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Correlation Dynamics between Asia-Pacific, EU and US Stock Returns

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Abstract

This paper investigates the correlation dynamics in the equity markets of 13 Asia-Pacific countries, Europe and the US using the asymmetric dynamic conditional correlation GARCH model (AG-DCC-GARCH) introduced by Cappiello, Engle and Sheppard (2006). We find significant variation in correlation between markets through time. Stocks exhibit asymmetries in conditional correlations in addition to conditional volatility. Yet asymmetry is less apparent in less integrated markets. The Asian crisis acts as a structural break, with correlations increasing markedly between crisis countries during this period though the bear market in the early 2000s is a more significant event for correlations with developed markets. Our findings also provide further evidence consistent with increasing global market integration. The documented asymmetries and correlation dynamics have important implications for international portfolio diversification and asset allocation.

Keywords: dynamic conditional correlation, asymmetry, international portfolio diversification

JEL Classification: C32, F3, G15

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1 Introduction

Over recent years there has been a large amount of research focussed on linkages between asset markets in developed economies and emerging markets. The level of interaction or interdependence between markets has important consequences in terms of predictability, portfolio diversification and asset allocation. Theory predicts that gains can be achieved through international portfolio diversification if returns in the different markets are not perfectly correlated. Policies of deregulation in and the liberalisation of capital markets, coupled with technological advances, suggests that markets have become more integrated over time. Increasing levels of integration suggests that opportunities for portfolio diversification are reduced. Moreover, evidence from crisis events such as the Asian financial crisis suggests that market comovements lead to contagion and consequently higher correlations reducing diversification opportunities. Understanding and careful estimation of the time varying nature of volatilities, covariances and correlations is paramount to capture changes in risk and identify the nature of comovement between markets.

Evidence of spillover and volatility transmission from one market to another is well established (see, *inter alia*, Engle, Ito and Lin, 1990; Hamao, Masulis and Ng, 1990). Further evidence on contagion and financial crises highlights the impact of events such as the Asian crisis and the Russian crisis on other markets across the globe (see, *inter alia*, Kaminsky and Reinhart, 1998; Edwards and Susmel, 2001; Bae, Karolyi and Stulz, 2003). In addition to these short run relationships, there is a body of evidence suggesting capital markets share common trends over the long term (Kasa, 1992; Garrett and Spyrou, 1999). This suggests that for investors with longer term investment horizons, the benefits of international portfolio diversification could be overstated. Despite the existence of such long run relationships it is unlikely that the benefits of diversification will be eroded since returns may only react very slowly to the trend. Indeed the benefits of diversification are likely to remain and hence accurate measurement of volatilities and correlations between markets is of great importance.

Moreover, it is well established that stock return correlations are not constant through time. Correlations tend to rise with economic or equity market integration (Erb, Harvey and Viskanta, 1994; Longin and Solnik, 1995; Goetzmann, Li and Rouwenhorst, 2005) They also tend to decline in bull markets and increase during bear markets (Longin and Solnik, 2001; Ang and Bekaert, 2002).

Longin and Solnik (1995, 2001) show that correlations between markets increase during periods of high market volatility, with the result that correlations would be higher than average exactly in the moment when diversification promises to yield gains. Consequently, such changes in correlations imply that the benefits to portfolio diversification may be rather modest during bear markets (Baele, 2005).

In this paper we investigate the correlation dynamics across the Asia-Pacific region and with Europe and the US using both local currency and US Dollar returns. Using the recently developed asymmetric generalised dynamic conditional correlation GARCH model (AG-DCC-GARCH) of Cappiello, Engle and Sheppard (2006) we examine how conditional correlations evolve over time. The model explicitly captures the asymmetric response of conditional volatilities and correlations to negative returns. We find evidence of asymmetries in conditional volatilities for local currency returns yet this asymmetry disappears in most markets for US Dollar returns. Further the lack of volatility feedback is most visible in countries with low correlations with the developed markets of the US and Europe. There are significant asymmetries in conditional correlations. These correlations evolve through time. Evidence of significant increases in correlation during the Asian crisis is largely limited to crisis countries. Correlations with the US and Europe do not systematically increase during this period, rather they peak during the most recent bear market. Our results also demonstrate that correlations are higher toward the end of the sample period than in the early 1990s indicative of greater market integration.

The remainder of the paper is organised as follows. Next, we briefly review the existing literature investigating asset market linkages in Asia-Pacific markets. In section three, we discuss the methodology while section four presents the results and analysis. Section five offers some concluding remarks.

2 Literature Review

Research into asset market linkages and integration in both developed markets and emerging markets has developed over recent years establishing the nature of these relationships for different assets and markets. As a consequence of the Asian financial crisis, the majority of studies have

focussed on emerging equity markets in the Pacific Basin (see, *inter alia*, Phylaktis and Ravazzolo, 2002; Manning, 2002), although there is evidence for other asset markets in the region (for example, Phylaktis (1999) using real interest rates) and for other emerging economies (for example, Bekaert and Harvey, 1995, 1997).

It is well understood that markets, developed and emerging, can move together over the short run. Janakiramanan and Lamba (1998) and Cha and Cheung (1998) examine linkages between Asia-Pacific equity markets and the US using vector autoregression (VAR) models, establishing that the US has a significant influence on these markets in addition to a number of interrelationships within the Asia-Pacific region. Further, while such research establishes spillovers in mean relationships between markets, there has been much research (initiated by Engle et al., 1990; Hamao et al., 1990) examining the presence of spillovers in volatility. More recent studies of financial crises and contagion provide further evidence that there is significant transmission across markets (Kaminsky and Reinhart, 1998; Bae et al., 2003). Consequently it is well documented that mean and volatility spillovers occur between asset markets suggesting that events in one market can be transmitted to others and that the magnitude of such inter-relationships maybe strengthened during crisis periods. Examining the nature of volatility spillovers from Japan and the US to the Pacific-Basin and the impact of financial liberalisation, Ng (2000) finds that both the US and Japan influence volatility in the Pacific-Basin region. While liberalisation is likely to be a key event, its influence describes only a small proportion of the total variation suggesting other intra-region influences are important. Similarly, Worthington and Higgs (2004) provide evidence of the transmission of return and volatility among 9 developed and emerging Asia-Pacific markets finding significant spillovers across markets using multivariate GARCH models. Kim (2005) investigates linkages between advanced Asia-Pacific markets (Australia, Hong Kong, Japan and Singapore) with the US uncovering contemporaneous return and volatility linkages which intensified after the Asian crisis.

In addition to mean and volatility spillovers, there is strong evidence to suggest that markets display common trends over the long term. A number of studies have investigated the existence of a long run equilibrium relationship between Asia-Pacific stock markets and between these markets and developed markets (see, *inter alia*, Chan, Gup and Pan, 1992; Garrett and Spyrou, 1999; Maish and Maish, 1999; Ghosh, Saidi and Johnson, 1999; Darrat and Zhong, 2002). However, recently

studies have investigated the stability of this long run relationship. Yang, Kolari and Sutanto (2004) find no evidence of long run cointegrating relationships between emerging markets and the US prior to the Asian financial crisis, but such relationships exist during the crisis period. Further, Yang, Kolari and Min (2003) examine both long run relationships and short run dynamics around the period of the Asian crisis demonstrating that linkages between markets strengthen during the crisis and that markets have remained more integrated post-crisis. Although, Manning (2002) argues that the convergence of South East Asian equity markets was abruptly halted and somewhat reversed by the crisis. The various alternative findings suggest these relationships vary thorough time and are naturally impacted by events such as the Asian crisis.

3 Methodology

In order to investigate the correlation dynamics between the Asia-Pacific equity markets we employ the asymmetric generalised dynamic conditional correlation GARCH model (AG-DCC-GARCH) of Cappiello et al. (2006). This model is the generalisation of the DCC-MVGARCH model of Engle (2002) to capture the conditional asymmetries in correlation. The DCC-MVGARCH is estimated using a two-stage procedure. In the first stage, we fit univariate GARCH models for each of the asset return series and standardized residuals (residuals standardized by their estimated standard deviations) are obtained. The second stage uses the standardized residuals to estimate the coefficients governing dynamic correlation.

Let r_t denotes a $n \times 1$ vector of return innovations (residuals) at time t , which is assumed to be conditionally normal with mean zero and covariance matrix H_t :

$$r_t | \Omega_{t-1} \sim N(0, H_t) \tag{1}$$

where Ω_{t-1} represents the information set at time $t - 1$, and the conditional covariance matrix H_t can be decomposed as follows:

$$H_t = D_t R_t D_t \tag{2}$$

where $D_t = \text{diag}\{\sqrt{h_{it}}\}$ is the $n \times n$ diagonal matrix of time-varying standard deviations from univariate GARCH models with $\sqrt{h_{it}}$ on the i th diagonal, and R_t is the $n \times n$ time-varying correlation matrix, containing conditional correlations. The proposed dynamic correlation structure is:

$$R_t = \text{diag}(Q_t)^{-1} Q_t \text{diag}(Q_t)^{-1} \quad (3)$$

$$Q_t = (\bar{Q} - A'\bar{Q}A - B'\bar{Q}B - G'\bar{N}G) + A'\varepsilon_{t-1}\varepsilon'_{t-1}A - B'Q_{t-1}B - G'\eta_{t-1}\eta'_{t-1}G \quad (4)$$

where $\text{diag}(Q_t) = [\sqrt{q_{iit}}]$ is a diagonal matrix containing the square root of the diagonal elements of Q_t , A , B and G are $n \times n$ parameter matrices, $\varepsilon_{it} = \frac{r_{it}}{\sqrt{h_{it}}}$ is the standardized residuals; $\bar{Q} = E[\varepsilon_t\varepsilon'_t] = T^{-1} \sum_{t=1}^T \varepsilon_t\varepsilon'_t$ is the unconditional correlation matrix of r_t , and $\bar{N} = E[\eta_t\eta'_t] = T^{-1} \sum_{t=1}^T \eta_t\eta'_t$, with $\eta_{it} = I[\varepsilon_{it} < 0] \circ \varepsilon_{it}$, where $I[\varepsilon_{it} < 0]$ is the indicator function which takes on value 1 if $\varepsilon_{it} < 0$ and 0 otherwise, “ \circ ” denotes the Hadamard product. This term will capture the conditional asymmetries in correlations. The generalized DCC (G-DCC) model is a special case of AG-DCC when $G = 0$. It is clear from equation (4) that Q_t will be positive-definite if $(\bar{Q} - A'\bar{Q}A - B'\bar{Q}B - G'\bar{N}G)$ is positive definite. The AG-DCC model is estimated using quasi-maximum likelihood (QMLE).¹

We can extend this model to allow for structural breaks in mean of the correlation equation. For example, we might wish to test whether a structural break has occurred in the intercept following the Asian financial crisis 1997. Let d_t be the dummy variable 1 if $t \geq \tau_{break} < T$ and 0 otherwise. In this case, equation (4) can be extended to:

$$Q_t = (\bar{Q}_1 - A'\bar{Q}_1A - B'\bar{Q}_1B - G'\bar{N}_1G)(1 - d_t) + (\bar{Q}_2 - A'\bar{Q}_2A - B'\bar{Q}_2B - G'\bar{N}_2G)(d_t) + A'\varepsilon_{t-1}\varepsilon'_{t-1}A - B'Q_{t-1}B - G'\eta_{t-1}\eta'_{t-1}G \quad (5)$$

where $\bar{Q}_1 = E[\varepsilon_t\varepsilon'_t]$ for $t < \tau_{break}$, and $\bar{Q}_2 = E[\varepsilon_t\varepsilon'_t]$ for $t > \tau_{break}$; \bar{N}_1 and \bar{N}_2 are analogously defined. Since the model in equation (5) nests the model in equation (4), it can be tested for breaks in mean of correlation process using likelihood ratio test with $k(k-1)/2$ degrees of freedom.

¹Details on the estimation method and log-likelihood functions are given in Appendix A.

We illustrate the asymmetric response of correlation to joint bad news and joint good news using news impact surfaces introduced by Kroner and Ng (1998). The news impact surface for correlation can be estimated as follows:

$$\begin{aligned}
f(\varepsilon_i \varepsilon_j) &= \frac{c_{ij} + (a_i a_j + g_i g_j) \varepsilon_i \varepsilon_j + b_i b_j \rho_{ijt}}{\sqrt{(c_{ii} + (a_i^2 + g_i^2) \varepsilon_i^2 + b_i^2)(c_{jj} + (a_j^2 + g_j^2) \varepsilon_j^2 + b_j^2)}} & \varepsilon_i, \varepsilon_j < 0 \\
f(\varepsilon_i \varepsilon_j) &= \frac{c_{ij} + a_i a_j \varepsilon_i \varepsilon_j + b_i b_j \rho_{ijt}}{\sqrt{(c_{ii} + (a_i^2 + g_i^2) \varepsilon_i^2 + b_i^2)(c_{jj} + a_j^2 \varepsilon_j^2 + b_j^2)}} & \varepsilon_i < 0, \varepsilon_j > 0 \\
f(\varepsilon_i \varepsilon_j) &= \frac{c_{ij} + a_i a_j \varepsilon_i \varepsilon_j + b_i b_j \rho_{ijt}}{\sqrt{(c_{ii} + a_i^2 \varepsilon_i^2 + b_i^2)(c_{jj} + (a_j^2 + g_j^2) \varepsilon_j^2 + b_j^2)}} & \varepsilon_i > 0, \varepsilon_j < 0 \\
f(\varepsilon_i \varepsilon_j) &= \frac{c_{ij} + a_i a_j \varepsilon_i \varepsilon_j + b_i b_j \rho_{ijt}}{\sqrt{(c_{ii} + a_i^2 \varepsilon_i^2 + b_i^2)(c_{jj} + a_j^2 \varepsilon_j^2 + b_j^2)}} & \varepsilon_i, \varepsilon_j > 0
\end{aligned} \tag{6}$$

where ε_i and ε_j are standardized residuals for markets i and j ; and c_{ii}, c_{ij}, c_{jj} are the corresponding elements of the constant matrix in correlation equation; a_i, b_i are the corresponding elements of matrices A and B ; and ρ_{ijt} is the corresponding element of unconditional correlation matrix \bar{Q} . Covariance news impact surfaces can also be obtained from the product of correlation surfaces with the appropriate component of the news impact curves from the univariate EGARCH models.

4 Data and Empirical Results

The data employed in this study are weekly observations on stock returns (continuously compounded returns based on Wednesday-to-Wednesday closing prices) from 13 Asia-Pacific equity markets, a European index and the US over the period 03/01/1991 to 28/12/2006. We choose to work with weekly data to alleviate problems associated with non-synchronous trading resulting from the fact that not all the markets are open during the same hours of the day. The specific markets are Australia (ASX All Ordinaries - AU), China (Shanghai Composite - CH), Hong Kong (Hang Seng - HK), India (BSE National - ID), Indonesia (Jakarta Composite - IN), Japan (Nikkei 225 - JP), Korea (KOSPI - KR), Malaysia (Kuala Lumpur Composite - ML), New Zealand (NZ

All share - NZ), Pakistan (Karachi SE 100 - PK), Singapore (Straits Times - SG), Taiwan (SE weighted - TW), Thailand (Bangkok SET - TH) and US (S&P500). The European index (EU) is a value weighted index of returns from France, Germany, Italy and the UK. All stock indices are expressed in both local currency and US dollars, representing unhedged and hedged returns. All data was obtained from Datastream. Figure 1 plots the local currency returns for each market over the sample period.

Tables 1 presents descriptive statistics for the returns series. Panel A reports the summary statistics for local currency returns, while panel B gives the figures for US dollar denominated returns. The majority of countries have positive mean returns with only Japan and New Zealand experiencing negative returns in local currency, while Indonesia, Japan and Thailand have negative returns in US dollars. All median returns are positive (with the exception of US dollar returns for Japan). Consistent with previous empirical evidence, most of the returns are negatively skewed.² All returns exhibit excess kurtosis and Jarque-Bera tests clearly reject the null of a Gaussian distribution in all cases.

Table 2 reports the unconditional correlations between returns in both local currency and US dollar terms. China and Pakistan have much lower correlations with the other markets, with means of 0.03 and 0.07 respectively in both local currency and US dollar terms. India has a mean correlation around 0.15 while all other markets are moderately correlated with mean correlations in the range 0.22 to 0.35.³ As would be expected the correlations with the US and the European markets relative to Australia, Hong Kong, Japan, New Zealand and Thailand are quite high. While the correlations for China, India, Indonesia, Malaysia and Pakistan are considerably smaller. Our results also take account of foreign exchange movements and the impact that this may have on the correlations. The table highlights that estimated correlations are different for local currency and US dollar returns for each market, accounting for currency variations has a significant although not systematic affect on correlation. This appears to particularly the case for countries with low correlations with the US and Europe, namely China, India, Indonesia and Pakistan. For example, the correlation between Malaysia and the US moves from 0.23 in local currency to 0.17 in US dollar terms, for a period

²China, Malaysia and Singapore have positively skewed local currency returns, while China, Japan and Thailand have positively skewed US dollar returns.

³The median correlation is (excluding China, India and Pakistan) 0.23 (0.28).

where the ringgit was pegged to the US dollar for a number of years during the current sample.

The first stage of the estimation process is to fit univariate GARCH specifications for each of the 15 return series. To account for possible asymmetry in conditional volatility we estimate EGARCH models in each case. We find evidence of asymmetry in most of the stock markets under investigation. It appears that there is very little evidence of asymmetry for a large number of the emerging markets. In particular markets that have low correlations with the US (and Europe) provide very little evidence of volatility feedback, namely China, India and Indonesia. This is the case for both local and US dollar returns.^{4,5} Parameter estimates from the univariate EGARCH models are reported in Table 3. Figure 2 plots news impact curves for 3 of the Asian markets (Korea, Malaysia and Thailand) in addition to the EU and the US for both hedged and unhedged returns. For those markets with significant volatility feedback, the curves provide clear evidence of an asymmetric response to bad news. Similarly in the case of Thailand the curves reinforce the lack of asymmetry findings of Table 3.

Given the large literature on the Asian crisis and contagion, we consider the possibility that the crisis period represented a structural break due to the large number of Asia-Pacific (and wider) markets effected. To account for this, we test for the existence of a structural break in the intercept. We also consider two alternate crisis dates: 02/07/1997 when the Thai Baht devalued and the crisis commenced, and 22/10/1997 when there were devaluations of the Taiwanese dollar and Korean won and a large fall in the Hong Kong equity market, representing the widening of the crisis. Table 4 reports the log-likelihood values from a series of models. The likelihood ratio tests reject the null hypothesis of no structural break in mean, indicating that all the models allowing for a mean break significantly outperform the non-break models. Similarly, all the asymmetric generalised DCC models outperform the non-asymmetric models. These results are supported by the BIC results. Moreover, in both local currency and US dollar models, adopting a break at 22/10/1997 (the widening of the crisis) rather than 02/07/1997 (when the crisis commenced) reduces the BIC, implying that 22/10/1997 is a more preferable break date for the crisis. We therefore report our

⁴Indeed, in some cases (China, India, New Zealand and Pakistan) we find the “good news” chasing effect documented in emerging markets, however, the positive asymmetry coefficient is typically always statistically insignificant.

⁵Evidence of asymmetry is much weaker for the hedged (US dollar) returns.

results for the AG-DCC-GARCH model with a mean break at 22/10/1997.⁶

The parameter estimates of the AG-DCC-GARCH model are reported in Table 5. Most parameter coefficients are statistically significant at conventional levels. In all cases except China, India and Indonesia we find evidence of asymmetries in conditional correlations. The conditional correlations and conditional covariances for local currency returns estimated from the AG-DCC-GARCH model with a mean break are plotted in Figure 3 for the correlations and covariances of the 14 markets with the US and Figure 4 for the correlations and covariances of the 13 markets with the EU. While correlations indicate the relationship between two returns, the covariance captures the amount of comovement between them. Thus it is possible to determine whether changes in comovement are due to a change in the correlations between markets or simply due to volatility. Figure 5 provides plots of the conditional correlations and conditional covariances between the 5 markets central to the Asian crisis; Indonesia, Korea, Malaysia, Taiwan and Thailand.⁷ On each plot the break date of 22/10/97 is marked with a vertical line, while the shaded area corresponds to the Asian crisis period 02/07/97 - 30/12/98. There is clear evidence of considerable variation in correlations and covariances in all cases. Typically the dynamic pattern of correlations is also witnessed in the corresponding covariances, although variation in volatility leads to periods of significantly different behaviour. There is evidence of further global market integration toward the end of the sample period, since correlations rise while covariances tend to fall as a consequence of decreasing volatility.

Correlations of Asia-Pacific countries with the US and the EU provide no clear pattern across the Asian crisis period. Indeed, consistent with Longin and Solnik (2001) and Ang and Bekaert (2002), analysing the time varying conditional correlations highlights that correlations with the US and the EU tend to increase and reach a maximum during the recent bear market between 2000 and 2003. Further, correlations tend to be higher post 2001 than in the early part of the sample, despite reduced correlations due to the bull market post 2003, suggesting greater equity market integration. This is particularly the case for newer emerging markets in the region such as China and India, although developed markets such as Japan also witness significantly higher correlations

⁶Aside from poorer in-sample performance, qualitatively the results do not change if a break date of 02/07/97 is adopted.

⁷We select these as the correlations and covariances to report and discuss, plots of all 105 local currency and all 105 US dollar correlations and covariances are available from the authors on request.

toward the end of the sample.

In contrast to correlations with the US and the EU, Figure 5 clearly shows a large increase in correlation among the 5 Asian crisis countries at the onset of the crisis. In most cases we witness correlations falling after the end of the crisis, yet correlations levels seem to remain higher than pre-crisis levels. The majority of correlations with Malaysia, Taiwan and Thailand in both local currency and US dollars, and with Indonesia and Korea in US dollars peak during the crisis period.⁸ The results show that the Asian crisis caused a significant increase in intra-regional correlations. However no such impact was witnessed with respect to correlations with the US and Europe.

To investigate further the impact of the observed asymmetries, we examine the news impact surfaces of Kroner and Ng (1998). Figures 6a, 6b and 6c plot the correlation news impact surfaces for Korea and Thailand with the US (6a), Europe (6b) and between themselves and Malaysia (6c) for both local currency and US dollar returns. The asymmetry in correlation to joint bad and joint good news is clearly visible in virtually all cases. The correlation news impact surface reveals a much larger response in the negative-negative (-/-) quadrant than in the positive-positive (+/+) quadrant. Hence the impact observed when negative shocks (bad news) occur simultaneously in both markets is higher than for joint positive shocks (good news) for both unhedged local currency returns and hedged US dollar returns. The effect is strongest for correlations with the US and Europe, while its presence is virtually undetectable for US dollar return correlations with Malaysia. This correspond with the relatively high levels of asymmetry reported in Table 5 for the US and the lack of asymmetry for Malaysia. The effect of asymmetry becomes even more striking when we examine the covariance news impact surfaces (Figures 7a, 7b and 7c). The combination of the correlation with the two conditional volatilities produces a huge increase in the -/- quadrant. The increase witnessed in response to joint good news is typically much lower. There is little evidence of asymmetry in the +/- and -/+ quadrants for covariances with the US and Europe, however these asymmetries are visible in covariances between Asia-Pacific markets.

⁸The results highlight that correlations with New Zealand peak in virtually every case during the Asian crisis (22/28 cases).

5 Conclusion

In this paper we investigate correlation dynamics between 13 Asia-Pacific stock markets, the EU and the US. Correlations are key to international portfolio diversification and asset allocation decisions. While most of previous literature on volatility transmission only concentrates on covariance between markets, we provide a more comprehensive view showing both dynamic covariance and dynamic correlation between asset prices across markets. Using the recently developed asymmetric generalised dynamic conditional correlation GARCH model (AG-DCC-GARCH) of Cappiello et al. (2006) we examine how conditional correlations and covariances for both local currency and hedged US Dollar returns evolve over time. We uncover evidence of wide variation in correlations through time, with conditional correlations deviating significantly from the levels of unconditional correlations. Importantly, we also establish significant asymmetry in correlations between many markets. Reinforcing the established view that correlations increase in response to bad news, crisis events, bear markets. Although importantly there seems to be little asymmetry in countries that are not highly correlated with developed markets, suggesting a link between levels of market integration and volatility feedback.

Incorporating a structural break due to the Asian crisis at 22/10/97 improves the fit of the estimated model. However, significantly, increases in conditional correlations during the Asian crisis seem to be mainly limited to crisis countries in the region, correlations involving other markets are not systematically effected. Although correlations with the US and Europe are relatively immune to the crisis, they do rise during the bear market in the early 2000s. In addition we document a general increase in correlations over the entire sample period indicative of greater global market integration.

Further we demonstrate the asymmetric response of both conditional correlations and covariances to join bad and good news highlighting that the impact of crises and bear markets on correlation are further compounded by volatility. These findings throw further light on correlation and covariance dynamics between equity markets. These dynamics highlight substantial time variation in international portfolio diversification opportunities across the Asia-Pacific, EU and US markets.

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A Maximum likelihood estimation of AG-DCC-MVGARCH model

Engle (2002) and Engle and Sheppard (2001) propose the two-step estimation of DCC-MVGARCH model:

$$r_t | \Omega_{t-1} \sim N(0, H_t) \sim N(0, D_t R_t D_t)$$

The normality assumption of r_t gives rise to a log-likelihood function. Without the normality assumption, the estimator will still have the Quasi-Maximum Likelihood (QML) interpretation. The log likelihood for this estimator can be written as:

$$L = -\frac{1}{2} \sum_{t=1}^T (n \log(2\pi) + \log |H_t| + r_t' H_t^{-1} r_t)$$

$$-\frac{1}{2} \sum_{t=1}^T (n \log(2\pi) + \log |D_t R_t D_t| + r_t' D_t^{-1} R_t^{-1} D_t^{-1} r_t)$$

Since the standardized residual, $\varepsilon_t = \frac{r_t}{\sqrt{h_t}} = D_t^{-1} r_t$, the log-likelihood function can be expressed as:

$$L = -\frac{1}{2} \sum_{t=1}^T (n \log(2\pi) + 2 \log |D_t| + \log |R_t| + \varepsilon_t' R_t^{-1} \varepsilon_t)$$

$$-\frac{1}{2} \sum_{t=1}^T (n \log(2\pi) + 2 \log |D_t| + r_t' D_t^{-1} D_t^{-1} r_t - \varepsilon_t' \varepsilon_t + \log |R_t| + \varepsilon_t' R_t^{-1} \varepsilon_t)$$

It is clear that there are two separate parts of the log-likelihood function, the volatility part containing D_t and the correlation part containing R_t . This gives rise to the two stage estimation procedure. In the first stage, each of D_t can be considered as an univariate GARCH model, therefore the log-likelihood of the volatility term is simply the sum of the log-likelihoods of the individual GARCH equations for the assets:

$$\begin{aligned}
L = & -\frac{1}{2} \sum_{t=1}^T (n \log(2\pi) + 2 \log |D_t| + r_t' D_t^{-1} D_t^{-1} r_t) \\
& -\frac{1}{2} \sum_{t=1}^T (n \log(2\pi) + 2 \log |D_t| + r_t' D_t^{-2} r_t) \\
& -\frac{1}{2} \sum_{t=1}^T \left(n \log(2\pi) + \sum_{i=1}^n \left(\log(h_{it}) + \frac{r_{it}^2}{h_{it}} \right) \right) \\
& -\frac{1}{2} \sum_{i=1}^n \left(T \log(2\pi) + \sum_{t=1}^T \left(\log(h_{it}) + \frac{r_{it}^2}{h_{it}} \right) \right)
\end{aligned}$$

In the second stage, the DCC parameters are estimated using the specified log-likelihood of the correlation part, conditioning on the parameters estimated in the first stage likelihood:

$$L_C = -\frac{1}{2} \sum_{t=1}^T (\log |R_t| + \varepsilon_t' R_t^{-1} \varepsilon_t - \varepsilon_t' \varepsilon_t)$$

It should be noted that the two-step estimation of the likelihood function means that estimation is inefficient, though consistent (Engle and Sheppard, 2001; Engle, 2002).

Table 1: Summary Statistics

This table reports summary statistics for weekly (Wednesday to Wednesday) stock returns. The sample period is 02/01/1991 - 27/12/2006. *AU* is the ASX All Ordinaries (Australia), *CH* is the Shanghai Composite (China), *HK* is the Hang Seng (Hong Kong), *ID* is the BSE National (India), *IN* is the Jakarta Composite (Indonesia), *JP* is the Nikkei 225 (Japan), *KR* is the Kopsi Composite (Korea), *ML* is the Kuala Lumpur Composite (Malaysia), *NZ* is the DS Total Market (New Zealand), *PK* is the Karachi SE 100 (Pakistan), *SG* is the Straits Times (Singapore), *TW* is the weighted SE index (Taiwan), *TH* is the Bangkok S.E.T. (Thailand), *EU* is a value weighted index of returns from France, Germany, Italy and the UK and *US* is the S&P500 Composite. * indicates significance at 1 percent.

Series	Mean	Median	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
Panel A: Local currency returns						
<i>AU</i>	0.0783	0.0809	0.7297	-0.2761	4.3363	43.84*
<i>CH</i>	0.1550	0.1148	2.5187	2.1910	28.601	813.36*
<i>HK</i>	0.0969	0.1736	1.4394	-0.5130	4.7359	56.716*
<i>ID</i>	0.1343	0.2783	1.7484	0.0412	6.2278	190.38*
<i>IN</i>	0.0778	0.1643	1.5015	-0.0892	5.3233	114.66*
<i>JP</i>	-0.0170	0.0189	1.2763	-0.0040	4.1727	38.348*
<i>KR</i>	0.0373	0.0212	1.7721	-0.1142	4.8708	80.917*
<i>ML</i>	0.0400	0.0562	1.5001	0.4260	12.3453	743.54*
<i>NZ</i>	-0.0670	0.0809	0.9003	-0.0979	6.7182	232.45*
<i>PK</i>	0.1472	0.2019	1.7280	-0.3452	5.0762	83.644*
<i>SG</i>	0.0603	0.0407	1.2476	0.0069	5.6091	138.47*
<i>TW</i>	0.0308	0.0686	1.6428	-0.1990	4.9570	83.962*
<i>TH</i>	0.0070	0.0615	1.7356	0.1723	4.3554	47.030*
<i>EU</i>	0.0653	0.1244	0.8981	-0.4187	6.1587	152.79*
<i>US</i>	0.0760	0.1292	0.9031	-0.1164	5.1680	102.16*
Panel B: US Dollar returns						
<i>AU</i>	0.0796	0.1740	0.9840	-0.3378	3.4653	16.213*
<i>CH</i>	0.1336	0.1232	2.6240	1.5121	25.047	1254.6*
<i>HK</i>	0.0971	0.1860	1.4474	-0.5121	4.6811	54.485*
<i>ID</i>	0.0879	0.1945	1.8118	-0.3037	5.5440	119.20*
<i>IN</i>	-0.0028	0.0000	2.4154	-0.8054	13.7600	528.74*
<i>JP</i>	-0.0099	-0.0040	1.4114	0.0929	4.1730	37.996*
<i>KR</i>	0.0237	0.0000	2.1223	-0.7821	10.0035	378.44*
<i>ML</i>	0.0262	0.0571	1.8264	-0.9958	21.203	1363.8*
<i>NZ</i>	0.0766	0.1825	1.1239	-0.3735	5.6568	120.84*
<i>PK</i>	0.0935	0.1780	1.7420	-0.3583	5.0629	81.921*
<i>SG</i>	0.0668	0.0642	1.3284	-0.1541	5.9226	160.09*
<i>TW</i>	0.0210	0.1005	1.7432	-0.2567	4.9055	77.809*
<i>TH</i>	-0.0111	0.0163	1.9437	0.0655	5.1981	105.66*
<i>EU</i>	0.0707	0.0943	0.9008	-0.4395	5.3717	95.049*

Table 2: Correlation Matrix

This table reports unconditional correlation coefficients for for weekly (Wednesday to Wednesday) stock returns. The sample period is 02/01/1991 - 27/12/2006. *AU* is the ASX All Ordinaries (Australia), *CH* is the Shanghai Composite (China), *HK* is the Hang Seng (Hong Kong), *ID* is the BSE National (India), *IN* is the Jakarta Composite (Indonesia), *JP* is the Nikkei 225 (Japan), *KR* is the Kopsi Composite (Korea), *ML* is the Kuala Lumpur Composite (Malaysia), *NZ* is the DS Total Market (New Zealand), *PK* is the Karachi SE 100 (Pakistan), *SG* is the Straits Times (Singapore), *TW* is the weighted SE index (Taiwan), *TH* is the Bangkok S.E.T. (Thailand), *EU* is a value weighted index of returns from France, Germany, Italy and the UK and *US* is the S&P500 Composite. Coefficients below the diagonal are US\$ returns, above the diagonal they are local currency returns.

	<i>AU</i>	<i>CH</i>	<i>HK</i>	<i>ID</i>	<i>IN</i>	<i>JP</i>	<i>KR</i>	<i>ML</i>	<i>NZ</i>	<i>PK</i>	<i>SG</i>	<i>TW</i>	<i>TH</i>	<i>EU</i>	<i>US</i>
<i>AU</i>	1	0.1017	0.4663	0.1751	0.2356	0.3726	0.2726	0.2754	0.5201	0.1151	0.4006	0.2415	0.2710	0.4148	0.5064
<i>CH</i>	0.0804	1	0.0537	0.0581	0.0532	0.0203	0.0108	0.0126	0.0506	0.0024	0.0437	0.0035	0.0334	0.0111	-0.0032
<i>HK</i>	0.4680	0.0384	1	0.1796	0.3102	0.3287	0.4105	0.4029	0.3426	0.0561	0.6094	0.3152	0.3955	0.4152	0.4228
<i>ID</i>	0.2120	0.0399	0.1663	1	0.1770	0.1571	0.2135	0.1272	0.1045	0.1559	0.2068	0.1809	0.1805	0.1159	0.1104
<i>IN</i>	0.2466	0.0370	0.3214	0.1273	1	0.1916	0.2434	0.4003	0.1603	0.1239	0.4020	0.2090	0.4382	0.1609	0.1438
<i>JP</i>	0.3249	0.0184	0.3148	0.1539	0.1653	1	0.3227	0.2141	0.2528	0.0193	0.3592	0.2821	0.1950	0.2842	0.3575
<i>KR</i>	0.2948	0.0096	0.3940	0.2040	0.2299	0.3432	1	0.2377	0.2154	0.0497	0.3800	0.2820	0.3720	0.2499	0.2800
<i>ML</i>	0.2289	-0.0043	0.3615	0.1253	0.4269	0.1996	0.2074	1	0.2525	0.1244	0.5578	0.2658	0.4379	0.1526	0.2266
<i>NZ</i>	0.5626	0.0594	0.3366	0.1212	0.1783	0.2769	0.2497	0.2110	1	0.0082	0.3220	0.2056	0.2170	0.3518	0.3726
<i>PK</i>	0.1183	-0.0092	0.0751	0.1578	0.0879	-0.0028	0.0020	0.0991	0.0454	1	0.1215	0.0472	0.1197	-0.0304	0.0470
<i>SG</i>	0.4155	0.0434	0.6046	0.2217	0.4215	0.3542	0.3504	0.5173	0.3608	0.1221	1	0.3253	0.5066	0.3389	0.3660
<i>TW</i>	0.2698	-0.0292	0.3397	0.1938	0.2029	0.2656	0.2831	0.2799	0.2351	0.0657	0.3654	1	0.2424	0.2275	0.2346
<i>TH</i>	0.3253	0.0283	0.4159	0.2018	0.4506	0.2035	0.3486	0.4450	0.2524	0.1342	0.5561	0.2753	1	0.2416	0.2316
<i>EU</i>	0.3917	0.0459	0.3841	0.1368	0.1012	0.2683	0.2461	0.1315	0.4002	0.0175	0.3365	0.2118	0.2002	1	0.6619
<i>US</i>	0.4229	0.0019	0.4204	0.1094	0.1120	0.3078	0.2697	0.1666	0.3281	0.05828	0.3437	0.2324	0.2143	0.6036	1

Table 3: Univariate Asymmetric GARCH models

This table reports parameter estimates for the univariate EGARCH models for weekly (Wednesday to Wednesday) stock returns. The sample period is 02/01/1991 - 27/12/2006. *AU* is the ASX All Ordinaries (Australia), *CH* is the Shanghai Composite (China), *HK* is the Hang Seng (Hong Kong), *ID* is the BSE National (India), *IN* is the Jakarta Composite (Indonesia), *JP* is the Nikkei 225 (Japan), *KR* is the Kopsi Composite (Korea), *ML* is the Kuala Lumpur Composite (Malaysia), *NZ* is the DS Total Market (New Zealand), *PK* is the Karachi SE 100 (Pakistan), *SG* is the Straits Times (Singapore), *TW* is the weighted SE index (Taiwan), *TH* is the Bangkok S.E.T. (Thailand), *EU* is a value weighted index of returns from France, Germany, Italy and the UK and *US* is the S&P500 Composite. * indicates parameters insignificant at 5%.

Series	Panel A: Local currency returns				Panel B: US Dollar returns			
	ω	α	β	γ	ω	α	β	γ
<i>AU</i>	-0.2074	0.1928	0.9230	-0.1185	-0.0360*	0.0214*	0.7304	-0.1636
<i>CH</i>	-0.2598	0.3901	0.9747	0.0380*	-0.2693	0.4079	0.9747	0.0303*
<i>HK</i>	-0.1350	0.1802	0.9858	-0.0023*	-0.1389	0.1849	0.9855	-0.0024*
<i>ID</i>	-0.2058	0.3936	0.9000	0.0003*	-0.0938*	0.3404	0.8510	-0.0411*
<i>IN</i>	-0.0866	0.1289	0.9834	-0.0103*	-0.1444	0.2150	0.9848	-0.0232*
<i>JP</i>	-0.0909	0.1395	0.9505	-0.0933	-0.1046	0.1602	0.9627	-0.0872
<i>KR</i>	-0.0686	0.0942	0.9921	-0.0467	-0.1093	0.1648	0.9813	-0.0669
<i>ML</i>	-0.1941	0.2625	0.9797	-0.0353	-0.1888	0.2599	0.9913	-0.0080*
<i>NZ</i>	-0.1226	0.1550	0.9833	0.0424	-0.1525	0.2082	0.9424	0.0011*
<i>PK</i>	-0.1828	0.4597	0.8267	0.0085*	-0.1619	0.4449	0.8223	0.0100*
<i>SG</i>	-0.1449	0.1940	0.9723	-0.0465	-0.1414	0.1937	0.9745	-0.0405
<i>TW</i>	-0.1698	0.2697	0.9485	-0.0306*	-0.1521	0.2704	0.9362	-0.0378*
<i>TH</i>	-0.0766	0.1098	0.9886	-0.0062*	-0.0811	0.1217	0.9863	-0.0131*
<i>EU</i>	-0.1672	0.1816	0.9425	-0.0982	-0.2038	0.2348	0.9439	-0.0757
<i>US</i>	-0.1441	0.1612	0.9582	-0.1129	-0.1441	0.1612	0.9582	-0.1129

Table 4: Log-likelihood values

This table reports log-likelihood values for six estimated DCC GARCH models for both local currency returns and US Dollar returns. *DCC* is the Dynamic Conditional Correlation, *AG-DCC* is Asymmetric Generalized Dynamic Conditional Correlation. We test for a break due to the Asian Crisis, at 02/07/1997 when the Thai Baht devalued (commencement of the crisis) and 22/10/1997 when the Taiwanese Dollar and Korean Won devalued and the Hong Kong stock market fell (crisis spreads throughout the region).

Model	Log-likelihood Value	No. of parameters in the correlation evolution	BIC
Panel A: Local currency returns			
<i>DCC</i>	-16191.5	105 + 2	39.644
<i>DCC</i> w/ mean break at 02/07/1997	-15811.1	210 + 2	39.578
<i>DCC</i> w/ mean break at 22/10/1997	-15802.3	210 + 2	39.557
<i>AG - DCC</i>	-15792.6	105 + 102	39.494
<i>AG - DCC</i> w/ mean break at 02/07/1997	-15427.3	210 + 102	39.465
<i>AG - DCC</i> w/ mean break at 22/10/1997	-15418.1	210 + 102	39.443
Panel B: US Dollar returns			
<i>DCC</i>	-16130.4	105 + 2	39.497
<i>DCC</i> w/ mean break at 02/07/1997	-15702.3	210 + 2	39.318
<i>DCC</i> w/ mean break at 22/10/1997	-15981.6	210 + 2	39.292
<i>AG - DCC</i>	-16001.3	105 + 102	39.994
<i>AG - DCC</i> w/ mean break at 02/07/1997	-15646.1	210 + 102	39.989
<i>AG - DCC</i> w/ mean break at 22/10/1997	-15633.6	210 + 102	39.959

Table 5: AG-DCC GARCH models

This table reports parameter estimates for the AG-DCC GARCH model for weekly (Wednesday to Wednesday) stock returns. The sample period is 02/01/1991 - 27/12/2006. *AU* is the ASX All Ordinaries (Australia), *CH* is the Shanghai Composite (China), *HK* is the Hang Seng (Hong Kong), *ID* is the BSE National (India), *IN* is the Jakarta Composite (Indonesia), *JP* is the Nikkei 225 (Japan), *KR* is the Kopsi Composite (Korea), *ML* is the Kuala Lumpur Composite (Malaysia), *NZ* is the DS Total Market (New Zealand), *PK* is the Karachi SE 100 (Pakistan), *SG* is the Straits Times (Singapore), *TW* is the weighted SE index (Taiwan), *TH* is the Bangkok S.E.T. (Thailand), *EU* is a value weighted index of returns from France, Germany, Italy and the UK and *US* is the S&P500 Composite. * indicates parameters insignificant at 5%.

Panel A: Local currency returns				Panel B: US Dollar returns		
Series	a^2	b^2	g^2	a^2	b^2	g^2
<i>AU</i>	0.0030	0.9778	0.0013	0.0022	0.9596	0.0015
<i>CH</i>	0.0009*	0.8126	0.0002*	0.0008*	0.6165	0.0001*
<i>HK</i>	0.0063	0.9489	0.0035	0.0058	0.9242	0.0018
<i>ID</i>	0.0011*	0.9358	0.0003*	0.0004*	0.8993	0.0001*
<i>IN</i>	0.0058	0.9416	0.0006*	0.0079	0.9273	0.0004*
<i>JP</i>	0.0031	0.9559	0.0019	0.0030	0.9486	0.0022
<i>KR</i>	0.0030	0.9526	0.0028	0.0019	0.9601	0.0028
<i>ML</i>	0.0049	0.9069	0.0015	0.0053	0.9006	0.0004*
<i>NZ</i>	0.0003*	0.9176	0.0013	0.0001*	0.8655	0.0002*
<i>PK</i>	0.0002*	0.7437	0.0001*	0.0001*	0.6961	0.0001*
<i>SG</i>	0.0077	0.9719	0.0020	0.0080	0.9628	0.0019
<i>TW</i>	0.0006	0.9152	0.0011	0.0005*	0.9167	0.0014
<i>TH</i>	0.0073	0.9010	0.0016	0.0066	0.8844	0.0022
<i>EU</i>	0.0032	0.9658	0.0027	0.0028	0.9598	0.0017
<i>US</i>	0.0020	0.9749	0.0051	0.0020	0.9745	0.0052

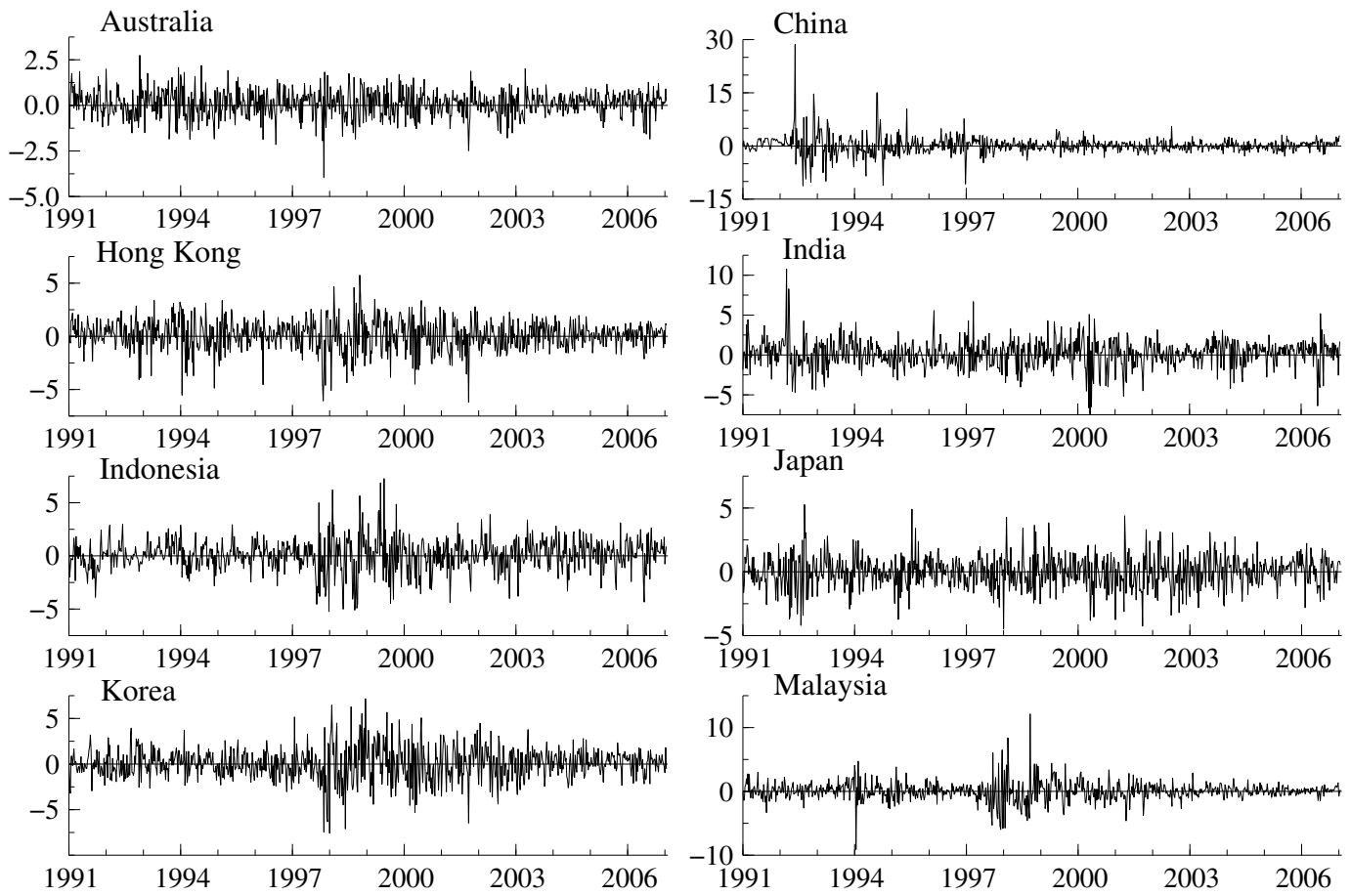


Figure 1: Stock Returns

Weekly (Wednesday to Wednesday) local currency returns from 03/01/1991 to 28/12/2006.

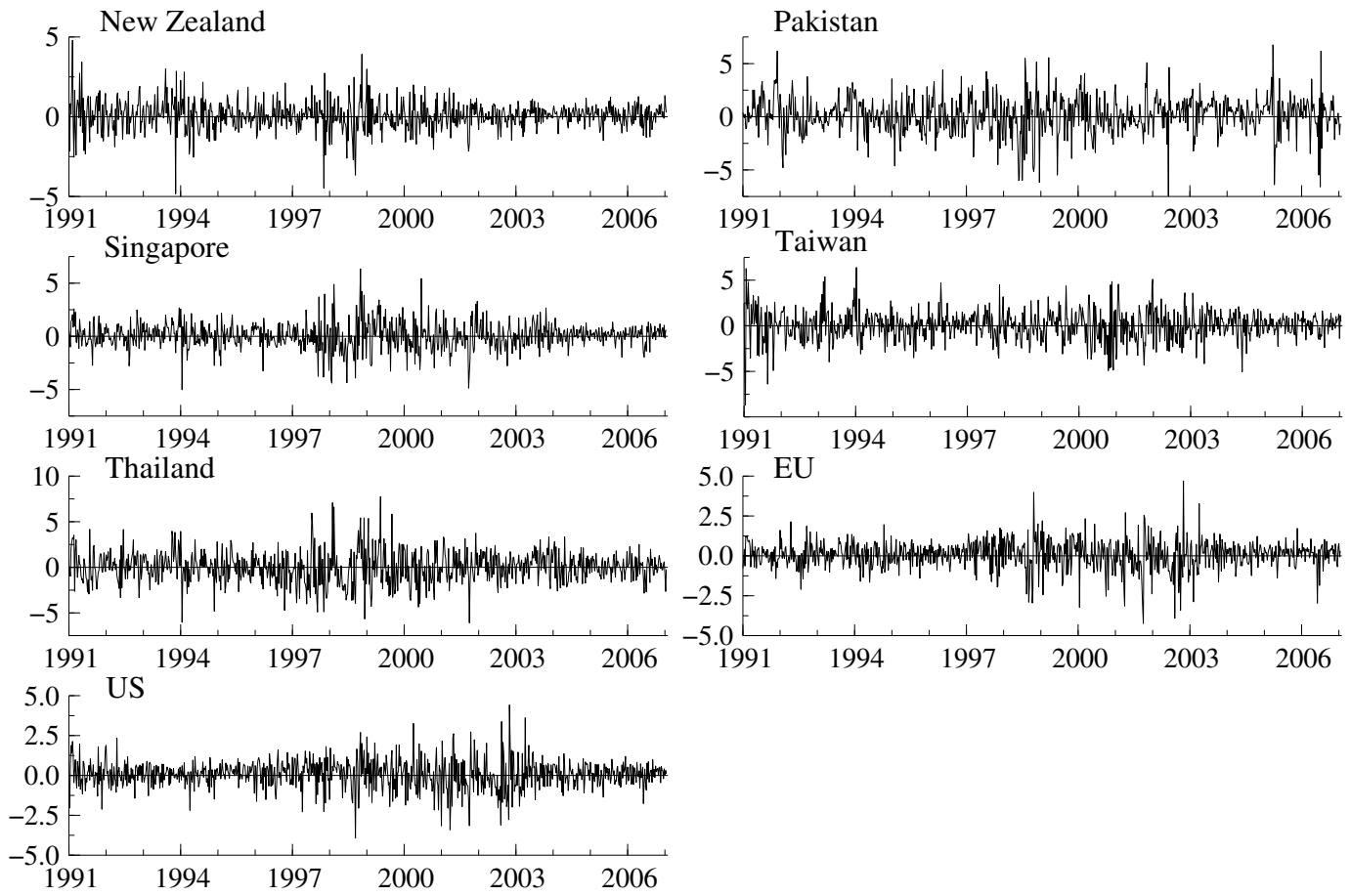


Figure 1 (cont.): Stock Returns

Weekly (Wednesday to Wednesday) local currency returns from 03/01/1991 to 28/12/2006.

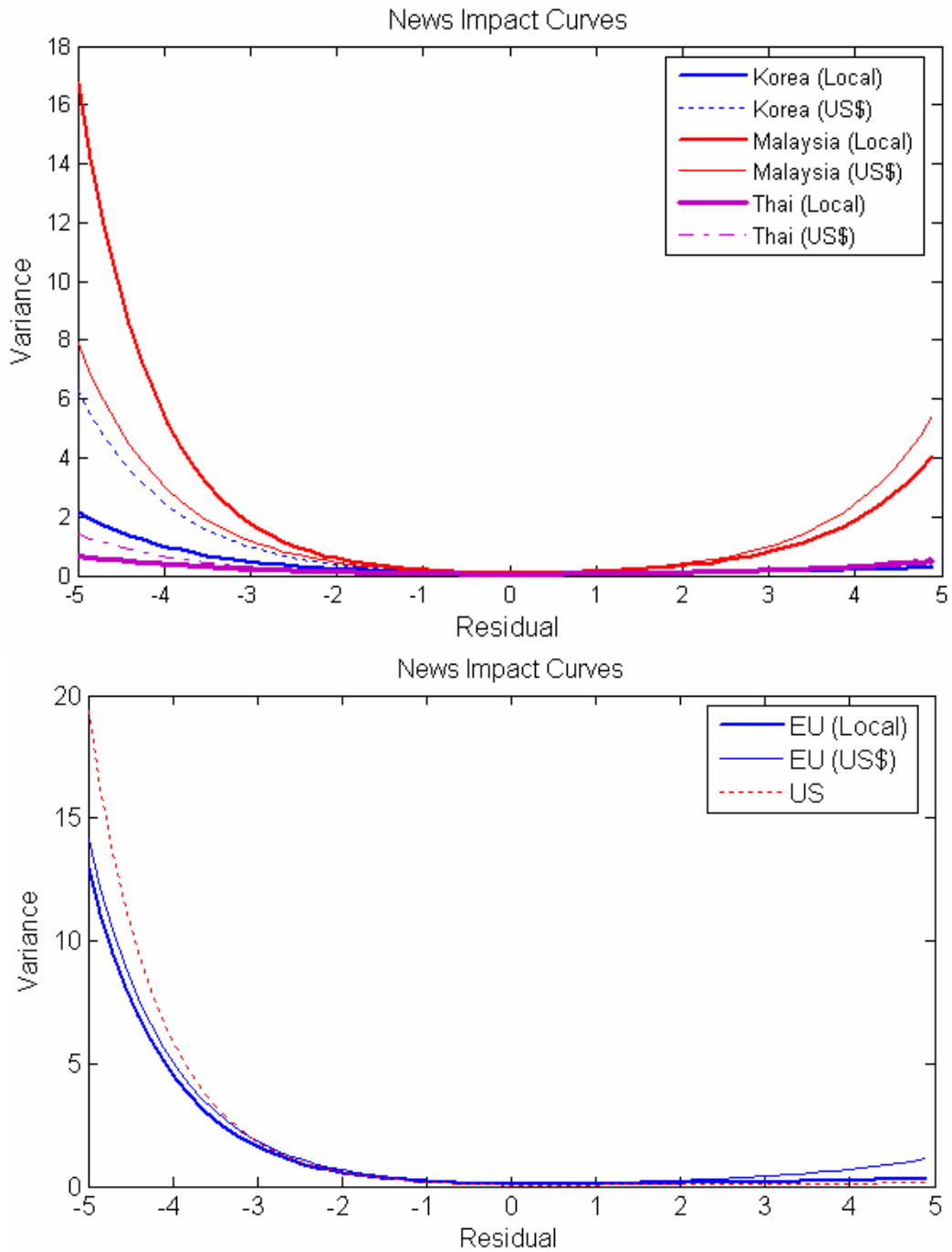


Figure 2 : News Impact Curves

News impact curves from univariate asymmetric GARCH models (for both local currency and US dollar returns) for Korea, Malaysia, Thailand, the EU and the US.

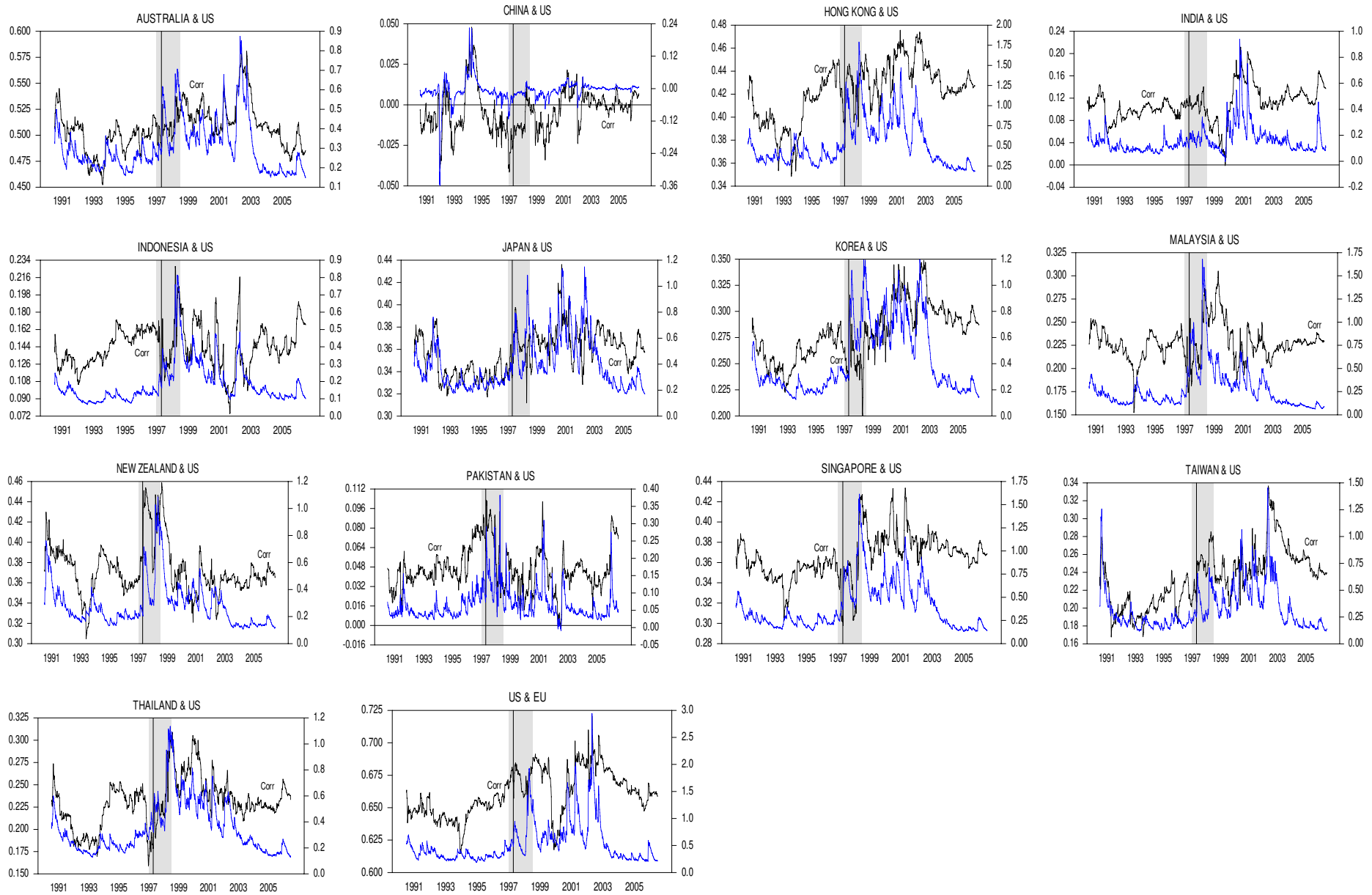


Figure 3 : Conditional Correlations and Conditional Covariances with US

Conditional correlations and covariances for local currency returns. Shaded area corresponds to Asian crisis period 02/07/1997 – 30/12/1998. Line corresponds to break at 22/10/1997.

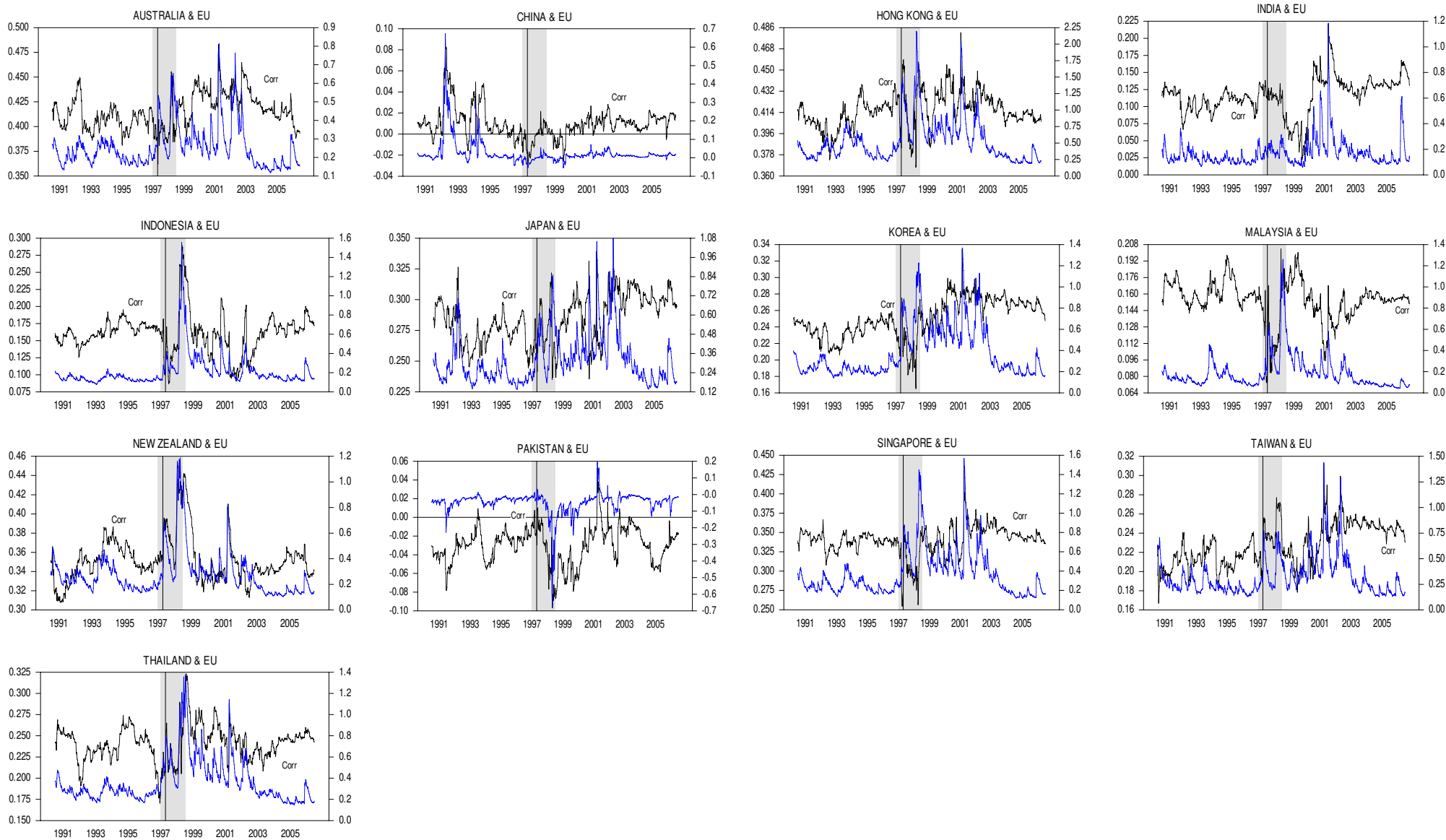


Figure 4 : Conditional Correlations and Conditional Covariances with EU

Conditional correlations and covariances for local currency returns. Shaded area corresponds to Asian crisis period 02/07/1997 – 30/12/1998.

Line corresponds to break at 22/10/1997.

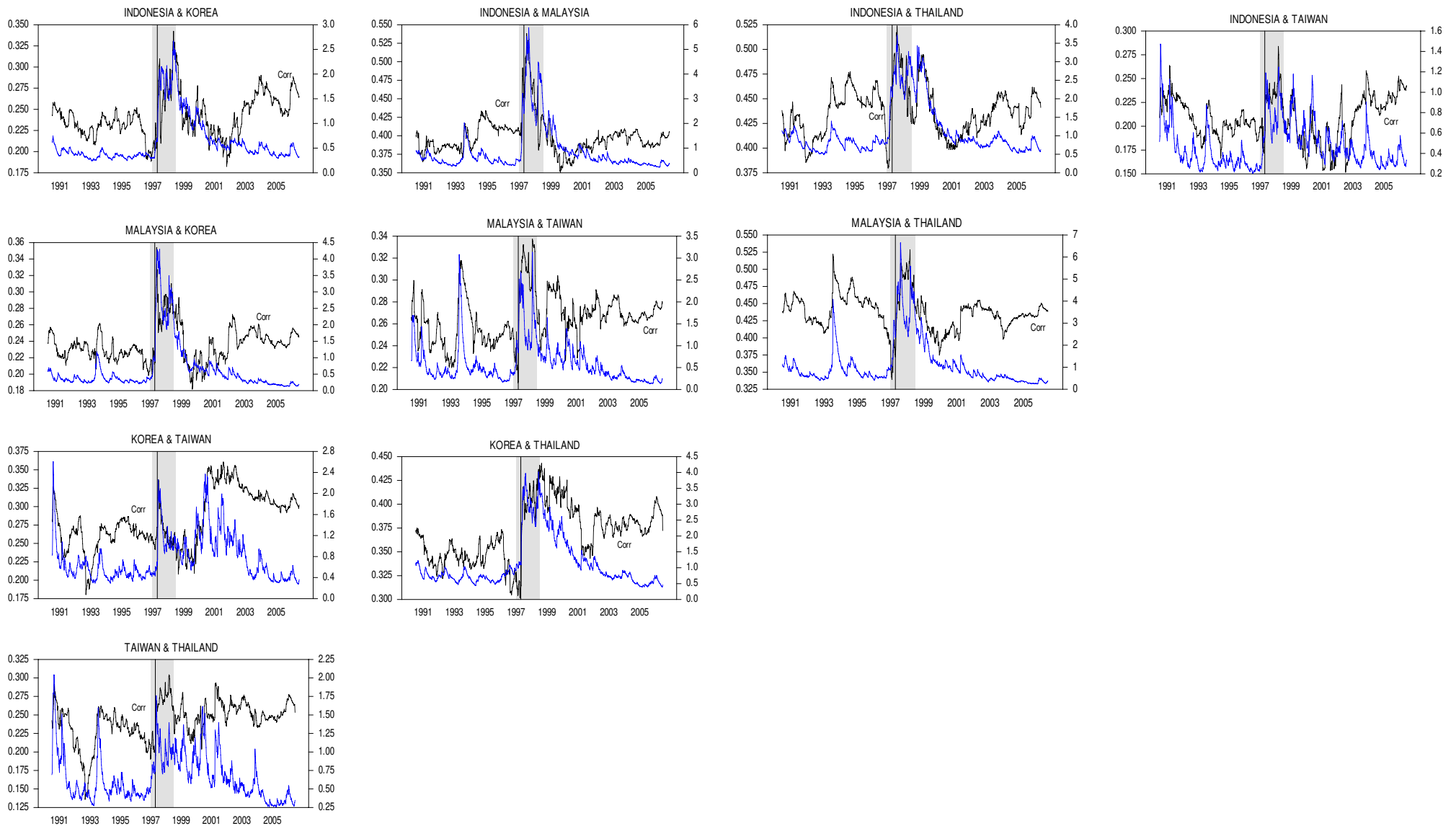
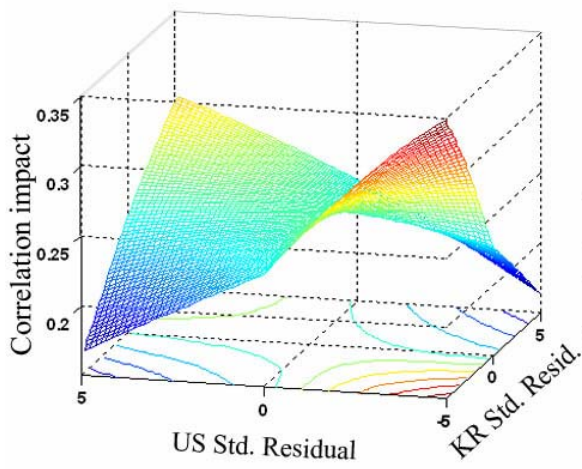
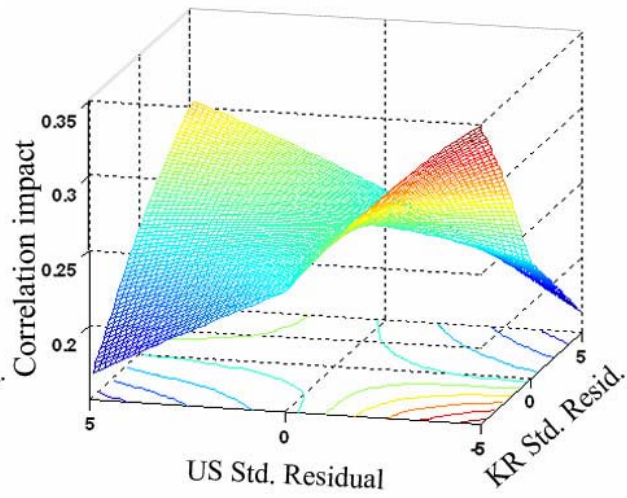


Figure 5 : Conditional Correlations and Conditional Covariances between Asian Crisis countries (Indonesia, Korea, Malaysia, Taiwan and Thailand).

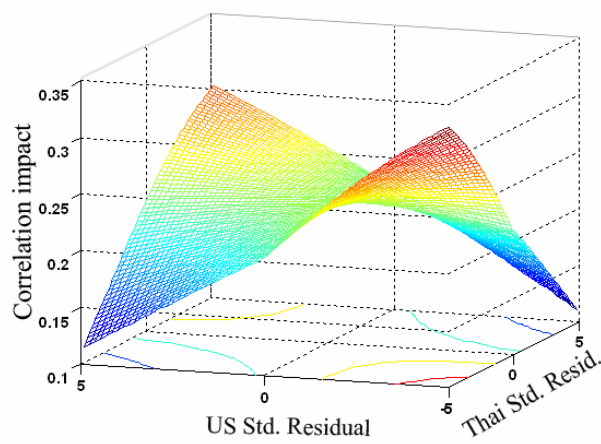
Conditional correlations and covariances for local currency returns. Shaded area corresponds to Asian crisis period 02/07/1997 – 30/12/1998. Line corresponds to break at 22/10/1997.



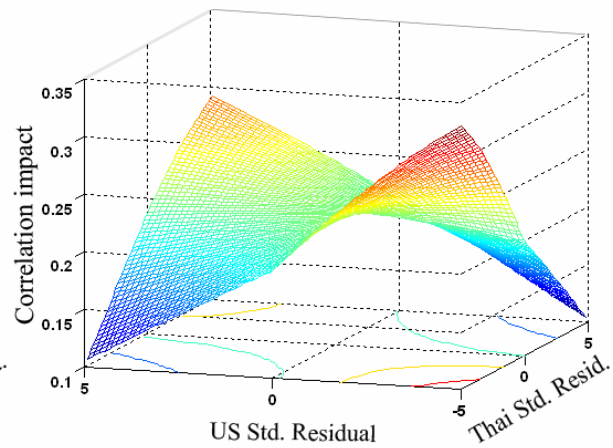
i) Local currency



ii) US dollar



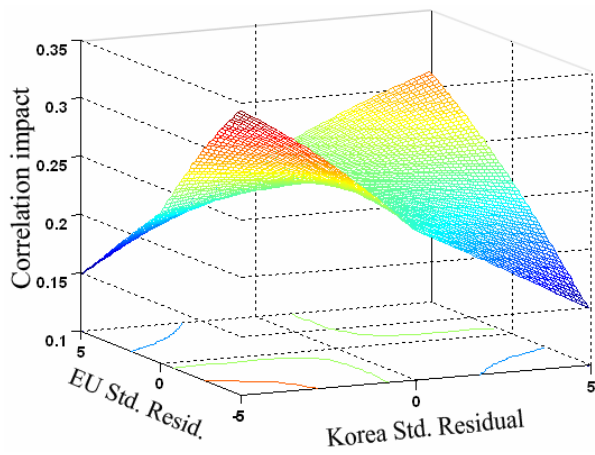
i) Local currency



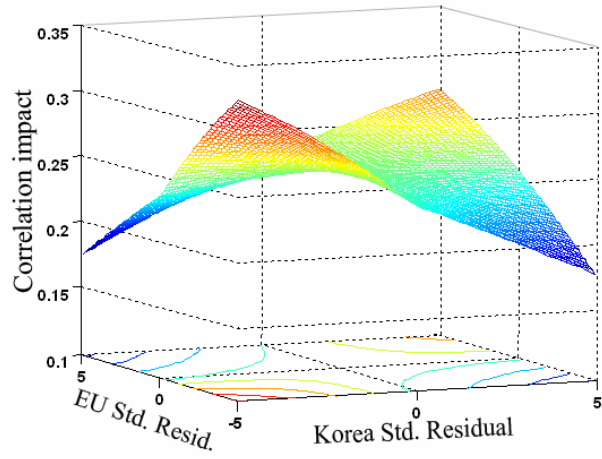
ii) US dollar

Figure 6a : Correlation news impact surfaces

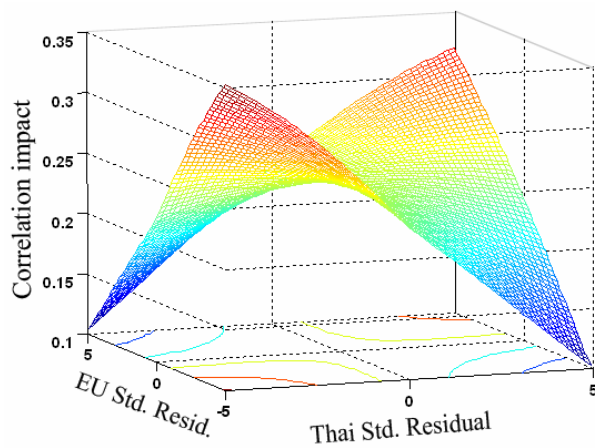
Conditional Correlation news impact surfaces for Korea and Thailand with the US.



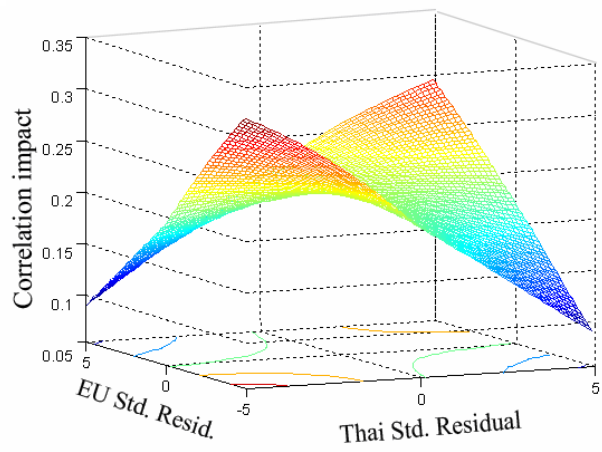
i) Local currency



ii) US dollar



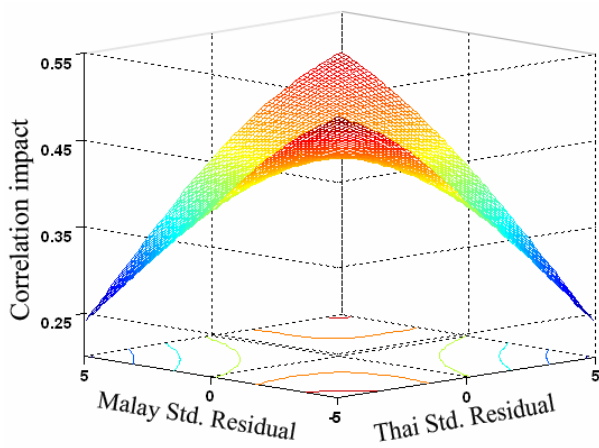
i) Local currency



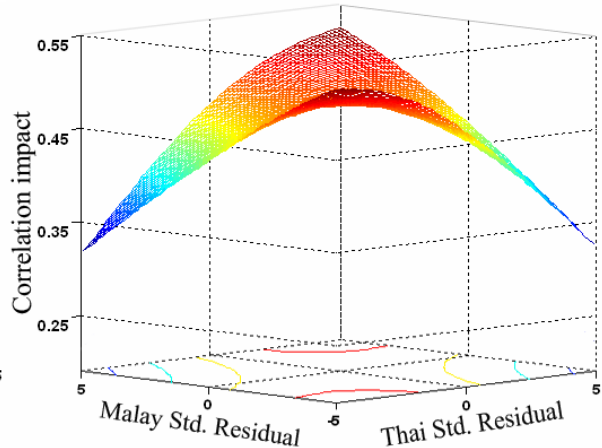
ii) US dollar

Figure 6b : Correlation news impact surfaces

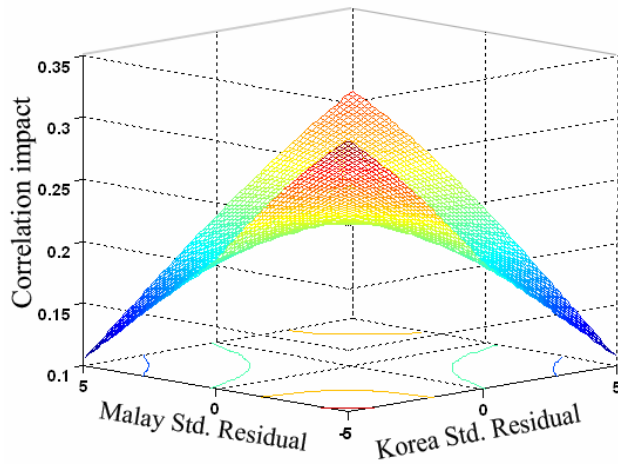
Conditional Correlation news impact surfaces for Korea and Thailand with the EU.



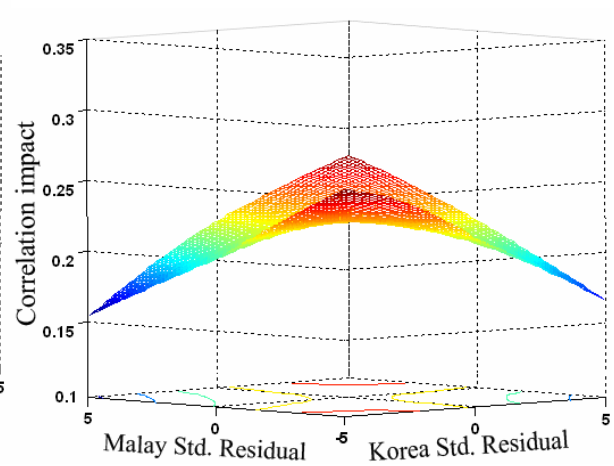
i) Local currency



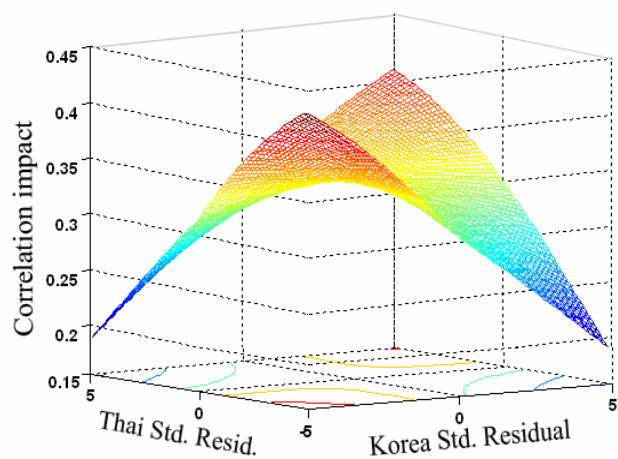
ii) US dollar



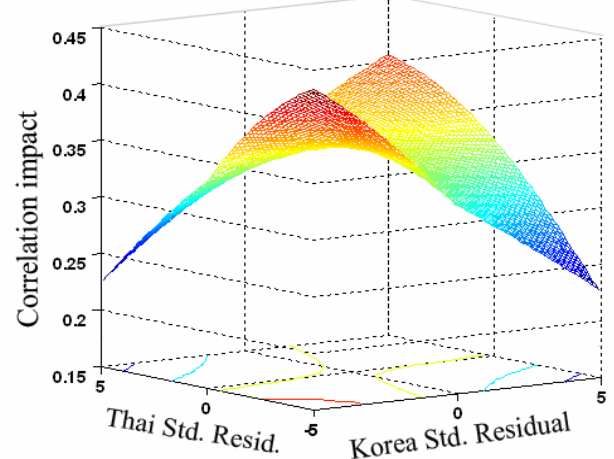
i) Local currency



ii) US dollar

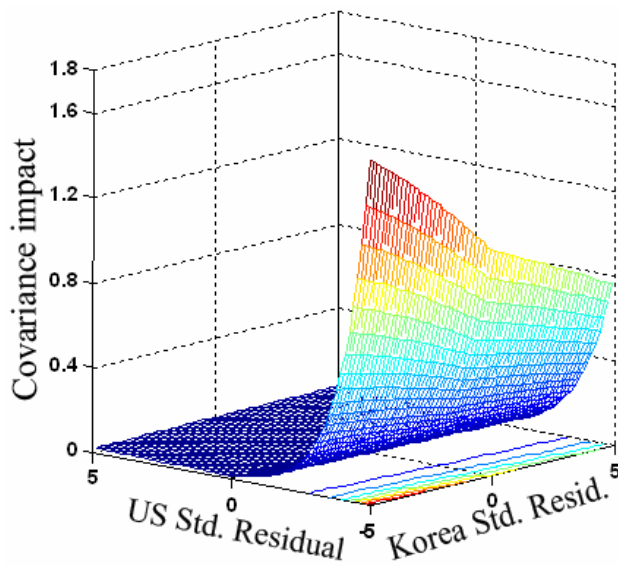


i) Local currency

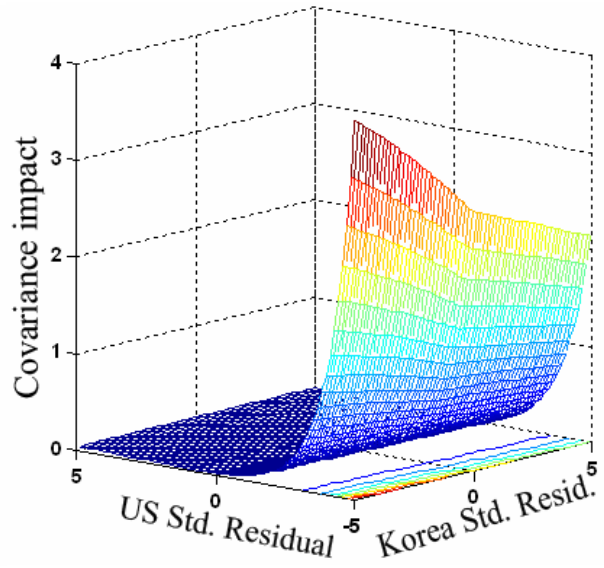


ii) US dollar

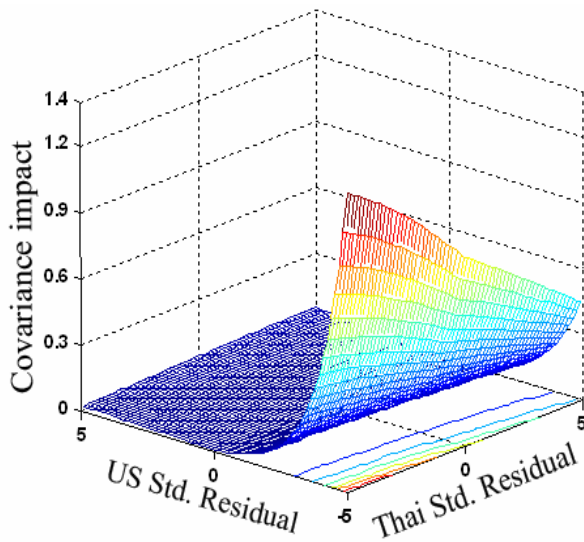
Figure 6c : Correlation news impact surfaces
 Conditional Correlation news impact surfaces between Korea, Malaysia and Thailand.



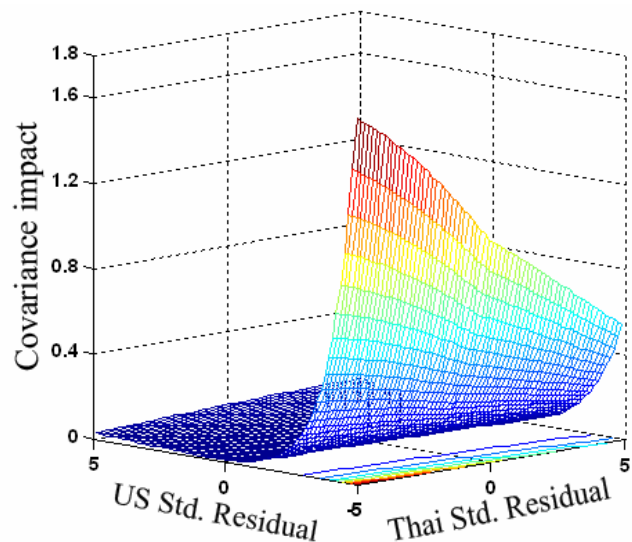
i) Local currency



ii) US dollar

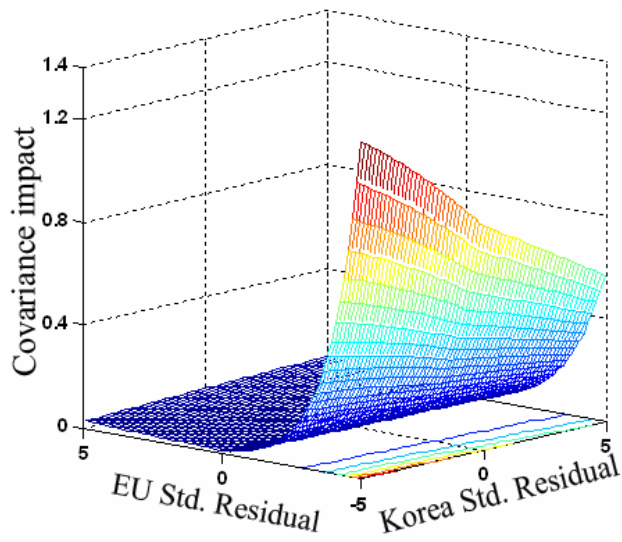


i) Local currency

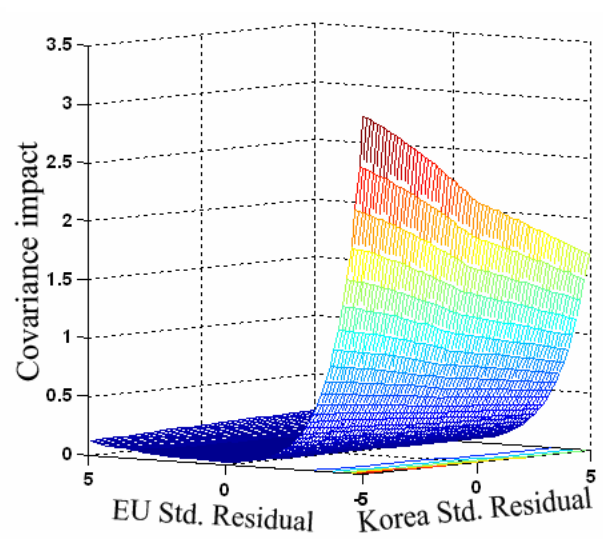


ii) US dollar

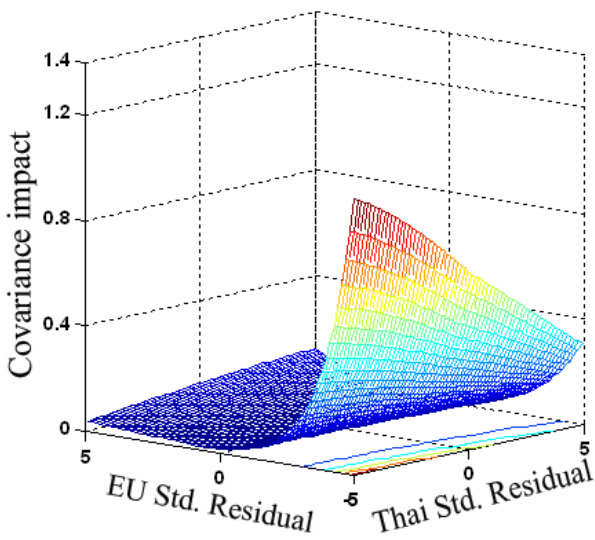
Figure 7a : Covariance news impact surfaces
 Conditional Covariance news impact surfaces for Korea and Thailand with the US.



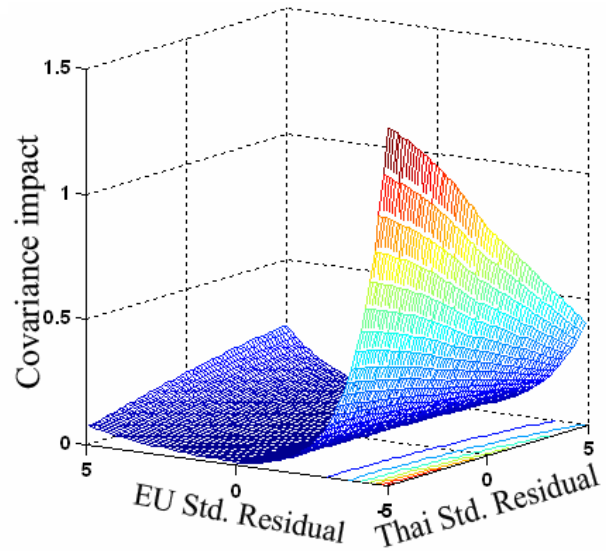
i) Local currency



ii) US dollar

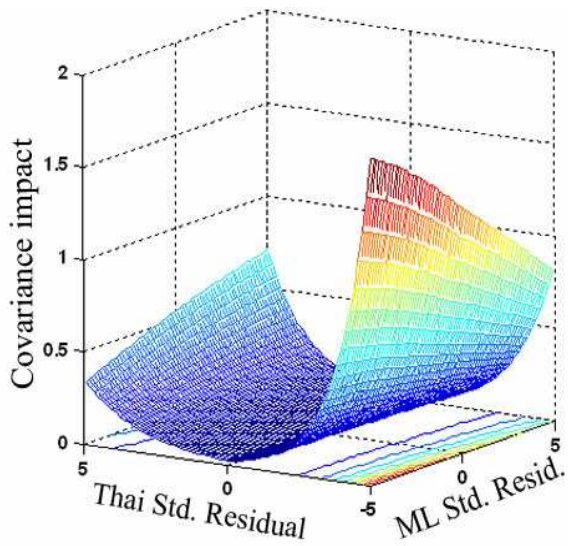


i) Local currency

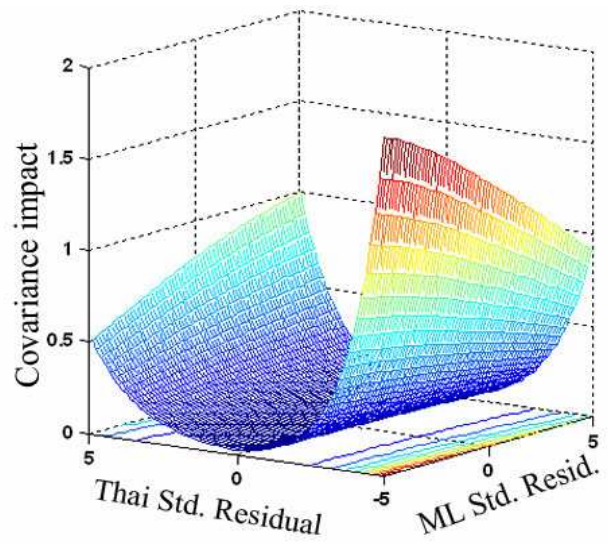


ii) US dollar

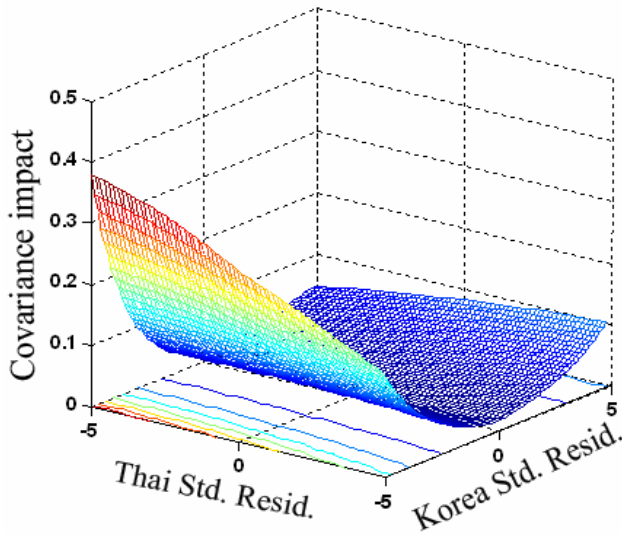
Figure 7b : Covariance news impact surfaces
 Conditional Covariance news impact surfaces for Korea and Thailand with the EU.



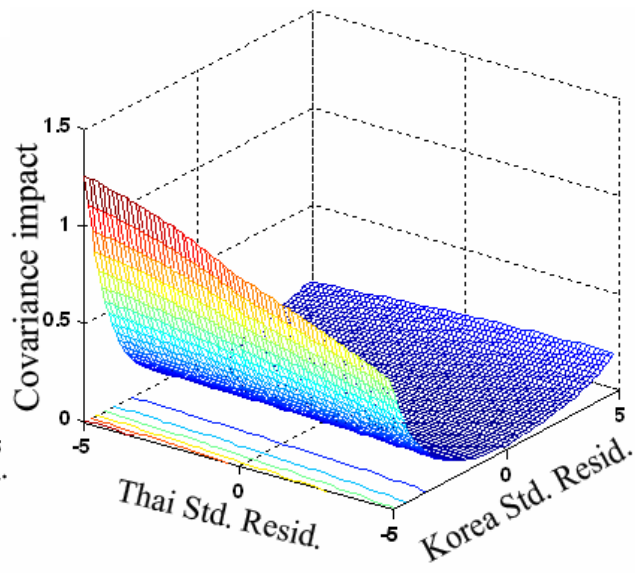
i) Local currency



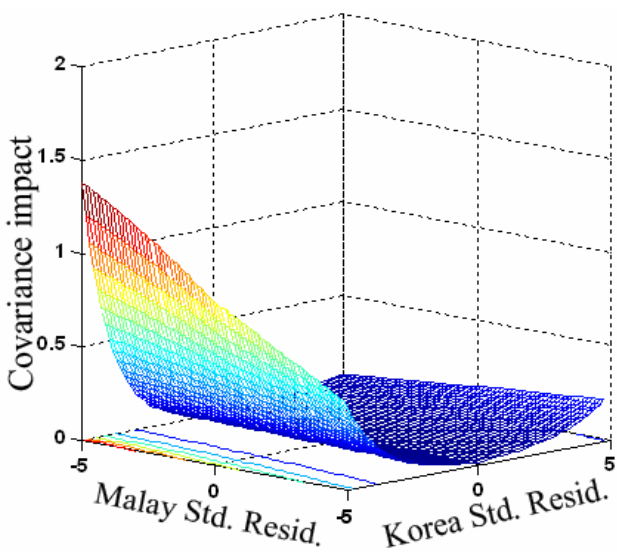
ii) US dollar



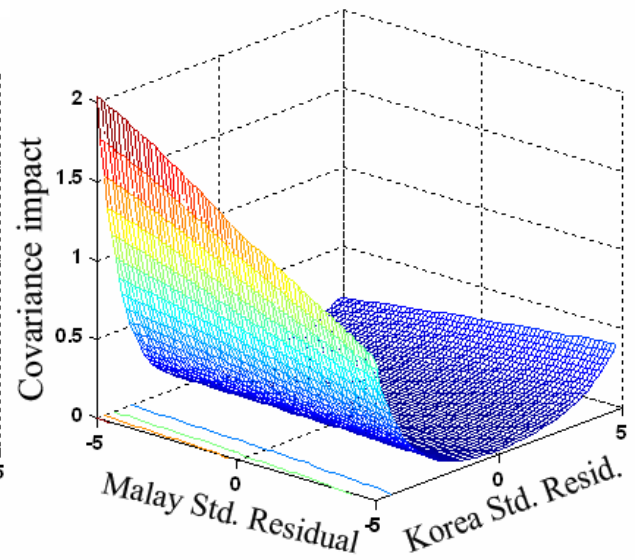
i) Local currency



ii) US dollar



i) Local currency



ii) US dollar

Figure 7c : Covariance news impact surfaces

Conditional Covariance news impact surfaces between Korea, Malaysia and Thailand.