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Volatility and Mean Spill-Over Effects in Asian Bond Markets

Abstract

This paper empirically examines the existence of volatility and mean spill-over effects from the US and EMU bond markets into those of seven Asian countries. Using a GARCH framework to capture the first and second moments of spill-overs during the 1996-2003 period, our results provide strong support mainly for the existence of volatility spill-over effects, and then primarily from the US bond market. Furthermore, the volatility spill-over effects from the US market appear to have increased over time. The extent of pure local volatility effects remains considerable in all test countries.

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I. Introduction

"I used to think I would like to be reincarnated as the pope or a baseball player with a .400 batting average, but now I know I would like to come back as the bond market. I could scare the hell out of anyone."

– James Carville, political adviser to former US President Bill Clinton

In recent years, a good deal of attention has been awarded to the increasing degree of financial integration in the international markets. Relatively little interest, however, has concerned the effect of this integration on *individual* capital markets. This holds for financial markets in general, and bond markets in particular. Understanding the behaviour and linkages between financial markets is important for several reasons. For instance, the benefits of geographically diversifying an investment portfolio decrease with high market integration. If markets are very much intertwined, shocks will spread through the markets, diminishing the advantage of spreading portfolio risks across countries.

In this paper, our main purpose is to examine the existence of mean and volatility spill-over effects from the bond markets in the US and aggregate EMU countries on those of seven Asian countries. The choice of *Asian* bond markets is warranted for two reasons mainly. First of all, lack of data has long proved an obstacle to conducting such a study. To our knowledge, we are therefore the first to do so. Secondly, the region has gone through a period of substantial economic, monetary, and financial integration with the rest of the financial world.

Why focus on *bond* markets? The importance of the market can hardly be overstated and has risen in recent years due to increasing bond issuance and a widening investor base. To put things in perspective, consider the fact that Merrill Lynch in 2002 estimated the world bond market to be approximately 33 trillion USD in size, far beyond that of the more closely scrutinized equity markets.

The subject is of current interest as financial markets around the world are currently experiencing an unprecedented development of financial assimilation. Our findings have important implications not only for investors looking to maximize their returns in a Markovitz mean-variance framework, but also for Central Banks and national governments, which will be able to make more informed decisions regarding the effects of integrating their economies with the rest of the world.

Previous papers by Christiansen (2003) and Skintzi (2004), both using variations of the test methodology pioneered by Engle, Ito, and Lin in 1990, support the existence of bond volatility spill-over effects. These papers, however, focus on US (world) and EMU (regional) spill-over effects on individual European countries and thus leave considerable scope for geographical expansion. This warrants a more far-reaching analysis of the proposed relationship for our chosen region. We implement a GARCH(1,1) framework, discussed in detail below, which studies the transmission mechanisms of the conditional first and second movements in common bond returns to test the proposed relationships. Our results lead to new insights into the behaviour of Asian bond markets and provide a solid basis for further research into the area.

Although we consider our paper to be a substantial step forward in understanding the effects of bond market integration, there are natural limitations which are important to bear in mind. For instance, lack of meaningful data forces us to limit our study to cover the time period from 1996 and only allows us to include seven test countries. Moreover, although we have strived to have identical bond composition for each world index, this has not always been feasible. Finally, the implemented test methodology only covers the transmission of first- and second movements (i.e. of mean- and volatility spill-over effects) and has certain short-comings covered in the methodology chapter.

The paper is organized as follows. In Section II we outline previous research on market integration and discuss various measures of spill-over effects. In

Section III, we give a short introduction to the implemented GARCH methodology. Section IV gives a more detailed description of our mean and volatility spill-over model. Section V presents some summary statistics concerning our data and how we obtained it. Section VI contains and analyses the main results of our paper. We perform validation experiments to test the robustness of our findings. Our conclusions are presented in Section VII. Finally, Section VIII contains suggestions for future lines of related research.

Previous Research on Market Integration

A growing body of research has focused on investigating the interdependence of different markets. Until recently, however, these studies have mainly focused on the equity markets. In 1979, Hilliard published a paper which concerned the contemporaneous and lagged correlation in daily closing prices changes across 10 major stock markets. Similarly, Jaffe and Westerfield (1985a, 1985b) looked at daily closing prices in Australia, Britain, Canada, Japan, and the US. Eun and Shim (1989) examined daily stock returns across nine national stock markets. A somewhat different approach was adopted by Barclay, Litzenberger, and Warner (1990), who scrutinized daily price volatility and volume for common stocks trading both in New York and Tokyo. The common finding of these studies, which all focused mainly on the conditional first moments of stock returns across international bond markets, was the reported evidence of positive correlations across daily close-to-close returns, indicating strong interdependence between the markets. Hamao, Masulis and Ng (1990), extended this research by investigating the transmission mechanism of both the conditional first and second movement of international stock returns. Using a Garch (1,1)-M model, they found significant volatility spill-over effects from the US and the UK stock markets to the Japanese markets. In a related strand of research, King and Wadhwani (1990) investigated why, in October 1987, almost all stock markets fell together despite widely differing economic circumstances. Their 'contagion' model produced evidence that rational agents attempt to infer information from price changes in other markets, concluding that idiosyncratic changes in one market may be transmitted to other markets, increasing volatility. Of particular importance, they introduced the concept of time-varying market correlations, i.e. correlations that rise following an increase in volatility. Likewise, Bekaert, Harvey, and Ng (2002) applied a two-factor model with time-varying betas accommodating various degrees of market integration between different markets on Europe, South-East Asia and Latin America to measure the proportion of volatility driven by global, regional, and local factors. Of particular interest to our study, they found economically meaningful increases in residual correlations in Asia, during the Asian crisis. Finally, Baele (2004) recently investigated to what extent globalization and regional integration lead to increasing equity market interdependence in Western Europe, finding that while both the EU and US shock spill-over intensity has increased over the 1980s and 1990s, the rise is most pronounced for EU spill-overs. The author contended that explanations for this development could be traced back to increased trade integration, equity market development, and low inflation. Of interest, is also the fact that some evidence was produced concerning market contagion for the US market to a number of local European equity markets during periods of high world market volatility.

Attempts to make similar analysis on international bond markets are relatively sparse. In 1995, Ilmanen published a paper which used a linear regression model incorporating both local and global instruments to forecast the excess returns of long-term international bonds. Importantly, he found world factors to be more important in explaining bond returns, indicating a high correlation across markets, i.e. strong bond market integration. Furthermore, he tested the degree of correlation between international stock and bond markets, finding little evidence of such a relationship. Ilmanen's approach was extended by Clare and Lekkos (2000), who examined the interaction between the German, UK, and US bond markets in a Value-at-Risk setting. Incorporating the short rates and term-structure slopes as endogenous variables, they found international factors dominated local factors in explaining the variance of the term-structure slopes. Driessen, Melenberg, and Nijman (2003) used principal components analysis to determine the common factors in German, Japanese, and US bond markets. In contrast to the Clare and Lekkos (2000) paper mentioned above, they found that the positive correlation between bond markets is primarily driven by the term structure *levels*, not by the term structure *slopes*. Using a five-factor model they were able to explain 96.5% of the total variation in (currency hedged) international bond returns.

Volatility spill-over analysis, in its current form, was pioneered by Engle, Ito and Lin in 1990. Their study on the Yen/USD exchange rate found strong evidence of volatility spill-over effects. In 1994, they conducted a similar study on the interrelationship between the Japanese and US stock markets, again finding evidence of volatility spill-over effects. This finding was confirmed by Eom, Subrahmanyam and Uno (2002), who found strong volatility spill-over effects from the US to the Japanese swap markets. Interestingly, the reverse relationship, i.e. volatility spill-over effects from the Japanese to the US bond market, was only weakly supported. Similar volatility models have been applied to a range of equity markets, finding support for volatility spill-over effects. Bekaert and Harvey (1997) examined emerging stock markets to find that capital market liberalizations significantly decrease volatility in emerging markets. Notably, these emerging markets remained virtually uninfluenced by world factors. Ng found evidence of regional volatility spill-over effects form Japan as well as world volatility spill-over effects from the US to the Pacific Basin. Baele (2004) inspected volatility effects from the US and Europe aggregate stock markets into individual European stock markets. In a fairly recent paper Charlotte Christiansen (2003) examined mean and volatility spill-over effects in European bond markets. Using a GARCH volatility spill-over model, the author found evidence of volatility spill-over effects from both the US and Europe into individual European bond markets. Mean spill-over effects, conversely, proved to be almost negligible. A noteworthy finding was the relative weakness of the US spill-over effects for EMU members. For these countries, the European volatility spill-over effect dominated. The opposite was true for non-EMU countries. These are very interesting findings, since they provide further support for the degree of economic integration in the EMU area. These results are also in line with those of Skintzi (2004), whose results, derived from a bivariate exponential GARCH model with a dynamic conditional correlation structure treating US effects as exogenous, suggested that significant volatility spill-over effects exist from both the aggregate Euro area bond market and the US bond market to the individual European markets. As in Christiansen, Skintzi found that volatility spill-overs have increased after the European Monetary Union for most European bond markets.

Having covered key previous research we now turn to the implemented test methodology.

II. (G)ARCH Methodology

Before we detail our testing procedure, a short introduction to important statistical concepts is warranted. In particular, a basic understanding of the ARCH family of statistical models is important. This section draws on Brooks (2002) and the E-Views help file.

ARCH (Auto Regressive Conditional Heteroscedasticity) models are specifically designed to model and forecast *conditional* variances, helping to overcome the issue of dynamic heteroscedasticity. Loosely speaking, heteroscedasticity can be thought of as time-varying variance (volatility). That the variance is conditional implies a dependence on current observations of the (immediate) past, and the autoregressive feature entails a feedback mechanism that makes use of past variances in the explanation of future variances. Specifically we motivate the use of GARCH models, which are time-series techniques that facilitate a modelling of the serial dependence of volatility.

To deal with the problem of time-varying volatility, Engle (1982) developed the ARCH model. The principal novelty of this model was the dependence of the conditional variance, σ, on past squared error terms, as well as (possible) exogenous variables. The ARCH(1) shows the model in its simplest form:

$$R_t = \gamma x_t + \varepsilon_t . \qquad (1)$$

and

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 . \qquad (2)$$

Note that in setting up an ARCH model, you require two specifications, one for the conditional mean, and one for the conditional variance.

In equation (1) the conditional mean is a function of:

- Exogenous variable(s): x_t
- An error term: ε_t

The conditional variance equation (2) depends on the following two terms:

- The mean: ω
- The lag of the squared residual from the mean equation (the ARCH term), which measures 'news' about volatility from the previous period: ε_{t-1}^2

Note that γ, ω, and α are estimated coefficients. ε_t denotes model residuals. Since σ_t^2 is the one-period ahead forecast variance based on past information, it is called the *conditional variance*. Equation (2) clearly shows that the conditional variance at a particular time *t*, is a positive function of the square of last period's error. A weakness of the ARCH model, concerns the fact that it cannot incorporate a stochastic component in the conditional variance at time *t*. It does, however, allow the inclusion of further squared error terms from prior periods.

In 1986, Bollerslev generalized the model by allowing the conditional variance, *σ*, to be a function not only of last period's error squared, but also of its conditional variance. His model offered a more parsimonious model, which lessened the computational burden through the use of fewer parameters. In his GARCH(1,1) (Generalized ARCH) model, the conditional variance of R at time *t* is of the following form:

$$R_t = \gamma x_t + \varepsilon_t.$$

and

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

Note that γ, ω, α, and β are estimated coefficients. ε_t denotes model residuals. You will notice that the GARCH (1,1) model specification differs from the ARCH specification above only in the inclusion of last period's variance forecast σ_{t-1} (the GARCH term).

We use a non-linear optimization technique, based on the iterative Berndt-Hall-Hall-Hausman algorithm (1974), to calculate the maximum-likelihood estimates. Further, we implement heteroscedasticity consistent covariances based on Bollerslev and Wooldridge (1992). The Ljung-Box Q statistic, which asymptotically follows a chi-square distribution, constitutes the principal specification test. It checks for a lack of serial correlation in model residuals (with residuals both in normal and squared form). It is also useful to look at the estimated coefficients for the third and fourth moments, i.e. skewness and kurtosis. Finally, a log likelihood ratio (LR) statistic, following a chi-square distribution, is used to evaluate the descriptive validity of the estimated model.

Although GARCH models are certainly very useful statistical tools in analyzing financial time series, it is important to be aware of their limitations. First of all they are a parametric specification, which implies that it works best under relatively stable market conditions. Even if the models are explicitly constructed to model time-varying conditional variances, they still have problems with capturing very irregular phenomena, such as market crashes and subsequent rebounds, which can lead to significant structural changes. It is therefore important to closely scrutinize the data.

III. The Spill-Over Model

This section introduces the applied model framework used to investigate the presence of volatility spill-over effects in the Asian countries. The model implemented is based on those specified by Bekaert and Harvey (1997), Ng (2000), and Baele (2004). The procedure, estimated independently using either US or EMU returns, is basically divided into three steps:

A. Step 1: GARCH on US (EMU) Returns

In the first step we run a univariate GARCH(1,1) model on US (EMU) returns, which uses lagged returns to explain today's returns:

$$R_{US,t} = c_{0,US} + c_{1,US} R_{US,t-1} + e_{US,t}.$$

$$\sigma^2_{US,t} = \omega_{US} + \alpha_{US} e^2_{US,t-1} + \beta_{US} \sigma^2_{US,t-1}.$$

Alternatively,

$$R_{EMU,t} = c_{0,EMU} + c_{1,EMU} R_{EMU,t-1} + e_{EMU,t}.$$

$$\sigma^2_{EMU,t} = \omega_{EMU} + \alpha_{EMU} e^2_{EMU,t-1} + \beta_{EMU} \sigma^2_{EMU,t-1}.$$

Note that $c_{0,US}$, $c_{1,US}$, ω_{US}, α_{US}, and β_{US} ($c_{0,EMU}$, $c_{0,EMU}$, ω_{EMU}, α_{EMU}, and β_{EMU}) are estimated coefficients. $e_{US,t}$ ($e_{EMU,t}$) denote model residuals. In a well-functioning 'efficient' market we expect $c_{1,US}$ ($c_{1,EMU}$) to be statistically insignificant. If it is not, this indicates autocorrelation in the return series, which (at least theoretically) could be used as a profitable trading strategy. The main objective of running these equations is, instead, to obtain the $e_{US,t}$ ($e_{EMU,t}$) residual series.

B. Step 2: Testing for US (EMU) Mean/Volatility Spill-Over Effects

In the following step we use lagged US (EMU) returns and the contemporaneous residuals from the US (EMU) GARCH(1,1) models in the preceding step to test for mean and volatility spill-over effects. In essence we reestimated the GARCH(1,1) models from above on the individual Asian countries, with the important modification of including lagged US (EMU) returns and contemporaneous US (EMU) residuals from above:

$$R_{i,t} = c_{0,i} + c_{1,i}R_{i,t-1} + \varphi_i R_{US,t-1} + \delta_i e_{US,t} + e_{i,t}.$$

or,

$$R_{i,t} = c_{0,i} + c_{1,i}R_{i,t-1} + \varphi_i R_{EMU,t-1} + \delta_i e_{EMU,t} + e_{i,t}.$$

where:

$$\sigma_{i,t}^2 = \omega_i + \alpha_i e_{i,t-1}^2 + \beta_i \sigma_{i,t-1}^2.$$

in both specifications.

$c_{0,i}$, $c_{1,i}$, φ_i, and δ_i are estimated coefficients. $e_{i,t}$ denotes model residuals. If φ_i (δ_i) are significant, this is indicative of mean (volatility) spill-over effects from the US (EMU area) into the individual Asian country.

C. Step 3: Quantifying the Impact of US (EMU) Spill-Over Effects

If we are unable to reject the existence of (primarily volatility) spill-over effects, a natural third (and final) step is to quantify the impact of these. Unfortunately, interpreting the size of the obtained coefficients is problematic. A common approach is, instead, to measure how large a portion of the conditional variance of the unexpected return of country *i* that can be explained by the inclusion of the lagged US (EMU) residuals. Note first that the conditional variance of the unexpected return of country *i* is given by the following formula:

$$h_{it}^{US} = E\left(\varepsilon_{i,t}^2 \mid I_{t-1}\right) = \delta_i^2 \sigma_{US,t}^2 + \sigma_{i,t}^2.$$

or,

$$h_{it}^{EMU} = E\left(\varepsilon_{i,t}^2 \mid I_{t-1}\right) = \delta_i^2 \sigma_{EMU,t}^2 + \sigma_{i,t}^2.$$

The conditional variance thus depends on the variance of the contemporary US (or EMU) and own idiosyncratic shocks. Since the US (EMU) residual series are squared ($\sigma_{US,t}^2$ or $\sigma_{EMU,t}^2$), it follows that if the volatility of the unexpected returns in the US (EMU) region is large (small), the conditional variance in country *i* will also tend to be large (small). This implies further, that the sign and significance of the δ_i^2 parameters can be used to determine the existence of volatility spill-over effects from the US (EMU) region into country *i*.

Finally, in order to measure the proportion of the variance of the unexpected return of country *i* that originates in the US/EMU, we make use of the following variance ratios:

$$VR_{i,t}^{US} = \frac{\delta_i^2 \sigma^2{}_{US,t}}{h_{i,t}^{US}}.$$

$$VR_{i,t}^{EMU} = \frac{\delta_i^2 \sigma^2{}_{EMU,t}}{h_{i,t}^{EMU}}.$$

These provide us with a measure of the impact of external US (or EMU) and local effects on the variance of the individual country. Note, ultimately, that this is a constant spill-over model, i.e. the spill-over parameters remain constant over the entire sample period.

With a better understanding of the implemented model framework, we now turn to the data used in our study.

IV. The Data

The data was collected from the EcoWin database. The HSBC USD Total Return Bond Index was gathered for the following countries: China, Indonesia, Philippines, Malaysia, Singapore, South Korea and Thailand.[1] "Total Return" implies that the received coupons are invested back into the bonds of the index. These were the only Asian countries available with dollar denominated total return indices in the EcoWin database. The indices, which report the daily closing price, were converted into weekly returns by taking the logarithm of today's closing index value divided by last week's closing index value (every Wednesday). Similarly, the daily return series were obtained by taking the logarithm of today's closing index value divided by the index closing value of the previous trading day.

The data period available for the countries mentioned above was 1996-12-31 through 2004-05-04 with the exception of Singapore which, peculiarly, only contained closing prices from 1999-08-10 through 2004-05-04. For the calculation of daily and weekly returns of US bonds the closing price was collected for the US($) Government Bond Index. To compute the EMU returns the corresponding index was collected for the matching period. A problem with the EMU index found was the fact that it was denominated in Euros. No USD denominated Euro Bond index was available in the EcoWin database which met the necessary criteria (primarily in terms of frequency and a sufficiently long time period). Hence, we had to convert the Euro denominated returns into dollar returns. This was achieved by adjusting the Euro values by the daily FX-rates. This constitutes a potential lag problem since fixing rates are usually set before noon each day in contrast to closing prices for bonds indices. Intuitively this should cause more problems on daily calculations than on weekly. Using weekly data partially overcomes the potential problem of non-synchronous data.

[1] We decided to exclude Japan from this study, leaving us primarily with emerging market economies. When reporting from Asia, it is not uncommon to make this distinction.

The data for the HSBC total return indices contained a few blanks at random dates which most certainly were local holidays. In the calculations of the daily and weekly returns all such blanks were replaced by the last available closing price.

The tables below summarize key data characteristics for the weekly data:

Table I
Summary Statistics on Weekly Data

Summary statistics on weekly data. All data except Singapore for the 1997:01-2004:04 period. Singapore for the 1999:08-2004:04 period. All returns are currency hedged (i.e. measured in USD). Skewness measures the asymmetry of the distribution around its mean. Kurtosis measures the peakedness or flatness of the distribution. A normal distribution carries a skewness of 0 and a kurtosis of 3.

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
USA	0.13%	0.13%	2.01%	-2.53%	0.68%	-0.35	3.83
EMU	0.12%	0.13%	3.74%	-3.97%	1.34%	-0.14	2.98
China	0.16%	0.20%	3.41%	-3.90%	0.79%	-0.43	6.05
Indonesia	0.01%	0.18%	27.05%	-38.36%	4.05%	-1.77	42.47
Malaysia	0.01%	0.18%	12.70%	-75.97%	4.21%	-14.54	259.18
Philippines	0.01%	0.26%	28.53%	-49.30%	3.54%	-6.25	113.27
Singapore	0.20%	0.21%	3.93%	-2.32%	0.82%	0.29	5.12
South Korea	0.17%	0.21%	15.28%	-18.99%	1.84%	-1.86	48.65
Thailand	0.15%	0.24%	11.07%	-21.88%	1.97%	-4.80	55.12

Average weekly returns are relatively widely dispersed, ranging from 0.01% (Indonesia, Malaysia, the Philippines) to 0.20% (Singapore). The maximum and minimum returns vary substantially. Remember that the series cover the period of the Asian Financial Crisis. Note especially Malaysia and the Philippines, which experienced substantial negative return surprises over the period. Interestingly, there appears to be a negative correlation between mean returns and their standard deviations. Over the period, the low risk alternatives (i.e. USA, EMU, China, Singapore) thus outperformed the more volatile bond markets. All return series except for Singapore are skewed to the left, i.e. have longer left tail than that implied by the normal distribution. With the notable exception of EMU, all series show relatively large kurtosis values, i.e. signs of excess peaking. The Jarque and Bera (1980) test rejects normality for all return series except for EMU. In Table II, the corresponding data is reported for data on the daily level. The key difference is the Jarque and Bera test rejects normality on all series on the daily level. Note the high (in absolute numbers) one-day maximum and minimum returns.

Table II
Summary Statistics on Daily Data

Summary statistics on daily data. All data except Singapore for the 1997:01-2004:04 period. Singapore for the 1999:08-2004:04 period. All returns are currency hedged (i.e. measured in USD). Skewness measures the asymmetry of the distribution around its mean. Kurtosis measures the peakedness or flatness of the distribution. A normal distribution carries a skewness of 0 and a kurtosis of 3.

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
USA	0.03%	0.02%	1.08%	-1.39%	0.31%	-0.38	4.24
EMU	0.02%	0.04%	1.90%	-3.35%	0.61%	-0.29	3.88
China	0.03%	0.02%	2.68%	-4.92%	0.37%	-1.32	25.89
Indonesia	0.00%	0.04%	28.18%	-39.86%	1.83%	-5.46	205.98
Malaysia	0.04%	0.02%	13.12%	-18.35%	0.82%	-2.47	192.58
Philippines	0.00%	0.02%	28.89%	-49.48%	1.57%	-14.23	584.32
Singapore	0.04%	0.01%	4.51%	-1.57%	0.40%	1.25	17.91
South Korea	0.03%	0.03%	8.63%	-19.64%	0.77%	-9.24	260.62
Thailand	0.03%	0.02%	10.15%	-21.48%	0.89%	-8.25	223.59

With a better understanding of the implemented model framework, and the data used, we now turn to reporting, validating, and analyzing the main empirical results.

V. Empirical Findings

This section is divided into four parts. We begin by investigating the mean/volatility spill-over effects on US and EMU weekly data in the first two sections. In section three and four, the testing procedure is re-estimated using daily data.

A. USA Weekly

A1. GARCH on Weekly US Returns

As mentioned above, we begin by estimating the univariate model for US daily returns. The results can be found in Table III below:

Table III
GARCH Output on US Weekly Returns

Output from the GARCH(1,1) model on US daily returns over the 1997:01-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	$100w_i$	α	β
US	0.12% ***	6.37%	0.00%	0.76%	99.00%***
	0.03%	4.93%	0.00%	0.98%	1.14%

Significant at 1% (***), 5% (**), 10% (*) levels.

The AR(1) parameter ($c_{1,i}$) is small, positive, but statistically insignificant. The volatility process appears to be quite persistent with $\hat{\alpha}_{US} + \hat{\beta}_{US} \approx 1$. This is common in (high-frequency) financial data.

Since the residuals from this first model are vital in the following steps, we test this basic model for misspecification errors. We examine the properties of the standardized residuals, $\frac{\hat{e}_{US,t}}{\hat{\sigma}_{US,t}}$, from the first step. In a well specified model they should have a mean of zero, no serial correlation, and no ARCH effects. The Ljung-Box (1978) Q-test is applied on first to fourth order lags and the ARCH-LM (Lagrange Multiplier) test is used to check for no ARCH(1) effects according to the methodology introduced by Engle (1982). Based on these two tests, the output of which was omitted due to space constraints, we conclude that we have a well-specified model.

A2. Testing for Weekly US Mean/Volatility Spill-Over Effects

In the second step we estimate the models for the individual Asian countries. This model therefore include the mean and volatility spill-over effects from the US market. The results are shown in Table IV below:

Table IV
Testing for Weekly US Mean/Volatility Spill-Over Effects

Output from the GARCH(1,1) model on individual country returns as well as lagged US returns and contemporary US residuals. All data except Singapore for the 1997:01-2004:04 period. Singapore for the 1999:08-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	ϕ	δ	$100w_i$	α	β
China	0.20% ***	-22.6% ***	30.7% ***	63.9% ***	0.00% *	20.9% **	75.7% ***
	0.00%	5.70%	5.50%	4.20%	0.01%	9.67%	8.69%
Indonesia	0.30% ***	10.30%	-7.00%	20.6%*	0.00%	41.3% **	81.2% ***
	0.10%	6.90%	8.70%	11.60%	0.03%	19.60%	5.34%
Malaysia	0.1% ***	10.90%	-7.00%	101.0% ***	0.0% **	53.1% **	60.1% ***
	0.00%	17.70%	31.20%	0.70%	0.10%	21.80%	5.29%
Philippines	-0.20%	13.40%	54.6% **	-23.60%	1.64%	-0.27%	87.1% ***
	0.20%	10.90%	22.30%	28.80%	2.25%	1.01%	24.90%
Singapore	0.3% ***	-30.9% **	6.30%	34.7% ***	0.00%	-1.40%	96.4% ***
	0.10%	14.10%	7.30%	12.40%	0.17%	3.86%	22.10%
South Korea	0.2% ***	28.30%	-11.20%	48.0% ***	0.00%	117.7% **	47.8% ***
	0.00%	22.20%	15.10%	4.00%	0.02%	59.50%	10.00%
Thailand	0.10%	8.20%	10.80%	55.0% ***	0.00%	3.70%	83.7% ***
	0.10%	7.10%	8.40%	0.0%	0.40%	2.77%	6.28%

Significant at 1% (***), 5% (**), 10% (*) levels.

Note first that mean spill-over effects from the US market exist for only two out of seven countries (China and the Philippines). Conversely, volatility spill-over effects appear to be present in all countries except for the Philippines. All statistically significant spill-over coefficients (both mean and variance) are positive, implying that an increase in US mean returns or volatility will lead to an increase in the mean/variance in the individual Asian country.

Not all the conditional volatility processes, reported in Table V below, are highly persistent however. In fact, it is only for three out of seven countries that the condition $\alpha_i + \beta_i \leq 1$ holds. If the sum exceeds one, this is indicative of an exploding volatility function which must be interpreted with caution. A problem with the employed estimation procedure is that the optimization algorithm may converge at a local maximum. To make certain that this is not the case, we re-run the estimation for those countries with non-persistent conditional volatility processes. The objective in this procedure is to maximize the log likelihood value. As seen in Appendix I, however, this has virtually no effect on the estimated coefficients. See Table V:

Table V
Persistence of Conditional Volatility Processes

Sum of ARCH (α) and GARCH (β) coefficients for each country. Number just below one indicates model persistence.

	α + β
China	0.97
Indonesia	1.23
Malaysia	1.13
Philippines	0.87
Singapore	0.95
South Korea	1.65
Thailand	0.87

For China, Philippines, Singapore, and Thailand the conditional variance process appears to evolve according to an Integrated GARCH process.

Next, we employ Wald Tests to test the joint hypothesis of no US spill-over effects at all, i.e. that both $\varphi_{US} = \delta_{US} = 0$ for each individual country. The results, which are reported in Table VI below, strongly reject the null hypothesis of no spill-over effects for all countries except Indonesia. Recall that Indonesia is the only country that appeared to be unaffected by US volatility.

Table VI
Wald Tests

Results of Wald Tests for the individual test countries. The test checks the *joint* hypothesis that both $\varphi_{US} = \delta_{US} = 0$.

	China	**Indonesia**	**Malaysia**	**Philippines**	**Singapore**	**South Korea**	**Thailand**
F-statistic	124.69 ***	2.10	10697.59 ***	3.06 **	3.94 **	103.80 ***	7.20 ***
Chi-square	249.37 ***	4.20	21395.18 ***	6.12 **	7.88 **	207.59 ***	14.39 ***

Significant at 1% (***), 5% (**), 10% (*) levels.

Overall, the results thus provide a strong indication of volatility spill-over effects from the US bond market into the individual Asian bond markets, whereas the mean spill-over effects from the US appear to be less evident.

A3. Quantifying the Impact of Weekly US Spill-Over Effects

Having discussed both the size and sign of the estimated parameters, a natural next step is to quantify the *degree* of spill-over effects, i.e. how much the US affects the variance of the unexpected returns in each individual country. In order to access the importance of such effects, however, the relative size of the parameters is of little practical importance. Instead, we focus on the time series of the variance ratios $VR_{i,t}^{US}$ (US spill-overs). The remainder, i.e. 1 - $VR_{i,t}^{US}$, equals $VR_{i,t}^{i}$ (local effects). In Table VII below, the mean of each variance ratio is reported.

Table VII
Variance Ratios

Mean and standard deviation of the variance ratios.

	$VR^{US}_{i,t}$	
	Mean	**Std. Dev.**
China	37.00%	15.30%
Indonesia	1.20%	2.00%
Malaysia	24.70%	13.80%
Philippines	0.20%	0.10%
Singapore	10.80%	3.70%
South Korea	20.30%	16.30%
Thailand	3.50%	1.40%

Over the test period, the weekly US spill-over effect thus explain between 0.2% and 37.0% of the conditional variance of the unexpected return of each country. Within this interval the explanatory power for each individual country appears to be spread quite evenly. Note that China, followed by Malaysia and South Korea are most severely affected by US volatility.

The time-varying variance ratios are reported in Figure I-VII in Appendix II. Six of the seven countries in the USA weekly GARCH regressions had significant volatility spill-over effects. Of particular interest is the fact that of the significant countries all have clear rising trends from the beginning of the study. Coincidently our study starts more or less at the same point in time as when the Asian Financial Crisis was creating a vivid turmoil in the financial markets around the world. The low variance ration during the beginning of the study indicates that US bond markets had little effect on the countries in our study during the Asian Crisis which lasted during 1997 through 1998. Intuitively, this also seems right since domestic factors, during a serious crisis like the Asian Financial Crisis, should affect the local markets more than the rest of the world. This phenomenon was also reported by Bekaert, Harvey, and Ng (2002), whose paper was briefly covered in the previous research section. As mentioned above, the ratio also increases as the crisis subsides, which indicates that there may be some sort of equilibrium level at a higher ratio. Here it would have been interesting to extend our testing further beyond 1/1/1997, which is the inception of our study. Unfortunately the HSBC total return bonds for these Asian countries doesn't date back further than that and no other total return bonds were available in the EcoWin database.

Looking at the aforementioned figures in Appendix I, the Philippines and Thailand display a rather odd peak and trough respectively. A closer scrutiny of the raw data series tells us that there was a peculiar return around the 19th November, 2003. The exact reason for this occurrence is unknown to us. We did, however, test the robustness of the results by removing this data point. The estimated coefficients and variance ratios remained virtually unaltered.

In sum, the US clearly appears to affect the individual countries, although the degree of influence clearly varies.

B. EMU Weekly

Having tested for US spill-over effects, we now turn to investigating the presence of similar effects from the EMU region

B1. GARCH Model on EMU Weekly Returns

First, a GARCH(1,1) model is estimated on EMU returns. The output is found in Table VIII below.

Table VIII
GARCH Output on EMU Weekly Returns

Output from the GARCH(1,1) model on EMU Returns over the 1997:01-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	$100w_i$	α	β
EMU	0.08%	1.33%	0.02%	3.11% ***	95.87% ***
	0.07%	4.78%	0.03%	1.20%	1.59%

Significant at 1% (***), 5% (**), 10% (*) levels.

The AR(1) parameter is small, positive, but statistically insignificant, as was the case for US returns above. Moreover, the volatility process again appears to be quite persistent. Even though the ARCH coefficient is statistically significant, the Ljung-Box Q-test and ARCH-LM (1) test give no sign of a model misspecification.

B2. Testing for Weekly EMU Mean/Volatility Spill-Over Effects

Satisfied with our EMU model specification, we next re-estimate the GARCH(1,1) models for the individual Asian countries, including the EMU mean- and volatility spill-over parameters. The results can be found in Table IX below:

Table IX
Testing for Weekly EMU Mean/Volatility Spill-Over Effects

Output from the GARCH(1,1) model on individual country returns as well as lagged EMU returns and contemporary EMU residuals. All data except Singapore for the 1997:01-2004:04 period. Singapore for the 1999:08-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	ψ	δ	$100w_i$	α	β
China	0.16% ***	0.10%	2.40%	1.80%	0.03%	11.97% *	84.52% ***
	0.04%	5.59%	2.74%	2.79%	0.02%	6.36%	6.39%
Indonesia	0.23% ***	12.57%	1.09%	2.11%	0.00%	39.99% **	81.06% ***
	0.06%	7.26%	6.20%	4.76%	0.03%	18.23%	5.21%
Malaysia	0.05%	42.02%	5.18%	90.88% ***	2.41% ***	75.19% **	-1.98%
	0.13%	19.76%	6.19%	9.33%	0.35%	37.69%	3.47%
Philippines	0.01%	15.14%	-26.87%	-10.32%	1.47%	-0.09%	84.63% **
	0.17%	9.47%	17.74%	20.65%	2.60%	0.94%	39.19%
Singapore	0.21% ***	-7.63%	-2.72%	0.67%	0.03%	1.54%	93.45% ***
	0.06%	6.63%	3.50%	3.95%	0.12%	2.42%	21.26%
South Korea	0.20% ***	21.09% *	5.39%	0.14%	0.08%	85.05%	48.56% ***
	0.04%	11.80%	3.33%	4.40%	0.06%	52.80%	15.24%
Thailand	0.00%	12.57%	-17.39% ***	28.54% ***	0.12%	1.14%	95.98% ***
	0.10%	8.61%	6.60%	8.9%	0.17%	1.38%	4.47%

Significant at 1% (***), 5% (**), 10% (*) levels.

Statistically significant mean spill-over effects occur only in Thailand, a country which is also affected by EMU volatility spill-overs. The only other country that enjoys any volatility spill-over effects is Malaysia. Again, all statistically significant coefficients are positive, indicating that an increase in the mean/volatility of EMU returns will increase the mean/volatility in the aforementioned countries Thailand and Malaysia.

The conditional volatility processes, reported below, are highly persistent in China, Malaysia, the Philippines, Singapore, and Thailand. The choppiness of the Malaysian and Thai variance ratios, also found at the daily level, is somewhat surprising, and not usually expected for a GARCH series. See Appendix I for re-estimations of the GARCH equations for Indonesia and South Korea using different starting values.

Table X
Persistence of Conditional Volatility Processes
Sum of ARCH (α) and GARCH (β) coefficients for each country. Number just below one indicates model persistence.

	$\alpha + \beta$
China	0.96
Indonesia	1.21
Malaysia	0.73
Philippines	0.85
Singapore	0.95
South Korea	1.34
Thailand	0.97

Again, we employ Wald Tests to check the joint hypothesis of no EMU spill-over effects at all, i.e. that both $\varphi_{EMU} = \delta_{EMU} = 0$ for each individual country. The results, which are reported below, show that the null hypothesis is rejected only in Malaysia, the Philippines, and Thailand. The fact that the Philippines would show signs of spill-over effects in the Wald Test is somewhat surprising, given the coefficients estimating the individual mean- and volatility spill-over effects, which have p-values of 13.0% and 61.7% respectively (exact p-values not reported in Table IX).

Table XI
Wald Tests

Results of Wald Tests for the individual test countries. The test checks the *joint* hypothesis that both $\varphi_{EMU} = \delta_{EMU} = 0$.

	China	Indonesia	Malaysia	Philippines	Singapore	South Korea	Thailand
F-statistic	0.53	0.12	47.62 ***	3.51 **	0.37	0.37	5.70 ***
Chi-square	1.06	0.24	95.25 ***	7.02 **	0.74	0.74	11.40 ***

Significant at 1% (***), 5% (**), 10% (*) levels.

On the whole, the results thus provide a weaker indication of volatility spill-over effects from the EMU bond market into the individual Asian bond markets, than that existing from the US area. Mean spill-over effects, on the other hand, appear to be of a similar insignificance in both regions.

B3. Quantifying the Impact of EMU Spill-Over Effects

Turning to the time-series of the variance ratios $VR_{i,t}^{EMU}$ (EMU spill-overs), the mean of each variance ratio is reported in Table XII below:

Table XII
Variance Ratios

Mean and standard deviation of the variance ratios.

	$VR^{EMU}_{i,t}$	
	Mean	**Std. Dev.**
China	0.13%	0.08%
Indonesia	0.05%	0.06%
Malaysia	29.85%	11.30%
Philippines	0.23%	0.11%
Singapore	0.01%	0.00%
South Korea	0.00%	0.00%
Thailand	4.88%	4.18%

Over the test period, the weekly EMU spill-over effects explain between 0.0% and 29.8% of the conditional variance of the unexpected return of each country. For most countries, however, the mean is below 5%. The one notable exception is Malaysia. In comparison to the variance ratios for the US area, the EMU ratios are considerable lower on average. In fact, the variance ratios show that our proposed volatility spill-over model is really only helpful in explaining the unexpected conditional variances in two out of the seven test countries

(Malaysia and Thailand). It is notable that the variance ratios for these countries is higher using EMU weekly returns than when using US weekly returns.

The time-varying behaviour of the variance ratios is shown in Figures VIII-XIV in Appendix II. They turn out to be of relatively little interest except for Thailand (Appendix II, Figure XIV). There we note an extremely high variance ratio in the beginning of 1997 which then declined steeply over the next few months. It remains low to today. It would be interesting to obtain data which stretches further back than the beginning of 1997 to see how the ratio was back then. Unfortunately no such data was available in the EcoWin system.

In sum, the spill-over effects are not only generally insignificant but also of limited use (when significant), in explaining the volatility of the individual test countries.

C. USA Daily

Having determined that (primarily volatility) spill-over effects do exist on some weekly data in general, and US data in particular, we found it interesting to re-estimate the models using daily data. First of all it will act as a robustness test and secondly, it allows us to test spill-over effects occurring in a shorter time interval. It is not impossible for the effects to exist at one frequency and not the other. As mentioned above, however, using daily data may lead us to wrongfully accept the existence of spill-over effects. The results should thus be interpreted with caution. Still, since we were unable to reject the existence spill-over effects on weekly data, it is interesting to investigate the effect of applying the models on higher-frequency data.

C1. GARCH Model on US Daily Returns

Table XIII below shows the output from the GARCH(1,1) model on US daily returns. Note that the lagged return series appears to hold some explanatory power in today's returns. This positive autocorrelation, which (theoretically) may constitute trading opportunities, was not present on the weekly level.

Table XIII
GARCH Output on US Daily Returns

Output from the GARCH(1,1) model on US weekly returns over the 1997:01-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	$100w_i$	α	β
US	0.02% ***	5.97% **	0.00% ***	8.28% ***	87.46% ***
	0.01%	2.37%	0.00%	1.79%	2.87%

Significant at 1% (***), 5% (**), 10% (*) levels.

Even though the ARCH coefficient is statistically significant, the Ljung-Box Q-test and ARCH-LM (1) test give little or no sign of a model misspecification, at least not at a reasonable level of statistical significance.

C2. Testing for US Daily Mean/Volatility Spill-Over Effects

Next, we re-estimated our spill-over model for the individual Asian countries. The results, summarized in Table XIV below, show that we are unable to reject the existence of mean spill-over effects five out of the seven countries. This is a remarkable difference compared to that found using weekly returns, where only two countries showed signs of statistically significant mean spill-overs. There is evidence of volatility spill-overs in five countries. The overlap is not perfect however. Only two countries (China and Singapore) have statistically significant mean *and* volatility spill-over effects. Comparing the results to those obtained using weekly data, it is interesting to note that Indonesia and Thailand, which had statistically significant volatility spill-over effects at the weekly level, no longer show any signs of such an effect.

Table XIV
Testing for US Mean/Volatility Spill-Over Effects

Output from the GARCH(1,1) model on individual country returns as well as lagged US returns and contemporary US residuals. All data except Singapore for the 1997:01-2004:04 period. Singapore for the 1999:08-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	ψ	δ	$100w_i$	α	β
China	0.03% ***	-5.81% ***	70.85% ***	6.08% ***	0.00%	9.04% **	92.40% ***
	0.01%	2.24%	3.69%	2.15%	0.00%	4.17%	3.16%
Indonesia	0.03% **	-4.3%	52.69 % **	3.95%	0.00%	7.82%	96.35% ***
	0.01%	4.7%	5.41%	4.29%	0.00%	5.43%	1.48%
Malaysia	0.19% ***	37.5%	-26.84%	63.78% ***	0.12% ***	107.04% ***	48.53% ***
	0.04%	25.4%	36.41%	5.23%	0.04%	40.87%	6.37%
Philippines	-0.04%	1.4%	17.05%	23.36% *	0.94%	3.89%	61.13% ***
	0.05%	5.5%	18.64%	13.24%	0.84%	3.10%	15.31%
Singapore	0.00%	4.1%	92.31% ***	13.96% ***	0.01%	12.45%	84.58% ***
	0.01%	3.0%	3.68%	3.54%	0.00%	8.90%	8.29%
South Korea	0.03% ***	23.9%	29.49%	16.92% ***	0.00%	53.88% ***	77.09% ***
	0.01%	22.9%	14.29%	3.41%	0.00%	17.03%	2.93%
Thailand	0.02%	-1.9%	68.37% ***	21.34%	0.03%	5.50%	92.60% ***
	0.02%	7.2%	3.33%	16.2%	0.02%	7.05%	5.10%

Significant at 1% (***), 5% (**), 10% (*) levels.

Most, but not all, processes appear to be highly persistent. The sum of the ARCH and GARCH terms (i.e. $\alpha + \beta$) are reported in Table XV. Thailand and Malaysia, had high numbers at the weekly level as well. Indonesia's figure decreased by 0.19 to 1.04, indicating that volatility shocks appear to be more persistent at the daily level for this country. Again we tested the robustness of the estimated coefficients by changing the starting values. The results, which we do not include due to space constraints, are virtually unaltered. This was also the case for the EMU daily tests reported below.

Table XV
Persistence of Conditional Volatility Processes

Sum of ARCH (α) and GARCH (β) coefficients for each country. Number just below one indicates model persistence.

	$\alpha + \beta$
China	1.01
Indonesia	1.04
Malaysia	1.24
Philippines	0.65
Singapore	0.97
South Korea	1.31
Thailand	0.98

The Wald Tests reject the null hypothesis of no spill-over effects at all (mean or volatility) at the 1 % level for all countries except the Philippines. Two things are especially noteworthy. The Wald Test for Indonesia using weekly data was unable to reject the null-hypothesis. Using daily data, it is rejected at the highest level. Conversely, the Philippines, where the null-hypothesis was rejected at the 5% level using weekly data, now shows no sign of any spill-overs. See Table XVI.

Table XVI
Wald Tests

Results of Wald Tests for the individual test countries. The test checks the *joint* hypothesis that both $\varphi_{US} = \delta_{US} = 0$.

	China	Indonesia	Malaysia	Philippines	Singapore	South Korea	Thailand
F-statistic	271.04 ***	47.61 ***	87.75 ***	1.79	385.17 ***	47.53 ***	258.48 ***
Chi-square	542.08 ***	95.21 ***	175.51 ***	3.57	770.33 ***	95.06 ***	516.96 ***

Significant at 1% (***), 5% (**), 10% (*) levels.

C3. Quantifying the Impact of US Daily Spill-Over Effects

Turning to the variance ratios, they are considerably smaller than their weekly counterparts, ranging from 0.05% to 3.61%. The only exception is the Philippines, which has a marginally (0.01%) higher variance ratio at this level. Note especially the large fall in explanatory power for China which fell from 37.0% to 0.8%. A similar, but less drastic fall is evident for Malaysia and South Korea.

Table XVII

Variance Ratios

Mean and standard deviation of the variance ratios.

	$VR^{US}_{i,t}$	
	Mean	**Std. Dev.**
China	0.79%	0.54%
Indonesia	0.05%	0.08%
Malaysia	3.44%	3.37%
Philippines	0.21%	0.10%
Singapore	3.61%	3.67%
South Korea	2.96%	1.43%
Thailand	0.88%	0.50%

Overall, using higher-frequency data has the effect of making US spill-over effects more evident. This is most evident for mean spill-overs. On the other hand, the explanatory power is reduced substantially. As discussed in the beginning, however, there is a risk that the relationship on the daily level is spurious. The results should therefore be interpreted with prudence. As should the results on EMU daily spill-over effects reported in the following section.

D. EMU Daily

D1. GARCH Model on EMU Daily Returns

Table XVIII below shows the output from the GARCH(1,1) model on EMU daily returns. Unlike the US daily returns, but similarly to EMU and US weekly returns, the lagged daily returns seem unable to explain any of today's return. Again, the ARCH-LM test and Ljung-Box Q statistic show no sign of a model misspecification.

Table XVIII
GARCH Output on EMU Returns

Output from the GARCH(1,1) model on EMU Returns over the 1997:01-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	$100w_i$	α	β
EMU	0.02%	0.76%	0.01% **	5.32% ***	92.69 %***
	0.01%	2.38%	0.00%	1.20%	2.02%

Significant at 1% (***), 5% (**), 10% (*) levels.

D2. Testing for EMU Daily Mean/Volatility Spill-Over Effects

The results, from the spill-over models using EMU daily data are summarized in Table XIX. In contrast to the results obtained using US daily returns, we are able to reject the existence of mean spill-over effects for five out of the seven countries (all but Singapore and Thailand). At the weekly level, only Thailand showed statistically significant signs of mean spill-over effects. Malaysia, Singapore and South Korea show signs of statistically significant volatility spill-over effects, although the coefficient for Malaysia is only significant at the 10% level. Interestingly, the very strong volatility spill-over effects found for Thailand at the weekly level are gone. The validity of the volatility spill-over effects found is questionable, however, especially since the all the statistically significant coefficients are of the 'wrong sign', i.e. negative. Again, we stress the importance of being cautious in interpreting the results, especially bearing the possible correlation effects imposed by the necessary currency adjustment in mind.

Table XIX
Testing for Daily EMU Mean/Volatility Spill-Over Effects

Output from the GARCH(1,1) model on individual country returns as well as lagged EMU returns and contemporary EMU residuals. All data except Singapore for the 1997:01-2004:04 period. Singapore for the 1999:08-2004:04 period. First row contains the estimated coefficients. Second row holds the corresponding t-values.

	$c_{0,i}$	$c_{1,i}$	ϕ	δ	$100w_i$	α	β
China	0.03% ***	-0.37%	1.25%	1.45%	0.00%	20.53% ***	80.47% ***
	0.01%	2.70%	1.32%	1.77%	0.00%	3.78%	3.79%
Indonesia	0.05% ***	-1.74%	-0.67%	-2.68%	0.00%	7.73%	96.32% ***
	0.02%	5.00%	2.85%	2.75%	0.00%	5.78%	1.67%
Malaysia	0.06% ***	17.41%	-2.46%	-5.82% *	0.01% *	36.72% *	79.00% ***
	0.01%	22.42%	2.36%	3.05%	0.01%	20.27%	4.12%
Philippines	-0.03%	-3.10%	3.58%	-4.11%	4.14% ***	7.66%	-2.27%
	0.03%	6.02%	4.22%	7.39%	1.52%	8.35%	3.04%
Singapore	0.08% ***	-6.33%	3.99% **	-4.89% ***	0.00%	7.03% **	92.40% ***
	0.01%	4.07%	2.02%	1.75%	0.00%	2.92%	3.91%
South Korea	0.05% ***	20.62%	-0.68%	-2.48% **	0.00%	34.44% *	80.08% ***
	0.01%	16.22%	1.61%	1.11%	0.00%	19.47%	4.47%
Thailand	0.05%	35.28% ***	17.07% ***	-4.59%	0.24% ***	315.59%	3.48%
	0.07%	9.00%	5.74%	8.8%	0.07%	207.33%	6.03%

Significant at 1% (***), 5% (**), 10% (*) levels.

Turning to model persistence, for most countries the ARCH + GARCH coefficients sum to approximately one. A notable exception is Thailand, which has a number beyond three. The instability of this process may help explain why the highly significant volatility spill-over effects found at the weekly level have disappeared completely. Also, the Philippines figure of 0.05 (with a negative GARCH component), hints that we must be careful in interpreting the numbers for this country.

Table XX
Persistence of Conditional Volatility Processes

Sum of ARCH (α) and GARCH (β) coefficients for each country. Number just below one indicates model persistence.

	$\alpha + \beta$
China	1.01
Indonesia	1.04
Malaysia	1.16
Philippines	0.05
Singapore	0.99
South Korea	1.15
Thailand	3.19

The Wald Tests reject the null hypothesis of no spill-over effects for Singapore (1% level), South Korea (10% level), and Thailand (1% level). At the weekly level, the null hypothesis was rejected for Malaysia, the Philippines, and Thailand. The only country for which spill-over effects from the EMU region appear to exist at both the weekly and daily level is thus Thailand. See Table XXI.

Table XXI
Wald Tests

Results of Wald Tests for the individual test countries. The test checks the *joint* hypothesis that both $\varphi_{EMU} = \delta_{EMU} = 0$, i.e. of no spill-over effects.

	China	Indonesia	Malaysia	Philippines	Singapore	South Korea	Thailand
F-statistic	0.94	0.50	1.83	0.62	5.76 ***	2.50 *	4.98 ***
Chi-square	1.87	1.00	3.65	1.24	11.52 ***	5.01 *	9.97 ***

Significant at 1% (***), 5% (**), 10% (*) levels.

Over the test period, the EMU spill-over effects explain between 0.07% and 2.19% of the conditional variance of the unexpected return of each country. This should be compared a maximum explanatory power of 29.8% found at the weekly level. For most countries, the mean is below 0.5%. In sum, the results indicate that the explanatory power is low for most countries at the daily level.

Table XXII
Variance Ratios

Mean and standard deviation of the variance ratios.

	$VR^{EMU}_{i,t}$	
	Mean	**Std. Dev.**
China	0.08%	0.05%
Indonesia	0.07%	0.10%
Malaysia	0.51%	0.39%
Philippines	2.19%	26.38%
Singapore	0.24%	0.20%
South Korea	0.69%	0.35%
Thailand	0.18%	0.11%

To summarize, using EMU daily data provided much weaker support for our mean/volatility spill-over hypothesis than when we used the corresponding data from the US. Even for the countries where the spill-over coefficients were statistically significant, their explanatory power, as measured by the variance ratios, is at such a low level that it would be tempting to disregard it. We suspect that a weak 'true' relationship in combination with the distortion caused by the currency adjustments, are driving forces behind these results.

This concludes our testing of mean- and volatility spill-over effects from the US and EMU regions into the Asian countries. Christiansen augmented her study by testing for structural breaks. A close scrutiny of our data in general, and the variance ratios in particular, intuitively do not motivate this procedure for the majority of the test countries. Furthermore, data limitations make the results of such test of questionable value. We return to this issue in the section presenting our suggestions for future research.

In the following section, we conclude by summarizing, and discussing the implications of, the key findings presented in the paper.

VI. Conclusions

This paper has investigated the extent of mean and volatility spill-over effects from the US and EMU area into a number of Asian bond markets. The issue is important both from an investor and a policy perspective. A GARCH(1,1) model allowing for spill-overs of the first and second moments has been used to this end. The model, which accommodates the time-varying characteristics of bond market volatility, is a commonly accepted and widely used tool in this type of study.

At a general level, volatility spill-over effects have appeared to be of substantial importance, whereas the mean spill-over effects were of a comparatively minor importance. This is in line with the findings of Christiansen (2003) who found mean spill-over effects to be almost negligible, whereas volatility spill-over effects were shown to be of an essential importance in explaining the returns of several key European bond markets.

Using a combination of weekly and daily data, we find it safe to conclude that the Asian countries tested generally are more influenced by the US than by the EMU area. Also, spill-over effects appear to be more important at the weekly level. Furthermore, it is interesting to note that the explanatory power of unexpected US returns is increasing over time. This is probably related to the occurrence of the Asian Financial Crisis which occurs in the beginning of our sample (1997:06-1998:12). Still, we had expected the explanatory power of the US to decrease over time as the relative importance of the EMU region increased. Our research provides no indication of such a development. With the growing weight of the EMU region, it will be interesting to see if the results hold in the future, as discussed in our suggestions for future research.

An interesting finding from our study is the evidence found on the widely varying nature of bond market volatility in the various Asian bond markets, especially in terms of their dependence on external (i.e. primarily US) spill-over effects. For instance, it is noteworthy that countries such as Indonesia and the

Philippines, which today actively participate in the global financial markets, appear virtually unaffected. Conversely, the sleeping financial giant in China is severely affected, with US volatility explaining more than one third of the country's unexpected return variance.

Overall, we have thus shown that any researcher, trader, or politician, with a serious interest in modelling Asian country bond market volatility, must therefore not only account for individual country effects, but also the developments of – and the co-movements with - the world bond market in general and the US bond market in particular.

In the next and final section, we present suggestions for future lines of related research.

VII. Suggestions for Future Research

In the process of conducting this study we have encountered numerous topics which are worthy of closer scrutiny. We suggest the following matters without ranking them internally:

- In our study, the extent of spill-overs clearly varied between the test countries. Intuitively, we had expected some divergences, but increasing trade integration and geographical proximity lead us to a priori expect the results to have been more similar (as was the case in Christensen's study). We suspect the divergence in result is related to the close economic and political integration in the EMU area. Still, it would be interesting to investigate the issue in more detail.
- With the increasing importance of the EMU region, it would be interesting to re-estimate our models in a few years (say, 2008). We suspect that the importance of the European region will have increased by then. Perhaps then it would be useful to introduce some form of test for the existence of a structural break.
- Although it has been the purpose of our study to use the best data available, the data in the EcoWin database proved limiting. Specifically, it would be useful to find a USD-denominated total return index and see how this would impact the results. Furthermore, it would be interesting to include some form of Asian index, to distinguish between global and regional spill-over effects.

VIII. References

A. Literature

Baele, L. (2004), Volatility Spill-Over Effects in European Equity Markets: Evidence from a Regime Switching Model, Working paper, Ghent University.

Barclay, M. J., R.H. Litzenberger, and J.B. Warner, 1990, "Private Information, Trading Volume, and Stock-Return Variances," *Review of Financial Studies* 3, 233-253.

Bekaert, G. and Harvey, C. R. (1997), 'Emerging Equity Market Volatility', *Journal of Financial Economics* 43, 29-77.

Bekaert, G., Harvey, C. R. and Ng, A. (2002), 'Market Integration and Contagion', *Journal of Business.*

Berndt, E. K., Hall, B. H., Hall, R. E. and Hausman, J. A. (1974), 'Estimation and Inference in Nonlinear Structural Models', *Annals of Economic and Social Measurement* 3, 653-665.

Bollerslev, T. (1986), 'Generalized Autoregressive Conditional Heteroskedasticity', *Journal of Econometrics* 31, 307-327.

Bollerslev, T. and Wooldridge, J. M. (1992), 'Quasimaximum Likelihood Estimation Dynamic Models with Time Varying Covariances', *Econometric Reviews* 11, 143-172.

Brooks, C., 2002, 'Introductory Econometrics for Finance', Cambridge University Press.

Christiansen, C., (2003), Volatility-Spillover Effects in European Bond Markets, working paper, Aarhus School of Business.

Clare, A. and Lekkos, I. (2000), An Analysis of the Relationship between International Bond Markets, Working paper, Bank of England.

Driessen, J., Melenberg, B. and Nijman, T. (2003), 'Common Factors in International Bond Returns', *Journal of International Money and Finance* 22(5), 629-656.

Engle, R. F. (1982), 'Autoregressive Conditional Heteroskedasticity with Estimates of the Variance of United Kingdom Inflation', *Econometrica* 50, 987-1007.

Engle, R. F., Ito, T. and Lin, W.-L. (1990), 'Meteor-Showers or Heat Waves? Heteroskedastic Intro-Daily Volatility in the Foreign Exchange Market', *Econometrica* 58(3), 525-542.

Eom, Y. H., Subrahmanyam, M. G. and Uno, J. (2002), 'The Transmission of Swap Spreads and Volatilities in the International Swap Markets', *Journal of Fixed Income* 12(1), 6-28.

Eun, C., and S. Shlm, 1989, "International Transmission of Stock Market Movements", *Journal of Financial and Quantitative Analysts* 24, 241-256.

Hamao, Y., R.W. Masulis, and V. Ng, 1990, "Correlations in Price Changes and Volatility Across International Stock Markets", University of California, San Diego.

Hilliard, J., 1979, "The Relationship between Equity Indices on World Exchanges," *Journal of Finance* 34, 103-114.

Ilmanen, A. (1995), 'Time-Varying Expected Returns in International Bond Markets', *Journal of Finance* 50(2), 481-506.

Jaffe, J., and R. Westerfield, 1985 a, "Patterns in Japanese Common Stock Returns: Day of the Week and Turn of the Year Effects," *Journal of Financial and Quantitative Analysts* 20, 261-272.

Jaffe, J., and R. Westerfield, 1985 b, The Week-End Effect in Common Stock Returns: The International Evidence," *Journal of Finance* 40, 433-454.

Jarque, C. M. and Bera, A. K. (1980), 'Efficient Tests for Normality', *Economics Letters* 6, 255-259.

King, M. A. and Wadhwani, S. (1990), 'Transmission of Volatility between Stock Markets', *Review of Financial Studies* 3(1), 5-33.

Lin, W.-L., Engle, R. F. and Ito, T. (1994), 'Do Bulls and Bears Move across Borders? International Transmission of Stock Returns and Volatility', *Review of Financial Studies* 7(3), 507-538.

Ljung, G. M. and Box, G. E. P. (1978), 'On a Measure of Lack of Fit in Time-Series Models', *Biometrika* 65, 297-303.

Ng, A. (2000), 'Volatility Spill-Over Effects from Japan and the US to the Pacific-Basin', *Journal of International Money and Finance* 19, 207-233.

Skintzi, V., (2004), 'Volatility Spill-Overs and Dynamic Correlation in European Bond Markets', *EFMA 2004 Basel Meeting Papers.*

B. Electronic Source

E-Views Help File

The E-Views Help File is a good reference for econometric models, providing an easy to understand account of the implemented statistical procedures.

C. Database

Ecowin

Ecowin is a database providing financial and macroeconomic data.

Appendix I – GARCH Robustness Test: Weekly Level

The results from re-estimating the GARCH (1,1) equation for those countries with an $\alpha + \beta$ coefficients higher than one are shown below. To make sure the optimization algorithm does not stop at a local maximum, various starting values are employed. The choice of starting value appears to have little – if any – significance on the obtained coefficients. See Tables AI and AII below:

Table AI
GARCH Robustness Test on US Weekly Data
Obtained values from re-estimating the GARCH equation with different starting values.

	Start Value	Log Likelihood	Arch(α)	Garch(β)	α+β
Indonesia	OLS/TSLS	895.87	0.412872	0.812185	1.225057
	0.8 X OLS/TSLS	895.87	0.412849	0.812192	1.225041
	0.5 X OLS/TSLS	895.87	0.412855	0.812191	1.225046
	0.3 X OLS/TSLS	895.87	0.412612	0.812265	1.224877
	ZERO	895.87	0.412601	0.812268	1.224869
Malaysia	OLS/TSLS	1112.93	0.530904	0.601117	1.132021
	0.8 X OLS/TSLS	1112.14	0.589885	0.599652	1.189537
	0.5 X OLS/TSLS	1112.78	0.552862	0.599927	1.152789
	0.3 X OLS/TSLS	1112.82	0.549231	0.599535	1.148766
	ZERO	1112.84	0.548355	0.598969	1.147324
South Korea	OLS/TSLS	1274.07	1.176624	0.477615	1.654239
	0.8 X OLS/TSLS	1274.07	1.176644	0.477613	1.654257
	0.5 X OLS/TSLS	1274.07	1.176542	0.477626	1.654168
	0.3 X OLS/TSLS	1274.07	1.176546	0.477625	1.654171
	ZERO	1274.07	1.176633	0.477614	1.654247

Table AII
GARCH Robustness Test on EMU Weekly Data
Obtained values from re-estimating the GARCH equation with different starting values.

	Start Value	Log Likelihood	Arch(α)	Garch(β)	α+β
Indonesia	OLS/TSLS	892.65	0.39985	0.810554	1.210404
	0.8 X OLS/TSLS	892.65	0.399778	0.810576	1.210354
	0.5 X OLS/TSLS	892.65	0.399699	0.810599	1.210298
	0.3 X OLS/TSLS	892.65	0.399637	0.810619	1.210256
	ZERO	892.65	0.399708	0.810596	1.210304
South Korea	OLS/TSLS	1219.93	0.85054	0.485599	1.336139
	0.8 X OLS/TSLS	1219.93	0.850543	0.485599	1.336142
	0.5 X OLS/TSLS	1219.93	0.850323	0.485646	1.335969
	0.3 X OLS/TSLS	1219.93	0.850463	0.485617	1.33608
	ZERO	1219.93	0.850431	0.485624	1.336055

Since the tests on the daily data level were mainly performed as a validation experiment, we have chosen not to include the results from the corresponding re-estimations at the daily level. Again, however, the results remained virtually unaltered.

Appendix II – Variance Ratios

A. USA Weekly

Figure I
Variance Ratios – USA/China
USA/China variance ratios over the 1997:01-2004:04 period.

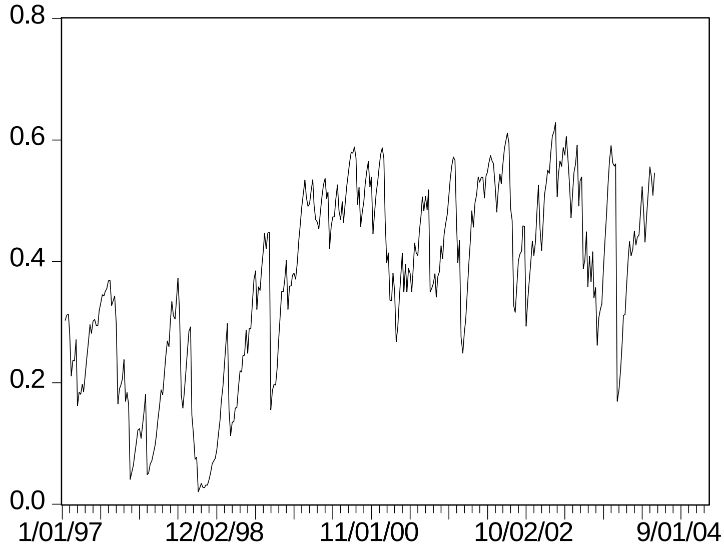


Figure II
Variance Ratios – USA/Indonesia
USA/Indonesia variance ratios over the 1997:01-2004:04 period.

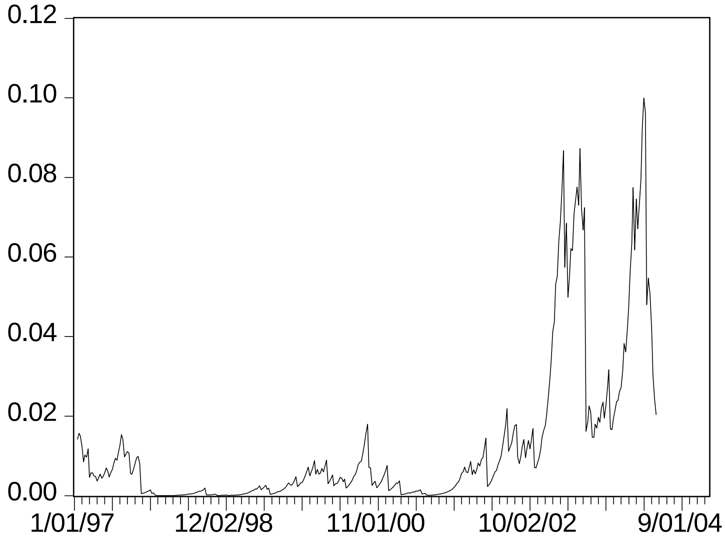


Figure III
Variance Ratios – USA/Malaysia

USA/Malaysia variance ratios over the 1997:01-2004:04 period.

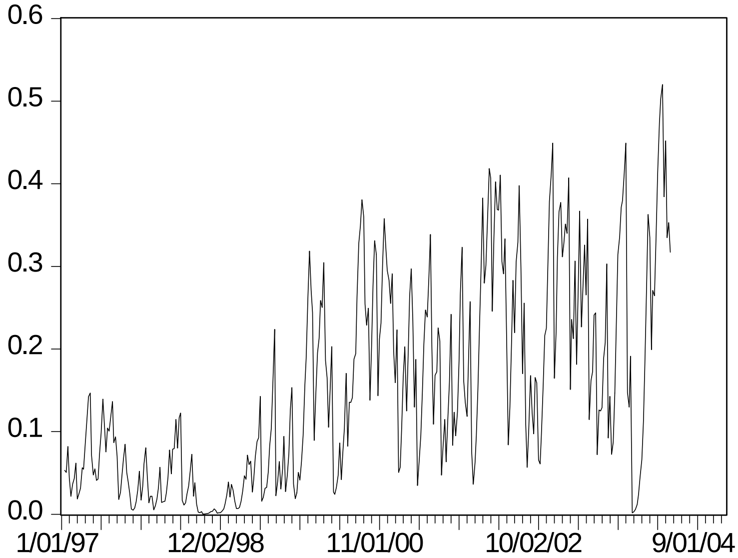


Figure IV
Variance Ratios – USA/Philippines

USA/Philippines variance ratios over the 1997:01-2004:04 period.

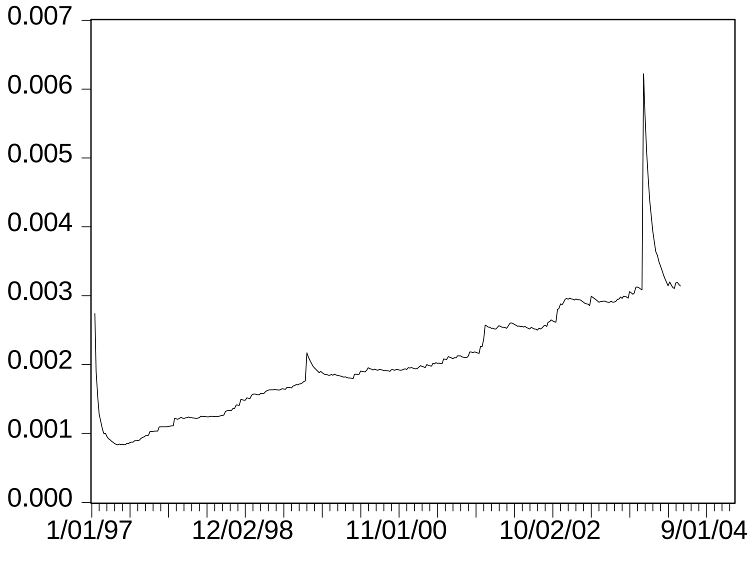


Figure V
Variance Ratios – USA/Singapore

USA/Singapore variance ratios over the 1999:08-2004:04 period.

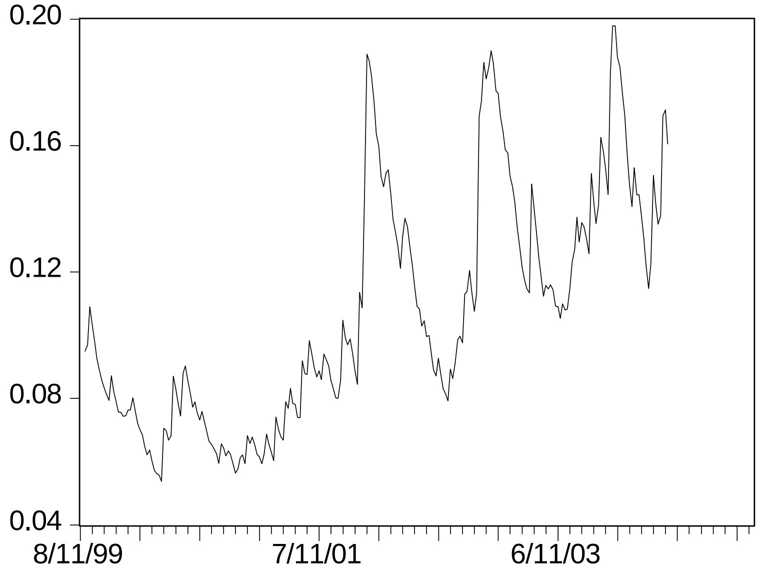


Figure VI
Variance Ratios – USA/South Korea

USA/South Korea variance ratios over the 1997:01-2004:04 period.

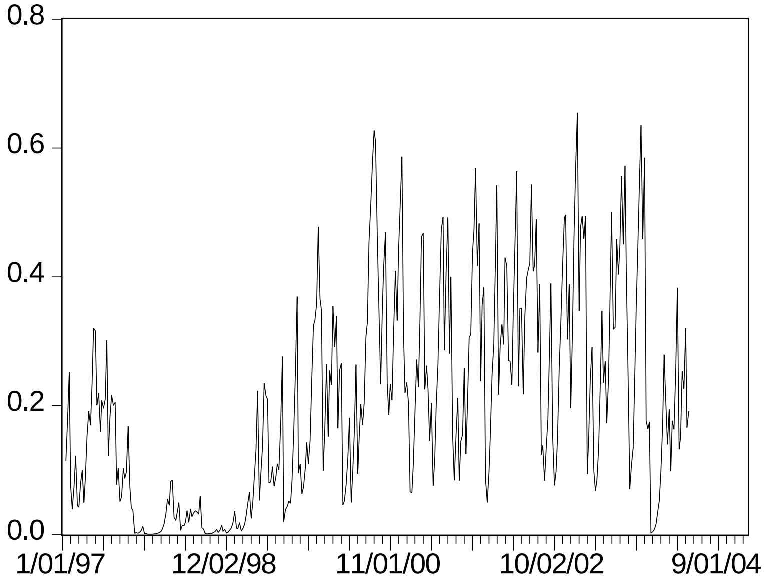
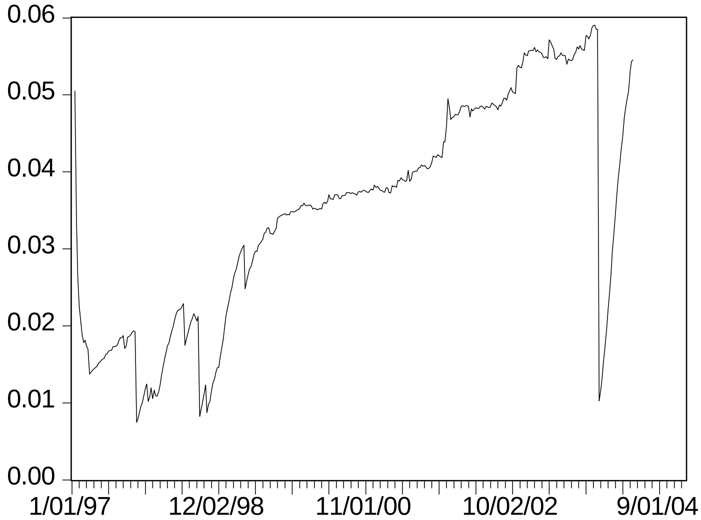


Figure VII
Variance Ratios – USA/Thailand

USA/Thailand variance ratios over the 1997:01-2004:04 period.



B. EMU Weekly

Figure VIII
Variance Ratios – EMU/China

EMU/China variance ratios over the 1997:01-2004:04 period.

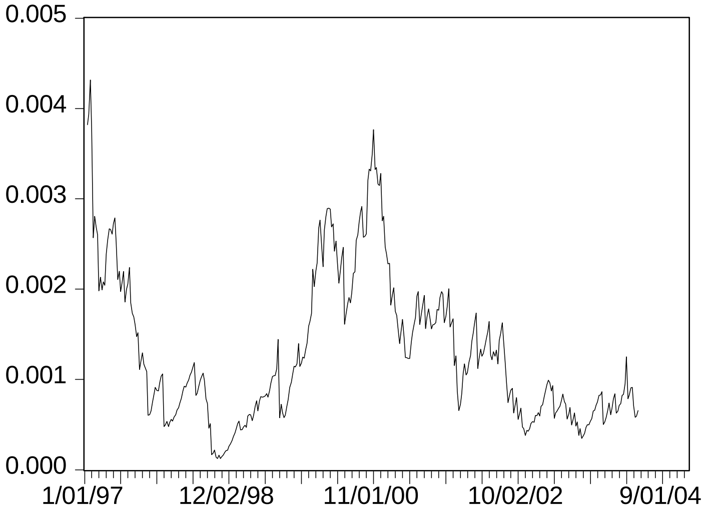


Figure IX
Variance Ratios – EMU/Indonesia

EMU/Indonesia variance ratios over the 1997:01-2004:04 period.

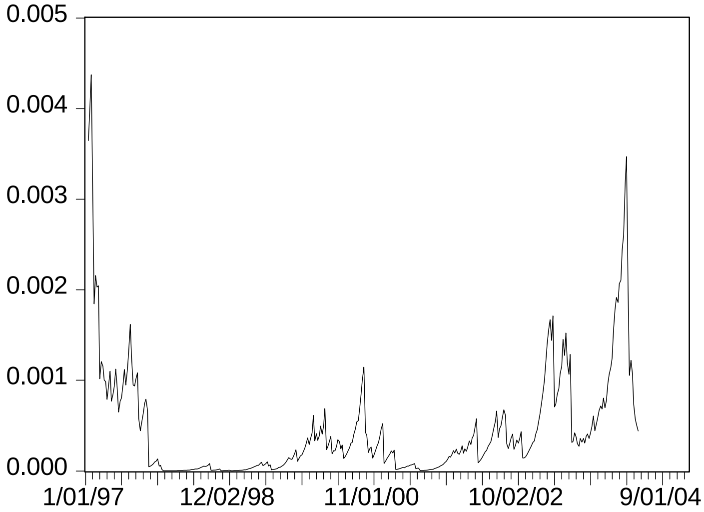


Figure X
Variance Ratios – EMU/Malaysia

EMU/Malaysia variance ratios over the 1997:01-2004:04 period.

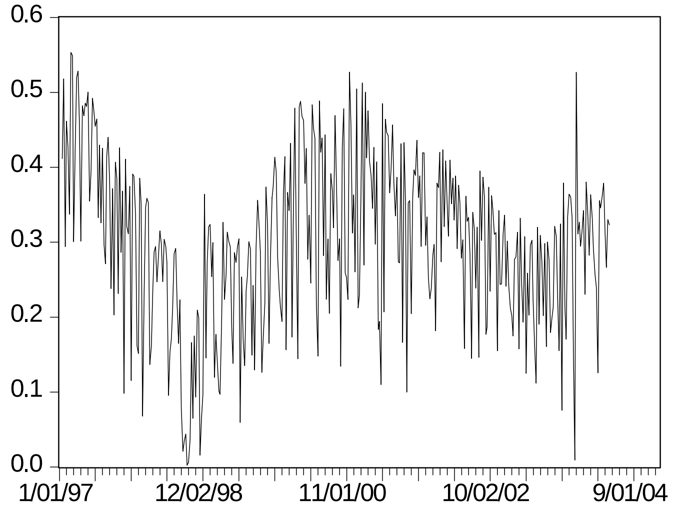


Figure XI
Variance Ratios – EMU/Philippines

EMU/Philippines variance ratios over the 1997:01-2004:04 period.

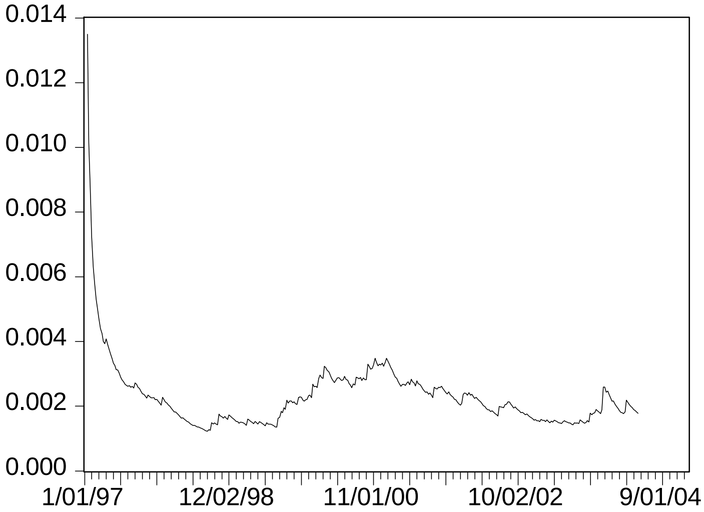


Figure XII
Variance Ratios – EMU/Singapore

EMU/Singapore variance ratios over the 1999:08-2004:04 period.

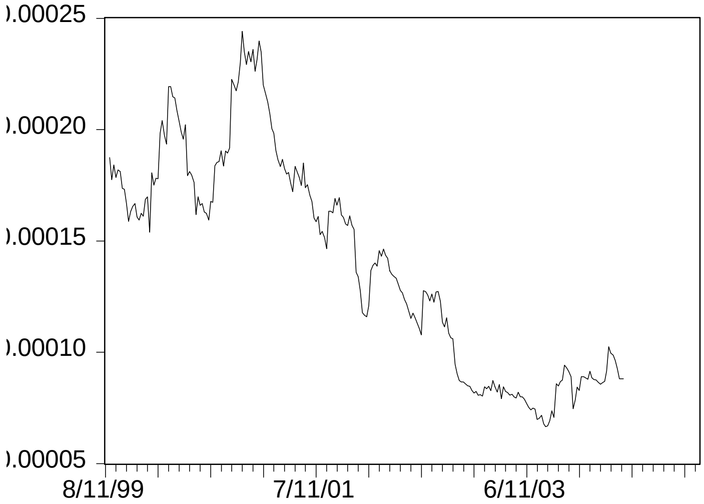


Figure XIII
Variance Ratios – EMU/South Korea

EMU/South Korea variance ratios over the 1997:01-2004:04 period.

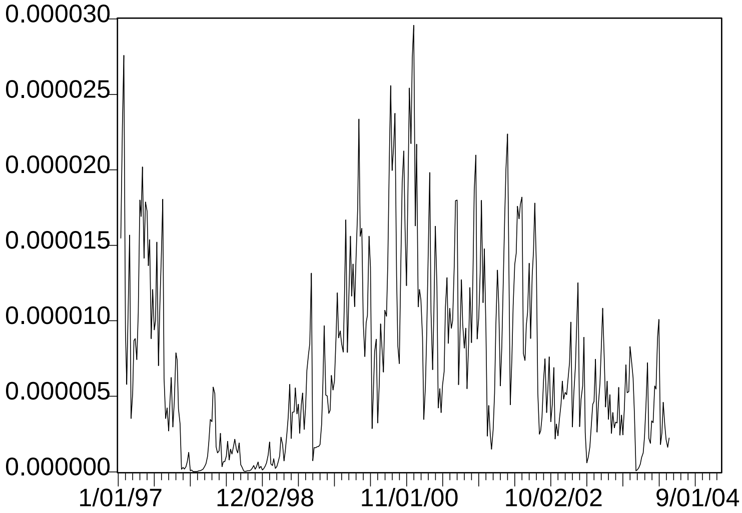


Figure XIV
Variance Ratios – EMU/Thailand

EMU/Thailand variance ratios over the 1997:01-2004:04 period.