mark exchange rates of the European countries in the 1970s prior to the introduction of a more coordinated exchange rate system for that region (see Giavazzi et al. (1986)). Moreover, taken together, Kearney and Muckley (2006b), Tse and Ng (1997) and Zhou (1998) identify rising Japanese yen effects on the Singapore dollar, the Taiwan dollar and the Thailand Baht. These findings further corroborate the emerging stability of our yen exchange rate set. Overall, therefore, we conclude that the selected yen rate returns are sufficiently stable to qualitatively satisfy the first aforementioned precondition.

The Table 1 also presents unconditional third and fourth moment summary statistics. In particular, it is noteworthy that all the exchange rate returns display significant skewness and positive excess kurtosis. This is a common feature of exchange rate returns. Indeed, it is widely acknowledged that the distribution of exchange rate changes generally exhibits leptokurtic behaviour even after allowing for GARCH effects. We therefore follow Bollerslev (1987) in specifying a student t-distribution for the standardised exchange rate innovations in our various GARCH models.

[Please Insert Table 1 here]

### **3 Multivariate Correlations: A Principal Component Analysis**

To examine our data with respect to the second precondition it is informative to estimate the multivariate correlations amongst all possible combinations of four

currencies in our dataset<sup>1</sup>. This is accomplished in a PC (principal component) analysis of all possible sub-systems. Denote a series of four bilateral yen rate returns by the matrix  $Y$  which has  $k = 4$  columns and  $T$  rows of observations. Each column is standardised  $\sim (0,1)$  such that the PC trajectories are independent of the variance discrepancies between the initial  $Y$  series. The  $k \times k$  symmetric covariance matrix,  $V$ , of the standardised data is then constructed as  $(X'X)/T$  where  $X$  is the standardised  $Y$  matrix. A decomposition of the matrix  $V$  provides the eigenvectors,  $W$ , and their corresponding eigenvalues,  $\lambda$ .

$$VW = W\lambda \quad (1)$$

The eigenvectors are used in the construction of the PC's matrix,  $P$

$$P = XW \quad (2)$$

We order the columns of the  $W$  matrix according to the size of their corresponding eigenvalues, so the  $m^{th}$  column of  $W$ ,  $w_m = (w_{1m}, \dots, w_{km})'$ , is the  $k \times 1$  eigenvector corresponding to eigenvalue  $\lambda_m$ . The eigenvalue,  $\lambda_m$ , is the  $m^{th}$  largest eigenvalue. The  $m^{th}$  PC of the system is therefore expressed as,

$$P_m = w_{1m}x_1 + \dots + w_{km}x_k \quad (3)$$

Therefore, each PC of the system is a time series of linear combinations of the standardised  $Y$  variables.

Table 2 shows the results of the PC analysis, which amounts to ranking all combinations of four variables according to their first eigenvalue i.e., their

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<sup>1</sup> Dimensionality constraints restrict our BEKK multivariate GARCH models to about four currencies at a time. We adopt this class of GARCH modelling specification to explore the third precondition.



multivariate correlations, or the extent to which the variance of the first PC captures the variance in the sub-system as a whole. The resulting currencies are the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht. Closer inspection of the Table reveals that the Hong Kong dollar appears in all of the first 10 combinations, 18 of the first 20 and 24 of the first 30. The Singapore dollar appears in 7 of the first 10 combinations, 13 of the first 20 and 20 of the first 30. The Thailand baht appears in 6 of the first 10 combinations, 10 of the first 20 and 12 of the first 30. The Taiwan dollar appears in 8 of the first 10 combinations, 15 of the first 20 and 21 of the first 30. This constitutes strong evidence with respect to the interrelatedness of our selected subset of exchange rates.

The PC results of the most highly correlated sub-system are presented in Table 3. The top panel of the Table presents the four PCs along with their eigenvalues and cumulative  $R^2$ s for the full period under analysis, and the lower panel shows the rescaled weights. It is noticeable that the eigenvalue corresponding to the first PC, at 2.895, is well above unity, with a cumulative  $R^2$  of 0.74. This shows that the first PC, which captures the trend in the data, explains almost three quarters of the total variation in the selected 4-variable system of bilateral yen exchange rate returns. It corresponds to a high degree of multilateral correlation in the sub-system. In contrast, none of the other PCs has eigenvalues in excess of one. The bottom panel shows that the rescaled weights on the first PC vary from approximately 0.26 for the Taiwan dollar and the Thailand baht to approximately 0.23 for the Singapore dollar. These weights seem intuitive in the light of the relative sizes of the economies and the importance of their currencies in the region. This sub-system of four currencies, therefore, serves as the focus of our more general multivariate GARCH models.

### **3.1 Orthogonal GARCH Modelling of Correlation Persistence**

Turning to an investigation of the time varying nature of correlations in the candidate sub-system of yen exchange rate returns. Figure 1 illustrates the behaviour over time of the six cross correlations and the multivariate correlation of our de-meaned, log differenced bilateral yen rate returns. It is readily apparent that the correlations are positively correlated and are not constant over time. These results are obtained by

first calculating the cumulative  $R^2$ s of the first principal component of the set of four bilateral yen rate returns over a 1 year window commencing in 1<sup>st</sup> October 1985. The 1 year window is then progressively moved forward 1 day at a time to the end of the period. The resulting time series of multivariate correlations corroborates the picture of positively correlated, but time-varying bilateral correlations.

Given our preliminary findings of fat tails in the distributions of our exchange rate changes and these findings of time-varying correlations, we use the t-distributed O-GARCH model of Alexander (2001, 2002) to examine the extent of persistence in the correlations. The O-GARCH model generalises the factor GARCH model of Engle, Ng and Rothschild (1990). It reduces the dimensionality problem of estimating the conditional covariance matrix by generating  $k \times k$  GARCH covariances from  $m$  univariate GARCH models, where  $k$  is the number of variables in the system and  $m$  is the number of principal components actually used. This allows us to capture the  $k$ -dimensions of the system by estimating  $m$  univariate GARCH models of the PCs of the larger system. The gain in efficiency depends on the extent to which  $m < k$ . In applying the O-GARCH model to our bilateral yen exchange rate returns, we focus on the first 2 PCs, so in our system,  $k = 9$  and  $m = 2$ . We consider the period 1<sup>st</sup> October 1985 to 1<sup>st</sup> October 2002.

Denoting the  $m \times m$  time-varying diagonal matrix of variances of the PCs by  $D_t$ , the  $k \times k$  time-varying covariance matrix of the original system  $V_t$  is approximated by

$$V_t = A D_t A' \quad (4)$$

[Please insert Figure 1 and Tables 1 and 2 here]

where  $A$  is the  $k \times m$  matrix of rescaled factor weights of the PCs. As pointed out by Alexander (2001), this representation delivers a reasonable chance of a positive definite matrix if a high cumulative  $R^2$  is achieved. A positive semi-definite matrix is assured at every point in time, even when the number of PCs,  $m$ , is much less than the number of variables,  $k$ , in the system. The accuracy of the system depends upon how correlated the data is and on how many PCs are used. In this instance the first two

PCs capture in excess of 80 percent of the total variation, so the system is highly correlated.

We estimate the standard t-GARCH (1, 1) model for the first 2 PCs of our system of 9 exchange rates.

$$\sigma_t^2 = \alpha + \beta \varepsilon_{t-1}^2 + \delta \sigma_{t-1}^2 \quad (5)$$

Here,  $\alpha$  is the constant,  $\beta$  is the market reaction term, and  $\delta$  is the volatility persistence term. Table 4 presents the results. For both PCs, the constant term is positive and statistically significant as expected. So are the market reaction terms in both equations. The volatility persistence terms indicate that there is considerable volatility persistence in both PCs. It is larger, however, in the first component, which represents the average behaviour of the overall system. This is a significant finding, because it demonstrates that although the correlations are not constant, neither do they move erratically in a way that might defy prediction. Therefore, the identified grouping of currencies is most highly correlated in a persistent fashion and, as a result, can be considered to qualitatively satisfy the second precondition.

#### 4 Volatility Interaction: Multivariate GARCH Modelling

The computing requirements to estimate multivariate GARCH models are widely known to be onerous. For example, a  $k$ -variable standard GARCH (1,1) model with parameters  $\alpha$ ,  $\beta$  and  $\delta$  necessitates the estimation of  $3[k(k+1)/2]+k$  parameters. Three methods have been proposed to get around this constraint. *First*, restrictions have been imposed on the correlation structure. In his multivariate GARCH analysis of European exchange rate volatility transmission, Bollerslev (1990) assumed

[Please insert Table 4 here]

constant conditional correlations to reduce the number of matrix inversions from 10,323 to 31 in estimating 30 parameters from 333 observations. This approach has become popular in multivariate GARCH models of stock market volatility transmission (Karolyi (1995), Koutmos and Booth (1995), Ghose and Kroner (1996), Koutmos (1996), and Theodossiou, Kahya, Koutmos and Christofi (1997)). As

Longin and Solnik (1995) and others have shown, however, neither equity returns nor exchange rate returns can be appropriately modelled under the assumption of constant correlation. *Second*, more efficient methods to model the correlations have recently been developed, including Alexander's (2001, 2002) orthogonal GARCH (O-GARCH) model and the dynamic conditional correlation (DCC-GARCH) model of Engle (2002) and Engle and Sheppard (2002). Although these latter models are useful for describing the evolution over time of the variance-covariance matrix of large systems, they do not allow examination of interactions between components of the system. This arises because the O-GARCH model imposes the assumption of zero conditional correlation between the principal components, while the DCC-GARCH model generates a conditional correlation matrix for which each element is a single ratio. *Third*, the order of multivariate GARCH specifications has been restricted to no more than five variables. Kearney and Patton (2000) point to the importance of examining sub-system specifications as the order of the model grows.

Following Fiorentini, Sentana and Calzolari (2002), we apply the student t version of the multivariate GARCH model by letting  $z_t$  denote the vector of  $N = 2, 3$  and 4 dependent variables in our models.

$$z_t = \mu_t(\Theta) + \sum_t^{1/2}(\Theta)\varepsilon_t \quad (6)$$

In (6),  $\mu_t()$  and  $vec[\sum_t()]$  are  $N$  and  $N(N+1)/2$  dimensional vectors of functions of true parameter values,  $\Theta$ .  $\sum_t^{1/2}(\Theta)$  is an  $N \times N$  'square root' matrix, and  $\varepsilon_t$  is a vector difference with the properties that

$$E(z_t / I_{t-1}) = \mu_t(\Theta), \quad (7)$$

$$V(z_t / I_{t-1}) = \sum_t(\Theta)\varepsilon_t, \quad (8)$$

and

$$\varepsilon_t = \sqrt{\frac{(v-2)\zeta_t}{\xi_t}} \mu_t \quad (9)$$

The latter property (9) implies that  $\varepsilon_t$ , conditional on  $I_{t-1}$ , the information set available at  $t-1$ , is independent and distributed as a standardised multivariate  $t$  with  $\nu$  degrees of freedom. In the expression for  $\varepsilon_t$ ,  $\xi_t$  is a Gamma variate with mean  $= \nu > 2$  and variance equal to  $2\nu$ , while the other variables are mutually independent. Because the multivariate student  $t$  approaches the multivariate normal as  $\nu \rightarrow \infty$ , the reciprocal of the degrees of freedom parameter,  $\eta = 1/\nu$  is typically used as a measure of the tail thickness.

The log likelihood function takes the following form.

$$L_T(\phi) = \sum_{t=1}^T l_t(\phi) \quad (10)$$

with,

$$l_t(\phi) = c(\eta) + d_t(\Phi) + g_t[\zeta_t(\theta), n] \quad (11)$$

$$c(\eta) = \ln \left[ \Gamma \left( \frac{N\eta + 1}{2\eta} \right) \right] - \ln \left[ \Gamma \left( \frac{1}{2\eta} \right) \right] - \frac{N}{2} \ln \left( \frac{1 - 2\eta}{\eta} \right) - \frac{N}{2} \ln \pi \quad (12)$$

$$d_t(\Theta) = -\frac{1}{2} \ln \left| \sum_t(\Theta) \right| \quad (13)$$

$$g_t[\zeta_t(\theta), n] = -\left( \frac{N\eta + 1}{2\eta} \right) \ln \left[ 1 + \frac{\eta}{1 - 2\eta} \zeta_t(\Theta) \right] \quad (14)$$

The specification of a parametric leptokurtic distribution is an alternative to the Gaussian pseudo-maximum likelihood procedure advocated by Bollerslev and Wooldridge (1992). The former approach will often yield more efficient estimators if the assumed conditional distribution is correct, but it might sacrifice consistency when it is not (see Newey and Steigerwald (1997)).

Two common parameterisations of the multivariate GARCH model are the *vec* and the Engle and Kroner (1995) *BEKK* parameterisations. We use the *BEKK* parameterisation here because it overcomes the difficulties associated with the *vec* parameterisation, namely that the latter (unless in some way constrained) does not ensure a positive definite  $\mathbf{H}_t$  matrix, which is necessary to ensure that the estimated variance is greater than or equal to zero and most importantly this is accomplished whilst parsimoniously imposing no cross equation restrictions. For the *vec* parameterisation to yield estimates which guarantee a positive semi-definite  $\mathbf{H}_t$  matrix, we would have to impose the restriction that all estimated parameters are greater than or equal to zero.

The *BEKK* parameterisation makes use of quadratic forms in such a way that no restrictions are required to ensure a positive definite  $\mathbf{H}_t$  matrix. The *BEKK* parameterisation for the multivariate GARCH (1, 1) model is written as:

$$\mathbf{H}_{t+1} = \mathbf{C}'\mathbf{C} + \mathbf{B}'\mathbf{H}_t\mathbf{B} + \mathbf{A}'\boldsymbol{\varepsilon}_t.\boldsymbol{\varepsilon}_t'\mathbf{A} \quad (15)$$

Here, the parameters  $\mathbf{C}$ ,  $\mathbf{B}$  and  $\mathbf{A}$  cannot be interpreted on an individual basis. Instead, the functions of the parameters which form the intercept terms and the coefficients of the lagged conditional variance and covariance terms and error terms that appear in Equation (15) are of interest. In order to conduct significance tests, we have to find the expected value and the standard errors of these non-linear functions, rather than the first two moments of the individual parameters that constitute them. We can calculate the expected value of a non-linear function of random variables as the function of the expected values of the parameters, if the estimated variables are unbiased. Finding the standard error of the function of estimated coefficients is not as straightforward, however, because it involves a first order Taylor series expansion of the function around its mean. This linearises the function and enables us to estimate its standard error by using the estimated asymptotic variance-covariance matrix of the parameters along with the mean and standard error vectors<sup>2</sup>. In estimating these models, we first estimate a diagonal *BEKK* model for all specifications of dimension

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<sup>2</sup> See Greene (2003) p. 70 for further discussion.

three or higher. This contributes to the achievement of convergence. Before using the derivative based *BHHH* methodology for convergence, both the diagonal and the full *BEKK* models employ a simplex technique to identify robust initial conditions. In contrast to its derivative based counterparts, this facilitates convergence by rejecting directions that cause the likelihood function to decrease. We now look at the results from our 2-, 3- and 4- variable multivariate GARCH models, showing only the coefficients that are significant at 5 percent or better in the Tables in order to ease interpretation of the results.

#### 4.1 The 2-variable models

A summary of the estimation results from the full set of possible bivariate t distributed GARCH models is presented in Table 5. The set of currencies considered contains the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht Japanese yen exchange rate returns. In all, six models are estimated on daily data, from 1<sup>st</sup> October 1985 to 1<sup>st</sup> October 2002. Rather than presenting the results of each model, the Table summarises the numbers of statistically significant parameters. Statistical significance is established at the 5 percent level both in this analysis and in the subsequent analyses of the higher dimensional models. Looking firstly at the lagged conditional variances, there is considerable interaction, with 18 of the possible 24 coefficients statistically significant. In addition, 7 of the possible 12 lagged conditional covariances are statistically significant. Looking next at the lagged variances and covariances, there is a similarly high level of interaction, with 24 of the 36 parameters statistically significant. In summary, the six bivariate GARCH models show a significant amount of interaction in the lagged conditional and unconditional variances and covariances, with no discernible evidence of any currency dominating the receipt or the transmission of the volatility.

[Please insert Table 5 here]

Regarding the extent to which the models provide a statistically adequate representation of the data we evaluate the standardised residuals,  $\tilde{\varepsilon}_t$ , where

$\tilde{\varepsilon}_t = \Sigma_t^{-1/2} \hat{\varepsilon}_t$ , of the conditional variance equations. The estimated residuals at time  $t$ ,  $\hat{\varepsilon}_t$ , are standardised by the conditional standard deviations predicted at time  $t-1$  for time  $t$ , obtained from the conditional covariance matrix,  $\Sigma_t$ , to compute the standardised residuals,  $\tilde{\varepsilon}_t$ . The Ljung-Box test statistics are computed. This test addresses whether the model adequately captures the presence of serial correlation in the first and second moments of the series. Its null hypothesis is lag length specific and the statistics for 5, 10, 15 and 20 lags are calculated. The null hypothesis characterises the process as exhibiting zero autocorrelation at the specified lag length. The diagnostic tests are not presented here for reasons of brevity; however, the Ljung-Box statistics indicate that while some models adequately capture serial correlations in the second moment others fail to do so at the 5 percent significance level<sup>3</sup>. The results are not surprising given that it would be unreasonable to expect an empirical model to completely account for the higher moments as we use daily returns that are highly leptokurtic. This article turns to higher dimensional models with a view to capturing the remaining serial correlation. Moreover, the estimation of this model on higher dimensional exchange rate systems may shed further light on volatility transmission in the region. The results of the higher dimensional models are discussed in the following Sections. Despite the unsatisfactory diagnostic tests on our bivariate t-distributed GARCH models, the models do reflect considerable volatility transmission across the set of 4 yen rate returns. This follows from the reported set of statistically significant parameter estimates.

## 4.2 The 3-variable models

As previously alluded to, it is insightful to examine the robustness of the results obtained in the 2-variable models. In this spirit, Tables 6 through 9 present the results from estimating all possible combinations of 3-variable t-distributed multivariate GARCH models using the sub-set of currencies selected in this article. Table 6 gives the results for the Hong Kong dollar – Singapore dollar – Taiwan dollar, Table 7 gives the results for Hong Kong dollar – Singapore dollar – Thailand baht, Table 8 looks at

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<sup>3</sup> The serial correlation in the second moment of the volatility of the Hong Kong dollar yen rate returns is captured to a large extent however the other currency second moments are not convincingly captured by the t-distributed 2 variable GARCH models.



Hong Kong dollar – Taiwan dollar – Thailand baht and Table 9 does likewise for Singapore dollar – Taiwan dollar – Thailand baht. Looking firstly at Table 6, virtually all the off-diagonal variance transmission coefficients and the covariance transmission coefficients are statistically significant. In particular, 13 of the 15 coefficient estimates are statistically significant. Similar results are provided for the lagged squared errors and the cross products of errors. There is substantial volatility interaction in every direction. Upon replacing the Taiwan dollar with the Thailand baht in Table 7, the interactions increase slightly, with all 36 parameter estimates statistically significant. Table 8, which replaces the Singapore dollar with the Taiwan dollar, also indicates that all parameters are statistically significant. Table 9 replaces the Hong Kong dollar with the Singapore dollar and provides curious results. It highlights the importance of considering various sub-systems of exchange rates. In contrast to Tables 7 and 8 (which also contain the Thailand Baht), Table 9 indicates that the Thailand Baht receives little volatility from the other currencies considered. Of a possible 10 parameters to capture the reception of volatility from the other currencies in the sub-system only 3 of these parameters are statistically significant. Again, for the sake of brevity, the summary diagnostic statistics are not presented, but are available from the authors on request. Summary statistics are provided for standardised residuals and squared standardised residuals. As with the 2-variable models serial correlation is tested for in the standardised and the squared standardised residuals using the Ljung and Box (1978) test. Overall, the results suggest that residuals from the estimated models are quite well behaved and that the model provides adequate descriptions of the daily exchange rate returns. Taken together, the Tables reflect considerable reception and transmission of volatility between all 4 exchange rates with the Thailand baht being the least intertwined component of this highly interdependent group.

[Please insert Tables 6, 7, 8 and 9 here]

### **4.3 The 4-variable model**

The 4-variable model of the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht is presented in Table 10. In general, the results corroborate those available from the 3 variable models, pointing to considerable interaction between all four currencies. Looking first at the conditional variance

terms, 7 of the 12 off-diagonal coefficients are statistically significant and 16 of the 36 conditional covariance terms are statistically significant. There is also considerable interaction in the squared errors and cross products of errors. 9 of the 12 off-diagonal lagged squared errors are statistically significant at the 5 percent level while 14 of the 36 parameters corresponding to the lagged cross products of residuals are statistically significant at that level. If we restrict our focus to the conditional variance and the conditional covariance terms, it is apparent that the Hong Kong dollar and the Thailand baht receive most volatility (with 8 and 9 significant terms respectfully), followed by the Taiwan dollar (with 5 significant terms), and then by the Singapore dollar receiving the least volatility (with 1 significant term). It is also noteworthy, that the Singapore dollar is the least influenced of the currencies on considering the squared errors and cross products of errors. Concerning the transmission of conditional volatility, the Singapore dollar transmits directly to each of the other three currencies, and the Hong Kong and the Taiwan dollars transmit directly to two others (excluding the Singapore dollar). The Thailand baht does not appear to transmit conditional volatility although it does transmit indirectly to the Hong Kong dollar via its lagged conditional covariance terms with the Taiwan dollar and the Singapore dollar. Equivalently, with respect to the reception of volatility, the Thailand baht receives volatility from the most sources, followed shortly after by the Hong Kong dollar, the Taiwan dollar and the Singapore dollar on considering conditional lagged variances and co-variances as well as lagged squared errors and cross products of errors.

Overall, concerning the model's capacity to capture serial correlation in the residuals' second moments, the 4-variable model does not appear as capable as the 3-variable models<sup>4</sup>. For example, while autocorrelation remains in the standardised squared residuals of the Singapore dollar and Thailand Baht series, results in respect to the Hong Kong dollar and the Taiwan dollar squared standardised residuals suggest that they are well behaved and that the model provides adequate descriptions of the daily exchange rate returns. It should be noted, however, that the Ljung-Box statistics, in respect to the Singapore dollar series reject the null hypothesis of zero serial autocorrelation at various lag lengths but not in an overwhelming sense. In contrast,

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<sup>4</sup> Again, for the sake of brevity, the summary diagnostic statistics are not presented here, but are available from the authors on request.

the null hypothesis of zero autocorrelation in the squared standardised residuals is strongly rejected for the Thailand Baht.

#### **4.4 Summary on Volatility Transmission**

Our examination of a suite of t-distributed multivariate GARCH models of different dimensions provides results that are quite robust to a distorted likelihood space and the idiosyncracies of the estimating algorithm used. We can summarise the results from our t-distributed multivariate GARCH models by recalling that our series of 6 2-variable BEKK models which capture all possible pair-wise combinations of the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht points to significant volatility interaction amongst all the currencies. This finding is corroborated by the results yielded in the four 3-variable models, and also in the 4-variable model. The conclusion emerges that this grouping of currencies appears to be quite close in terms of volatility interaction, and this finding is robust to variations with respect to dimension in our models. Taken together these results provide considerable evidence consistent with the third statistical precondition for the successful extension of the region's traditional currency basket arrangement to include the Japanese yen. In the light of this precondition, it makes sense to consider these currencies as the core of a future more coordinated exchange rate system for the region.

[Please insert Table 10 here]

### **5 Summary and Conclusions**

An extension of the traditional North and Southeast Asian exchange rate regime, i.e., an exclusive US dollar peg, to a common currency basket including the Japanese yen, is motivated by the emerging intra-regional and international nature of regional investment and trade linkages. These emerging linkages underscore the deficiencies of the traditional US dollar peg exchange rate regime and exacerbate the corresponding intrinsic susceptibility of that regime to financial crises. In the light of this motivation, this article has specified three simple and intuitive statistical preconditions for the successful extension of the traditional exchange rate regime to

include the Japanese yen. These preconditions relate to the stability, multivariate correlations and volatility of yen exchange rate returns.

Overall, the evidence gathered is consistent with the contention that the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand Baht comprise an eligible nucleus to a more co-ordinated regional exchange rate arrangement, based on the extension of the traditional US dollar peg, to a basket of currencies including both the Japanese yen and the US dollar. Specifically, this article examined nine North and Southeast Asian currencies, observed at a daily frequency, over the period 1<sup>st</sup> October 1985 through 1<sup>st</sup> October 2002. The unconditional statistical properties motivated the adoption of the multivariate student t distribution in our volatility modelling and the aforementioned set of yen rates was identified as exhibiting the greatest degree of stability. This evidence concerns the first statistical precondition. This article then adopted a principal components framework alongside the orthogonal GARCH model and found that the same set of currencies exhibits the highest degree of multivariate correlation, of all sets of that size. The correlations were demonstrated to be markedly time varying, however, it was established that there was also a high degree of persistence in the level of correlation in this set of currencies. The persistent co-movements lend considerable support to the prospect of managing these currencies as a homogeneous set relative to the Japanese yen as well as the US dollar. This constitutes evidence that the selected set of currencies satisfies, to a convincing extent, the second precondition. Finally, the article calibrated the degree of volatility transmission in the set of currencies using a suite of 2- 3- and 4- variable, BEKK specified, t-distributed multivariate GARCH models. This multi-model approach, in conjunction with a carefully implemented estimation procedure, yields results that are relatively robust to idiosyncracies in the likelihood space. Evidence consistent with common factors determining volatility was revealed. This evidence pertains to the third statistical precondition. As the three statistical preconditions are approximately satisfied it is apparent that, from a time series perspective, these bilateral yen rates might act as the nucleus of a more integrative exchange rate arrangement in North and Southeast Asia.

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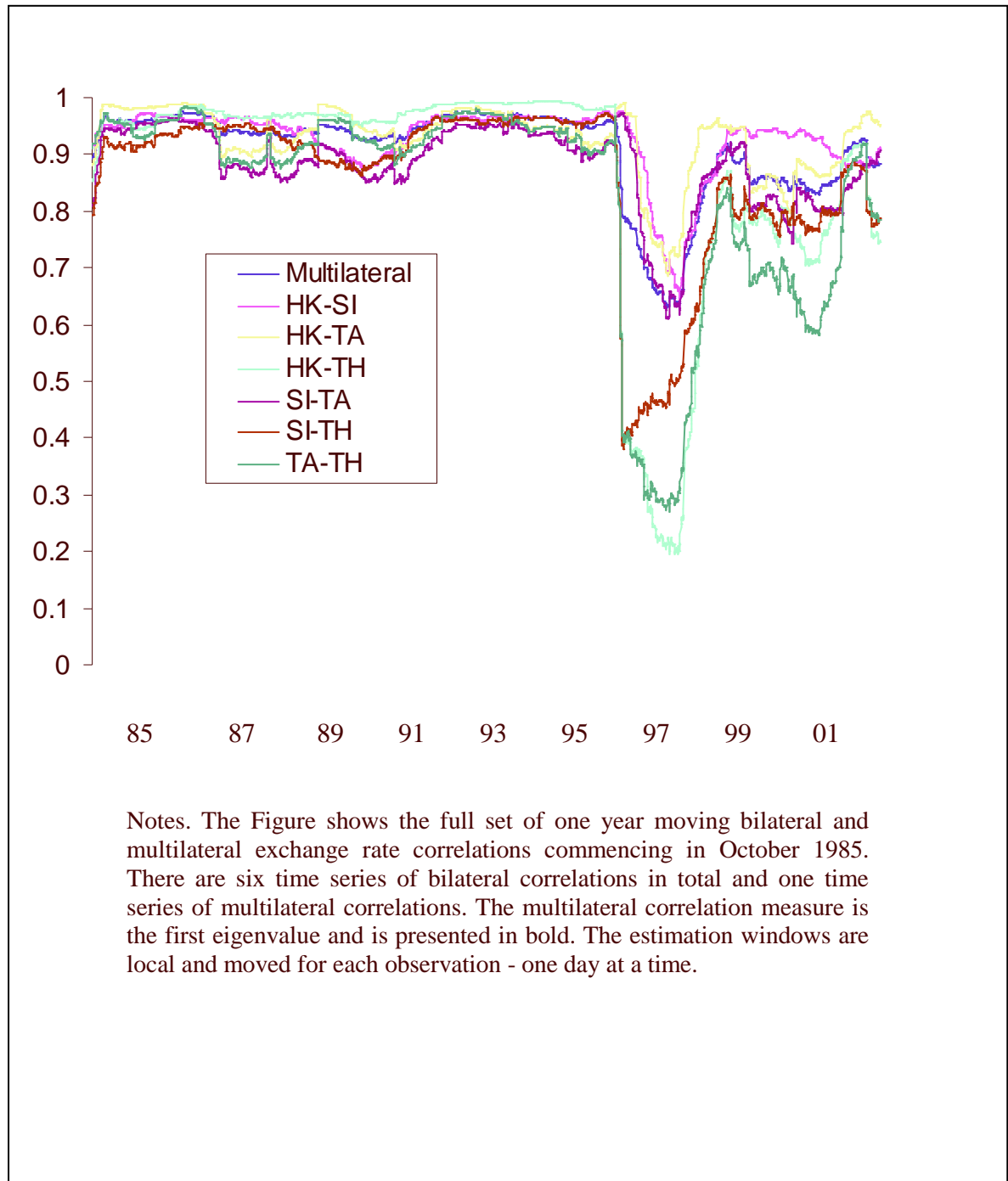
**Table 1**  
**Summary Statistics for Asian Bilateral Yen Exchange Rates**

	<b>Greatest Appreciation</b>	<b>Greatest Depreciation</b>	<b>Variance</b>	<b>Skewness</b>	<b>Kurtosis</b>
<b>China</b>	-3.425	17.734	0.255	12.889 (0.00)	405.351 (0.00)
<b>Hong Kong</b>	-1.591	2.857	0.103	0.458 (0.00)	3.830 (0.00)
<b>Indonesia</b>	-8.777	15.968	3.451	3.450 (0.00)	82.436 (0.00)
<b>Korea</b>	-8.697	6.064	0.227	-0.252 (0.00)	48.28 (0.00)
<b>Malaysia</b>	-5.113	15.615	0.196	9.327 (0.00)	360.702 (0.00)
<b>Philippines</b>	-4.583	5.389	0.226	0.726 (0.00)	15.189 (0.00)
<b>Singapore</b>	-1.643	2.326	0.096	0.368 (0.00)	2.579 (0.00)
<b>Taiwan</b>	-2.028	2.701	0.118	0.197 (0.00)	3.835 (0.00)
<b>Thailand</b>	-2.843	3.107	0.149	0.576 (0.00)	9.918 (0.00)

Notes. The Table presents summary statistics for the Asian bilateral yen exchange rates over the period 1<sup>st</sup> October 1985 to 1<sup>st</sup> October 2002. All rates are de-meanned log-differenced units of foreign currency per 1 unit of Japanese yen, multiplied by 100. The p-values in brackets are the marginal significance levels. The null hypothesis of a unit root for the log-differenced series of yen rates is rejected at the 0.01 level using both the Phillips-Perron and the Augmented Dickey Fuller tests



**Figure 1**  
**Bilateral and Multilateral Correlations of Log**  
**Differenced Yen Rates**



**Table 2**  
**Hierarchy of 4-variable Combinations with respect to Correlation**

Rank	Combination	1st Eigenvalue
1	HK SI TH TA	0.74241
2	HK MA SI TA	0.73674
3	HK PH SI TA	0.72726
4	HK KO SI TA	0.72463
5	HK SI TA Yu	0.70398
6	HK MA SI TH	0.69858
7	HK PH TH TA	0.69684
8	HK MA TH TA	0.68888
9	HK KO TH TA	0.68851
10	HK PH SI TH	0.68652
11	HK KO PH TA	0.68009
12	HK MA PH SI	0.67689
13	HK KO SI TH	0.67605
14	HK MA PH TA	0.67495
15	HK KO MA TA	0.67234
16	HK KO MA SI	0.67210
17	PH SI TH TA	0.66821
18	MA SI TH TA	0.66422
19	HK TH TA Yu	0.66343
20	HK IN SI TA	0.66066
21	HK KO PH SI	0.65913
22	HK SI TH Yu	0.65904
23	KO SI TH TA	0.65742
24	HK MA SI Yu	0.65591
25	HK KO TA Yu	0.65504
26	HK PH TA Yu	0.65319
27	HK MA TA Yu	0.64785
28	MA PH SI TA	0.64495
29	KO PH SI TA	0.64412
30	HK PH SI Yu	0.64029

Notes. The Table presents the hierarchy of those 30 combinations of 4 yen rates which exhibit the highest levels of multivariate correlation, the highest value of the 1st eigenvalue, over the period 1st October 1985 to 1st October 2002.

**Table 3**  
**Principal Component Analysis of Asian Yen Exchange Rates**

<i>Eigenvalues</i>		
<b>Component</b>	<b>Eigenvalue</b>	<b>Cumulative R<sup>2</sup></b>
P1	2.895	0.742
P2	0.530	0.856
P3	0.381	0.952
P4	0.193	0.999
<i>Rescaled Factor Weights</i>		
	<b>P1</b>	<b>P2</b>
Hong Kong dollar	-0.2466	0.1874
Singapore dollar	-0.2279	0.2374
Taiwan dollar	-0.2646	-0.0903
Thailand baht	-0.2609	-0.4849
<p>Notes. The Table presents P1 and P2 which denote, respectively, the 1<sup>st</sup> and 2<sup>nd</sup> principal components of the sub-system of daily bilateral yen exchange rates under analysis i.e., the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht over the period 1<sup>st</sup> October 1985 to 1<sup>st</sup> October 2002. The rescaled factor weights are normalized i.e. the division by series specific standard deviation has been reversed out such that the weights correspond to the initial data rather than the standardized data and the results are then standardised to sum to 1 on each principal component.</p>		

**Table 4**  
**GARCH (1, 1) Models of the First 2 Principal Components on**  
**Yen Bilateral Exchange Rates**

	<i>First principal component</i>	<i>Second principal component</i>
$\alpha$	0.039 (3.82)	2.0E-04 (5.79)
$\beta$	0.025 (6.36)	0.022 (12.01)
$\delta$	0.932 (86.93)	0.936 (216.24)

Notes. The Table presents the estimates of the orthogonal GARCH (1, 1) model. The equation estimated is specified

$$\sigma_t^2 = \alpha + \beta \varepsilon_{t-1}^2 + \delta \sigma_{t-1}^2$$

It is estimated, using the student-t conditional distribution, on the 1<sup>st</sup> and 2<sup>nd</sup> principal components of the Hong Kong dollar, the Singapore dollar, the Taiwan dollar and the Thailand baht over the period from 1<sup>st</sup> October 1985 to 1<sup>st</sup> October 2002. All exchange rates are de-meaned log-differenced units of foreign currency per 1 unit of Japanese yen, multiplied by 100. The figures in brackets are t-statistics.

**Table 5**  
**Bivariate t-distributed GARCH models**

INPUTS	NUMBER OF SIGNIFICANT INPUTS	INPUT DETAILS
<b>Lagged Conditional Variances</b>	18 total possible: 24	SI:HK(1,1)(2,2); SI:TA(1,1)(2,1)(2,2); SI:TH(all); HK:TA(1,1)(2,1)(2,2); HK:TH(1,2)(2,2); TA:TH(all)
<b>Lagged Conditional Covariances</b>	7 total possible: 12	SI:HK(2); SI:TA(2); SI:TH(all); HK:TA(2); TA:TH(all)
<b>Lagged Variances</b>	17 total possible: 24	SI:HK(1,1)(2,1)(2,2); SI:TA(1,1)(2,1)(2,2); SI:TH(1,1)(2,1)(2,2); HK:TA(1,1)(2,1)(2,2); HK:TH(1,1)(2,2); TA:TH(1,1)(2,1)(2,2)
<b>Lagged Covariances</b>	7 total possible: 12	SI:HK(2); SI:TA(2); SI:TH(all); HK:TA(2); TA:TH(all)

The Table provides a summary of all bivariate t-distributed GARCH models between the Hong Kong dollar (HK), the Singapore dollar (SI), the Taiwan dollar (TA) and the Thai baht (TH). 6 models are estimated in total. The models are estimated on daily data from 1st October 1985 through 1st October 2002. All presented inputs are significant. Significance is defined as statistical significance at the 0.05 level. The term 'all' refers to the maximum no. of observations of the respective input that exist across the models. Input details are interpreted as follows; e.g. *Lagged Conditional Variances* - SI:TA (1,1),(2,1),(2,2) - this refers to the SI lagged conditional variance in the SI conditional variance expression and to the SI and TA lagged conditional variances in the TA conditional variance expression. Similarly; e.g. *Lagged covariances* - SI:HK(2) - this refers to the lagged covariance in the HK conditional variance expression only.

**Table 6**  
**A Trivariate GARCH Model of the**  
**Hong Kong Dollar, the Singapore Dollar and the Taiwan Dollar**

Independent Variable	CV(HK) <sub>t+1</sub>	CV(SI) <sub>t+1</sub>	CV(TA) <sub>t+1</sub>
CV(HK) <sub>t</sub>	7.18E-01	7.80E-02	4.67E-02
CV(SI) <sub>t</sub>	5.46E-05		1.10E-02
CV(TA) <sub>t</sub>	3.41E-02	1.74E-01	5.86E-01
Cov(HK,SI) <sub>t</sub>	-3.90E-02		-4.70E-02
Cov(HK,TA) <sub>t</sub>	-3.13E-01	2.33E-01	-3.31E-01
Cov(SI,TA) <sub>t</sub>	8.00E-03		1.67E-01
e <sup>2</sup> (HK) <sub>t</sub>	2.14E-01	2.34E-01	1.57E-01
e <sup>2</sup> (SI) <sub>t</sub>	6.30E-02	1.26E+00	
e <sup>2</sup> (TA) <sub>t</sub>	1.10E-02	2.71E-01	2.86E-01
e(HK) <sub>t</sub> *e(SI) <sub>t</sub>	-2.33E-01	-1.08E+00	
e(HK) <sub>t</sub> *e(TA) <sub>t</sub>	-9.57E-02	5.04E-01	-4.24E-01
e(SI) <sub>t</sub> *e(TA) <sub>t</sub>	5.20E-02	-1.17E+00	6.91E-03

Notes. The Table provides the t-distributed multivariate GARCH estimates with the HongKong dollar (HK), the Singapore dollar (SI) and the Taiwan dollar (TA) on daily data from 1st October 1985 to 1st October 2002. Letting Xi denote the currencies, CV(Xi)<sub>t+1</sub> and CV(Xi)<sub>t</sub> denote, respectively, their conditional and lagged conditional variances, Cov(Xi,Xj)<sub>t</sub> denotes their conditional covariances, e<sup>2</sup>(Xi)<sub>t</sub> denotes their squared errors or ARCH effects, the e(Xi)<sub>t</sub>\*e(Xj)<sub>t</sub> denotes their products of errors. Only the statistically significant coefficients at the 0.05 level are reported.

**Table 7**  
**A Trivariate GARCH Model of the**  
**Hong Kong Dollar, the Singapore Dollar and the Thailand Baht**

Independent Variable	CV(HK)t+1	CV(Si)t+1	CV(TH)t+1
CV(HK)t	9.81E-01	8.01E-06	2.66E-05
CV(SI)t	1.72E-06	9.49E-01	5.47E-05
CV(TH)t	1.60E-07	2.29E-04	9.59E-01
Cov(HK,SI)t	0.00259	5.51E-03	7.64E-05
Cov(HK,TH)t	-7.92E-04	8.57E-05	1.01E-02
Cov(SI,TH)t	-1.05E-06	0.02948	0.01449
e <sup>2</sup> (HK)t	6.34E-02	1.33E-06	2.69E-06
e <sup>2</sup> (SI)t	4.12E-06	7.63E-02	9.34E-06
e <sup>2</sup> (TH)t	1.06E-04	2.38E-06	5.87E-02
e(HK)t*e(SI)t	1.02E-03	6.37E-04	-1.00E-05
e(HK)t*e(TH)t	-5.18E-03	-3.55E-06	7.94E-04
e(SI)t*e(TH)t	-4.18E-05	-8.52E-04	-1.48E-03
<p>Notes. The Table provides the t-distributed multivariate GARCH estimates with the Hong Kong dollar (HK), the Singapore dollar (SI) and the Thai baht (TH) on daily data from the 1st October 1985 to 1st October 2002. Letting Xi denote the currencies, CV(Xi)t+1 and CV(Xi)t denote, respectively, their conditional and lagged conditional variances, Cov(Xi,Xj)t denotes their conditional covariances, e<sup>2</sup>(Xi)t denotes their squared errors or ARCH effects, the e(Xi)t*e(Xj)t denotes their products of errors. Only the statistically significant coefficients at the 0.05 level are reported.</p>			

**Table 8**  
**A Trivariate GARCH Model**  
**of the Hong Kong Dollar, the Taiwan Dollar and the Thailand Baht**

Independent Variable	CV(HK)t+1	CV(TA)t+1	CV(TH)t+1
CV(HK)t	9.13E-01	7.81E-05	5.08E-06
CV(TA)t	1.16E-04	0.90685	3.58E-04
CV(TH)t	3.05E-06	4.61E-05	9.08E-01
Cov(HK,TA)t	2.06E-02	0.01684	8.52E-05
Cov(HK,TH)t	0.00334	1.20E-04	4.29E-03
Cov(TA,TH)t	3.76E-05	0.01293	0.03604
e <sup>2</sup> (HK)t	5.09E-01	8.18E-03	1.30E-02
e <sup>2</sup> (TA)t	1.01E-02	0.44589	8.46E-03
e <sup>2</sup> (TH)t	2.30E-02	0.00494	1.81E-01
e(HK)t*e(TA)t	1.43E-01	0.12078	2.10E-02
e(HK)t*e(TH)t	-2.16E-01	-1.27E-02	9.68E-02
e(TA)t*e(TH)t	-3.04E-02	-0.09388	7.82E-02
<p>Notes. The Table provides the t-distributed multivariate GARCH estimates with the Hong Kong dollar (HK), the Taiwan dollar (TA) and the Thai baht (TH) on daily data from 1st October 1985 to 1st October 2002. Letting Xi denote the currencies, CV(Xi)t+1 and CV(Xi)t denote, respectively, their conditional and lagged conditional variances, Cov(Xi,Xj)t denotes their conditional covariances, e<sup>2</sup>(Xi)t denotes their squared errors or ARCH effects, the e(Xi)t*e(Xj)t denotes their products of errors. Only the statistically significant coefficients at the 0.05 level are reported.</p>			



**Table 9**  
**A Trivariate GARCH Model**  
**of the Singapore Dollar, the Taiwan Dollar and the Thailand Baht**

Independent Variable	CV(SI)t+1	CV(Ta)t+1	CV(TH)t+1
CV(SI)t	8.13E-01		
CV(TA)t	5.00E-04	8.08E-01	
CV(TH)t	0.00209		0.86537
Cov(SI,TA)t	0.04032		
Cov(SI,TH)t	-8.25E-02		1.49E-02
Cov(TH,TA)t	-0.00205	-0.03604	
e <sup>2</sup> (SI)t	0.54999	3.78E-03	
e <sup>2</sup> (TA)t	1.84E-03	4.98E-01	2.98E-02
e <sup>2</sup> (TH)t	0.48266	5.75E-01	-1.07E+00
e(SI)t*e(TA)t	-6.36E-02	8.68E-02	
e(SI)t*e(TH)t	-1.03045	-9.32E-02	
e(TH)t*e(TA)t	0.05953	-1.07E+00	-4.61E-02

Notes. The Table provides the t-distributed multivariate GARCH estimates with the Singapore dollar (SI), the Taiwan dollar (TA) and the Thailand baht (TH) on daily data from the 1<sup>st</sup> October 1985 to the 1<sup>st</sup> October 2002. Letting  $X^i$  denote the currencies,  $CV(X_i)t+1$  and  $CV(X_i)t$  denote, respectively, their conditional and lagged conditional variances,  $Cov(X_i,X_j)t$  denotes their conditional covariances,  $e^2(X_i)t$  denotes their squared errors or ARCH effects, the  $e(X_i)t*e(X_j)t$  denotes their products of errors. Only the statistically significant coefficients at the 0.01 level are reported.

**Table 10**  
**The 4-Variable GARCH Model of the Hong Kong Dollar,**  
**the Singapore Dollar, the Taiwan Dollar and the Thailand Baht**

Independent Variable	CV(HK)t+1	CV(SI)t+1	CV(TA)t+1	CV(TH)t+1
<b>CV(HK)t</b>	8.72E-01		1.91E-02	1.41E-03
<b>CV(SI)t</b>	2.94E-04	9.71E-01	3.58E-04	4.39E-04
<b>CV(TA)t</b>	1.30E-03		0.68478	4.15E-04
<b>CV(TH)t</b>				9.63E-01
<b>Cov(HK,SI)t</b>	3.21E-02		5.24E-03	-1.57E-03
<b>Cov(HK,TA)t</b>	0.0673		0.22895	-1.53E-03
<b>Cov(HK,TH)t</b>	-3.51E-03			-7.37E-02
<b>Cov(SI,TA)t</b>	1.24E-03	0.03214	0.03133	8.53E-04
<b>Cov(SI,TH)t</b>	-6.45E-05			4.11E-02
<b>Cov(TH,TA)t</b>	-1.35E-04			0.00203
<b>e<sup>2</sup>(HK)t</b>	1.76E-01		2.13E-01	3.58E-02
<b>e<sup>2</sup>(SI)t</b>	0.01276	0.04356	0.01101	1.48E-02
<b>e<sup>2</sup>(TA)t</b>	1.46E-02	4.13E-03	0.55262	0.0063
<b>e<sup>2</sup>(TH)t</b>			2.50E-06	0.03814
<b>e(HK)t*e(SI)t</b>	-0.09479		9.68E-02	-4.60E-02
<b>e(HK)t*e(TA)t</b>	-1.01E-01		-6.86E-01	-0.03005
<b>e(HK)t*e(TH)t</b>				7.40E-02
<b>e(SI)t*e(TH)t</b>				-4.75E-02
<b>e(SI)t*e(TA)t</b>	0.02732	-2.68E-02	-0.15601	0.0193
<b>e(TH)t*e(TA)t</b>		-1.02E-03		-0.031
<p>The Table provides the t-distributed multivariate GARCH estimates with the Hong Kong dollar (HK), the Singapore dollar (SI), the Taiwan dollar (Ta) and the Thai baht (TH) on daily data from the 1st October 1985 to the 1st October 2002. Letting Xi denote the currencies, CV(Xi)t+1 and CV(Xi)t denote, respectively, their conditional and lagged conditional variances, Cov(Xi,Xj)t denotes their conditional covariances, e2(Xi)t denotes their squared errors or ARCH effects, the e(Xi)t*e(Xj)t denotes their products of errors. Only the statistically significant coefficients at the 0.05 level are reported.</p>				