Estimating Time-Varying Currency Betas: New Evidence from Nine Developed and Emerging Markets

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Abstract

This paper examines the conditional time-varying currency betas from five developed markets and four emerging markets. We employ BEKK multivariate GARCH models of Engle and Kroner (1995) to estimate the time-varying conditional variance and covariance of returns of stock index, the world market portfolio and changes in bilateral exchange rate between the US dollar and the local currency. It is found that currency betas are more volatile than those of the world market betas. Currency betas in emerging markets are more volatile than those in the developed markets. Moreover, we find evidence of long-memory in currency betas. The usefulness of time-varying currency betas are illustrated by two applications.

Key Words: time-varying currency betas; multivariate GARCH-M models; international CAPM; long memory; stochastic dominance

JEL Classification: C22; F31; F37; G12; G15

1. Introduction

Ever since the breakdown of the Bretton Woods system in the early 1970s, especially the increased globalization and recent global financial crisis, the volatility of exchange rates and its associated risks have become an increasingly important issue for international financial management. It is widely believed that firm value is sensitive to exchange rate movements as the fluctuations in exchange rates affect both the cash flow of a firm's operations and its discount rate employed to value a firm. However, empirical work on exchange rate exposure has found only limited support of a significant relationship between firm value and exchange rate changes. For instance, Jorion (1990) examines the exchange rate exposures of 287 US multinational corporations (MNCs) but finds that only a very small percentage exhibits significant exposure. Similarly, Bodnar and Gentry (1993) study industry-level exchange rate exposures for Canada, Japan and the USA, and find that only 9 of 39 two-digit industry portfolios exhibit significant exchange rate exposure at the 5% level from 1979 to 1988. A few empirical studies found significant exchange rate risk sensitivity under certain conditions. Bartov and Bodnar (1994) found that abnormal returns are related to lagged changes of exchange rates, which supports market inefficiency. The studies by Chow and Chen (1998) and Bodnar and Wong (2000), show the association between firm value and exchange rate changes becomes significant when the time horizon is increased. Williamson (2001) incorporates changes in the industry competitive environment and finds substantial time-varying foreign exchange exposure.[1] Using a weighted market portfolios approach, Bodnar and Wong (2003) are the first to demonstrate the importance of the definition of the stock market risk factor. They find that, because large firms are over-represented in these indices, value-weighted market indices induce a positive bias in exposure coefficients.

Recently several studies employ time-varying second moments to derive time-varying exchange rate exposure (see, for instance, Hunter, 2005; Lim, 2005; Tai, 2010; Jayasinghe et al., 2011). Hunter (2005) analyzes the time-varying exchange rate exposure of small and large firms using size-based portfolios of the Fama-French-type,

[1] Allayannis (1997), Chiao and Hung (2000), Allayannis and Ihrig (2001), and Bodner et al. (2002) employ pre-specified determinants of exposure coefficients to analyze the time-variation of exchange rate exposure, but the results are mixed. Bodner et al. (2002) did not find evidence of time-varying exposure.

and Lim (2005) derives both market and currency betas at country level, with allowance for non-orthogonality between risk factors. Using industry data for Japan, Tai (2010) finds strong evidence of time-varying foreign exchange risk premium and significant exchange rate betas based on the tests of conditional asset pricing models using MGARCH-M approach where both conditional first and second moments of industry returns and risk factors are estimated simultaneously. The most recent study by Fu et al. (2011) use daily industry-level stock data over the period 1994-2007 to study volatility transmission between the Japanese stock and foreign exchange markets. Their results indicate that news shocks in the Japanese currency market account for volatility transmission in eight of the ten industrial sectors considered. It is observed that most of the early studies on foreign exchange rate exposures focus on the US stock market (with a few on Japan), and it is not clear how these empirical results relate to other countries, especially the emerging economies and markets. The purpose of this paper is to provide new evidence on the foreign exchange rate exposures in both the developed and emerging markets by extending previous studies through the employment of a trivariate BEKK-GARCH framework and the most recent daily dataset. This study will advance our better understanding of volatility transmissions from exchange rate shocks to conditional stock market returns volatility in different countries and markets.

In this study, we adopt the general framework of conditional international capital asset pricing model (ICAPM) proposed by Adler and Dumas (1983) and De Santis and Gerard (1998) to estimate the time varying currency betas and the time-varying market betas for nine developed and emerging countries. Unlike the previous studies, we employ the Baba, Engle, Kraft and Kroner (BEKK) multivariate GARCH models of Engle and Kroner (1995) to estimate the conditional variance and covariance of return variables using a set of daily data spanning from 5 January 1999 to 25 July 2012. In particular, we compute the time-varying currency betas and market betas using estimates of the conditional variance and covariance of returns from country stock index, world market portfolio and changes in exchange rate of the trading country. To the best of our knowledge, this is the first study that estimates such betas from a trivariate BEKK-GARCH-type specification based on daily returns with the most updated dataset in both developed and emerging markets. The main advantage of the BEKK parameterization is that it guarantees the variance and covariance matrix to be positive definiteness during estimation, and the often alleged difficulty of interpreting parameters in BEKK models is not an issue. Our results indicate that currency betas are generally more volatile than that of the world market betas. In addition, currency betas in the four emerging markets are more volatile than those in the developed markets. We also find some evidence of long-memory in the estimated currency betas. The findings have important implications for investment and hedging strategies.

The rest of this paper is organized as follows. The conditional version of international CAPM is outlined in Section 2. Section 3 presents the methodology employed to estimate currency betas and market betas from the conditional variance and covariance of return variables. Section 4 presents the sample data and preliminary results. In Section 5 we report and discuss the main empirical findings, and assess the usefulness of the conditional time-varying betas series as a source of information for decision making. Some concluding remarks are given in Section 6.

2. The ICAPM Framework

The standard capital asset pricing model (CAPM) analyses how investors are compensated for investing in risky assets in their country of residence, and hence, the different expected return is gained by taking the different risk levels. Based on CAPM, the international capital asset pricing model (ICAPM) proposed by Adler and Dumas (1983) and others[2] takes countries as stock portfolios in the global market. Under this setting the systematic risk of the portfolio could be decreased without decline in expected return by investing different capital markets since the stock prices are affected by domestic or local events. In other words, domestic systematic risk can be diversified away by investing internationally without paying a price in terms of lower returns. This has important implications for international portfolio investors. We highlight some of the salient features of conditional ICAPM as follows.

In a world of $(L + 1)$ countries, the expected excess returns on equity/asset i can be expressed as:

$$E_{t-1}\left(r_{i,t}\right) = \lambda_{m,t-1} Cov_{t-1}\left(r_{i,t}, r_{m,t}\right) + \sum_{l=1}^{L} \lambda_{\pi,l,t-1} Cov_{t-1}\left(r_{i,t}, \pi_{l,t}\right) \quad (1)$$

[2] Their model was initially known as international asset pricing model. Dumas and Solnik (1995) and De Santis and Gerard (1998) test the validity of conditional ICAPM.

where $E_{t-1}(.)$ and $Cov_{t-1}(.)$ denote the expectation and covariance, conditional on the available information set I_{t-1} at time *(t – 1)*. $r_{i,t}$ denotes the excess return on asset *i* in excess of a risk free rate of return in the currency of denomination in country *l*; $r_{m,t}$ denotes the excess return on the world market portfolio denominated in the reference currency; $\pi_{l,t}$ denotes the inflation rate in country *l* which includes the domestic inflation and changes in the exchange rate between the reference currency and the currency of denomination; $\lambda_{m,t-1}$ is the price of world market risk. The covariance between $r_{i,t}$ and $r_{m,t}$ measures the world market risk. In addition, $\lambda_{\pi,l,t-1}$ denotes the price of asset risk in country *l* and the covariance between $r_{i,t}$ and $\pi_{l,t}$ is used to gauge the inflation risk and the risk of exchange rate changes.

We consider two practical applications of the Adler and Dumas model. First, following Dumas and Solnik (1995) and De Santis and Gerard (1998), we assume non-stochastic inflation [3] so that the PPP deviations are mostly reflected in the exchange rate changes. Given our daily data set used in this study, the changes in price levels can be negligible as compared to the volatilities of exchange rate changes (Cappiello et al., 2003). As a result, $\pi_{l,t}$ will be effectively reduced to currency risk ($\pi_{x,t}$), and accordingly, $\lambda_{\pi,l,t-1}$ will be reduced to $\lambda_{x,l,t-1}$, which is the price of currency risk associated with country *l*.

Second, for parsimonious purposes, we assume that returns on a country stock index is a reasonable proxy for returns on assets or portfolios in that country, and that investors in each country will invest in assets in the United States. With this assumption, the second term on the right hand side of equation (1) is reduced to only one bilateral exchange rate between the US dollar and currency of the trading country. Although this may lead to the incomplete specification of the Adler and Dumas model since other currency premiums are still in the expected return equation, this issue is not our main concern as the objective of this study is to investigate the properties of time-varying currency betas, rather than to test the validity of ICAPM.[4] As returns on assets in each country is gauged by changes in the exchange rate with the US dollar,

[3] When inflation in a country is treated as stochastic, the expected returns are dependent on three premiums, namely, market, currency and inflation. See Moerman and van Dijk (2006) for details. However, we do not consider the inflation factor here.

[4] See De Santis and Gerard (1998) and Cappiello et al (2003) for testing the validity of ICAPM by a set of exchange rates.

the proposed parsimonious structure is able to serve as a common yard stick to compare exposure to currency risk in each country. The conditional ICAPM relationship in equation (1) can thus be rewritten as the sum of the product of time varying betas and the respective expected returns of risk factors:

$$E_{t-1}(r_{i,t}) = \beta_{m,t-1}E_{t-1}(r_{m,t}) + \beta_{x,t-1}E_{t-1}(r_{x,t}). \quad (2)$$

where $\beta_{m,t-1} = \frac{Cov_{t-1}(r_{i,t}, r_{m,t})}{Var_{t-1}(r_{m,t})}$ and $\beta_{x,t-1} = \frac{Cov_{t-1}(r_{i,t}, r_{x,t})}{Var_{t-1}(r_{x,t})}$. The world market beta ($\beta_{m,t-1}$) measures the asset's exposure to the world market risk while the currency beta ($\beta_{x,t-1}$) measures its exposure to the currency risk.

Following Lim (2005), we allow for possible non-orthogonality relationship between the world market returns and exchange rate changes. This leads to the following specifications for the expected returns for stock index, world market portfolio and changes in exchange rates:

$$E_{t-1}(r_{i,t}) = \lambda_{x,t-1}Cov_{t-1}(r_{i,t}, r_{x,t}) + \lambda_{m,t-1}Cov_{t-1}(r_{i,t}, r_{m,t}) \quad (3)$$

$$E_{t-1}(r_{x,t}) = \lambda_{x,t-1}Var_{t-1}(r_{x,t}) + \lambda_{m,t-1}Cov_{t-1}(r_{x,t}, r_{m,t}) \quad (4)$$

$$E_{t-1}(r_{m,t}) = \lambda_{x,t-1}Cov_{t-1}(r_{m,t}, r_{x,t}) + \lambda_{m,t-1}Var_{t-1}(r_{m,t}) \quad (5)$$

where $r_{i,t}$ is the return on country l's stock index at time t; $r_{m,t}$ indicates the return on the world market portfolio at time t; $r_{x,t}$ is the change in bilateral nominal exchange rate between the US dollar and currency of country l at time t; $\lambda_{m,t-1}$ refers to the time-varying market price of risk; and $\lambda_{x,t-1}$ is the time-varying currency price of risk.[5] Owing to non-orthogonality between the world market returns and exchange rate changes, a non-zero $Cov_{t-1}(r_{m,t}, r_{x,t})$ term is included in the mean equations in (4) and (5).

Moreover, as specified in equation (2), the expected return on asset/portfolio at time t is proportional to the world market returns and changes in exchange rates,

[5] The evidence in Harvey (1991), Dumas and Solnik (1995) and De Santis and Gerard (1998) suggests that the prices of all the sources of risk are time varying, and failing to allow them to vary over time could mislead one to conclude that the corresponding risks are not priced.

conditional on the information available at time (*t-1*). Intuitively, the proportionality factors (i.e. the world market and exchange rate exposure) should be time-varying because investors are sensitive to the new information periodically available, and hence able to adjust their investment strategies accordingly.[6]

3. Empirical Methodology

We employ a trivariate BEKK (*k*)-GARCH (*p, q*)-M (in mean) specification of Engle and Kroner (1995) to estimate the currency betas and market betas from the conditional second moments of various returns. To allow for time-varying world market and currency risk prices, we follow Merton (1980), De Santis and Gerard (1998) and Tai (2007) to model the dynamics of market risk price ($\lambda_{m,t-1}$) and currency risk price ($\lambda_{x,t-1}$) respectively as an exponential function and a linear function of a set of instruments observed at the end of time (t-1). The model is specified as follows:

$$r_t = \mu + \lambda_{x,t-1} H_{x,t} + \lambda_{m,t-1} H_{m,t} + \varepsilon_t \qquad (6)$$

where $r_t = (r_{i,t}, r_{x,t}, r_{m,t})'$

$$\varepsilon_t \mid I_{t-1} = (\varepsilon_{i,t}, \varepsilon_{x,t}, \varepsilon_{m,t})' \mid I_{t-1} \sim N(0, H_t)$$

$$\lambda_{x,t-1} = \delta'_{x,j} z_{t-1}; \; \lambda_{m,t-1} = \exp(\delta'_{m,j} z_{t-1})$$

$$H_t = C'C + \sum_{k=1}^{K}\sum_{n=1}^{p} B'_{kn} H_{t-1} B_{kn} + \sum_{k=1}^{K}\sum_{l=1}^{q} A'_{kl} \varepsilon_{t-1} \varepsilon'_{t-1} A_{kl} \qquad (7)$$

$$H_t = [H_{i,t}, H_{x,t}, H_{m,t}] = \begin{bmatrix} H_t^{qq} & H_t^{qk} \\ H_t^{kq} & H_t^{kk} \end{bmatrix} \qquad (8)$$

$$\begin{bmatrix} \beta_{x,t-1} \\ \beta_{m,t-1} \end{bmatrix} = \left[H_t^{kk}\right]^{-1} H_t^{kq} \qquad (9)$$

In equation (6), r_t is the 3 x 1 vector consisting of returns from time (t – 1) to time t on country index ($r_{i,t}$), return on the world market portfolio ($r_{m,t}$) and changes in bilateral nominal exchange rate between the US dollar and currency of the trading

[6] See Harvey (1991) for details.

country $l\,(r_{x,t})$,[7] respectively. Parameters λ_m and λ_x denote the time-varying market price of risk and currency price of risk, δ's are time-invariant vectors of weights and z_{t-1} is a set of information variables observed at the end of time (*t-1*). The information variables are used to explain changes in the prices of world market and currency risks, including the widely used world market information and also regional information variables detailed in the data description section. $H_{x,t}$ and $H_{m,t}$ are both 3 x 1 column vectors containing elements from the second and third columns of H_t. Note that $H_{x,t}$ represents the conditional covariance of changes in exchange rate with returns of the word market portfolio, itself and returns on country index, respectively. Similarly, $H_{m,t}$ represents the conditional covariance of returns of world market portfolio with respectively returns on country index, changes in exchange rate, and itself. μ is the intercept, and $\varepsilon_t \mid I_{t-1}$ denote the 3 x 1 vector of random errors at time t given all available information at time (*t-1*), which is assumed to follow a normal distribution with mean zero and variance H_t, whereas H_t is the corresponding 3 x 3 conditional variance and covariance matrix.

In equation (7), C is an upper triangular 3 x 3 matrix that contains constant parameters in the conditional variance and covariance matrix, and both A_{kl} and B_{kn} are 3 x 3 parameter matrices. A_{kl} captures the relationship between conditional variances and past residual terms ε, and B_{kn} indicates how current conditional variances and past variances are correlated. For parsimony, we set $K=1$ in the trivariate BEKK-GARCH-M model. The variance and covariance matrix of the proposed trivariate BEKK (*1*) - GARCH (*1, 1*)-M model can be simplified as follows:

$$H_t = \begin{bmatrix} h_{i,t} & h_{ix,t} & h_{im,t} \\ h_{xi,t} & h_{x,t} & h_{xm,t} \\ h_{mi,t} & h_{mx,t} & h_{m,t} \end{bmatrix} = \begin{bmatrix} c_i & 0 & 0 \\ c_{ix} & c_x & 0 \\ c_{im} & c_{xm} & c_m \end{bmatrix} \begin{bmatrix} c_i & c_{ix} & c_{im} \\ 0 & c_x & c_{xm} \\ 0 & 0 & c_m \end{bmatrix}$$

$$+ \begin{bmatrix} b_i & b_{ix} & b_{im} \\ 0 & b_x & b_{xm} \\ 0 & 0 & b_m \end{bmatrix} \begin{bmatrix} h_{i,t-1} & h_{ix,t-1} & h_{im,t-1} \\ h_{xi,t-1} & h_{x,t-1} & h_{xm,t-1} \\ h_{mi,t-1} & h_{mx,t-1} & h_{m,t-1} \end{bmatrix} \begin{bmatrix} b_i & 0 & 0 \\ b_{ix} & b_x & 0 \\ b_{im} & b_{xm} & b_m \end{bmatrix}$$

[7] Exchange rate is expressed as the US dollar price of foreign currency. An increase implies a depreciation of US dollar relative to the relevant currency.

$$+\begin{bmatrix} a_i & a_{ix} & a_{im} \\ 0 & a_x & a_{xm} \\ 0 & 0 & a_m \end{bmatrix}\begin{bmatrix} \varepsilon_{i,t-1} \\ \varepsilon_{x,t-1} \\ \varepsilon_{m,t-1} \end{bmatrix}\begin{bmatrix} \varepsilon_{i,t-1} & \varepsilon_{x,t-1} & \varepsilon_{m,t-1} \end{bmatrix}\begin{bmatrix} a_i & 0 & 0 \\ a_{ix} & a_x & 0 \\ a_{im} & a_{xm} & a_m \end{bmatrix} \qquad (10)$$

As specified in equation (9), the time-varying market betas and exchange rate exposure can be estimated using sub-matrices $H_t^{kk} = \begin{bmatrix} h_{x,t} & h_{xm,t} \\ h_{xm,t} & h_{m,t} \end{bmatrix}$ and $H_t^{kq} = \begin{bmatrix} h_{ix,t} \\ h_{im,t} \end{bmatrix}$. When market returns and exchange rate changes are not orthogonal, the market betas and currency betas are expressed as below:

$$\beta_{m,t-1} = \frac{h_{x,t}h_{im,t} - h_{xm,t}h_{ix,t}}{h_{x,t}h_{m,t} - [h_{xm,t}]^2} \qquad (11)$$

$$\beta_{x,t-1} = \frac{h_{m,t}h_{ix,t} - h_{xm,t}h_{im,t}}{h_{x,t}h_{m,t} - [h_{xm,t}]^2}. \qquad (12)$$

If they are orthogonal, H_t^{kk} become a diagonal matrix, and the market beta and currency beta are reduced to:

$$\beta_{m,t-1} = \frac{h_{im,t}}{h_{m,t}} \text{ and } \beta_{x,t-1} = \frac{h_{ix,t}}{h_{x,t}} \qquad (13)$$

In comparison, we believe that equations (11) and (12) provide more precise estimates of betas than those models using pre-specified determinants (see, for instance, Allayanis, 1997; Allayannis and Ihrig, 2001), and our model should also be more adequate than those employing less appropriate mean structures to obtain the time-varying betas (see Brooks et al., 2000 and 2002; McClain et al., 1996; Choudhry, 2002 and 2005).[8]

[8] Brooks et al. (2000) and (2002) take zero as the expected value of returns ($r_{i,t} = \varepsilon_{i,t}$), McClain et al. (1996) assume constant expected returns ($r_{i,t} = c + \varepsilon_{i,t}$), and Choudhry (2002 and 2005) uses the MA(1) process. However, this comment does not apply to studies like Giannopoulos (1995), Gonzales-Rivera (1996) and Choudhry (2005).

Assuming that the standardized residuals of the proposed trivariate BEKK (*1*)-GARCH (*1, 1*)-M model are conditionally normally distributed, then the conditional log-likelihood of residual vector ε_t at time *t* can be written as follows:

$$\ell(\theta)_t = -\frac{1}{2}\ln(2\pi) - \frac{1}{2}\ln|H_t| - \frac{1}{2}\varepsilon_t' H_t^{-1}\varepsilon_t \tag{14}$$

The log-likelihood function of the sample becomes $L(\theta) = \sum_{t=1}^{T} \ell(\theta)_t$ with T denoting the number of observations. The parameter vector θ can be estimated by maximizing L with respect to θ. To accommodate the non-normal country stock returns and the exchange rate changes, we estimate the parameters using the quasi-maximum likelihood (QML) estimation method as proposed by Bollerslev and Wooldridge (1992). Under certain regularity conditions, the QML estimates are consistent and asymptotically normal. Hence, statistical inference can be made using the robust standard errors. The required computer programs are coded in GAUSS and the BHHH optimization algorithm is employed to compute the QML estimates.

4. Data and Preliminary Results

Our sample dataset is drawn from five developed markets (the United States, United Kingdom, Canada, Japan, and Australia) and four emerging markets (Korea, Singapore, Taiwan and Thailand). For each country, we use a set of 3537 daily closing prices spanning from 5 January 1999 to 25 July 2012. The series are culled from Morgan Stanley Capital International (MSCI) and DataStream. The country level portfolios are proxied by the MSCI country indexes measured in local currency. The world market portfolio is represented by the MSCI world market index, which is a value-weighted index free from exchange rate fluctuations[9] (see Giannopoulos, 1995; MSCI, 1998). Bilateral exchange rates for the non-US countries are proxied by MSCI rates, which are then converted to the dollar price. A trade-weighted exchange rate compiled by the Bank of England is used to measure the exposure of the US assets.

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[9] Our approach is consistent with Giannopoulos (1995) to the effect that the market risk and currency risk should not be aggregated, and conversion of country index returns into a common currency will have an adverse impact on their volatility.

The daily returns (in percentage) of country stock index (*i*), world market index (*m*), and the bilateral exchange rate (*x*) are computed, on a continuously compounding basis, as follows:

$$r_{j,t} = \ln\left(R_{j,t} \Big/ R_{j,t-1} \right) * 100 \qquad j = i, m, x \qquad (15)$$

where $R_{j,t}$ and $R_{j,t-1}$ are the closing prices for trading days (*t - 1*) and *t*, respectively.

Following Harvey (1991), Dumas and Solnik (1995), De Santis and Gerard (1998) and Tai (2007), we select a set of information variables used to model the dynamics of $\lambda_{m,t-1}$ and $\lambda_{x,t-1}$, including the variation in the US term premium (*DUSTP*) which is measured by the yield spread between 10-year US Treasury notes and 3-month US Treasury bills, the US default premium measured by the yield difference between Moody's Baa-rated and Aaa-rated US corporate bond (*USDP*), the change in the S&P's 500 stock market index return (*SPX*), the change in return on MSCI high dividend yield index (*MHDY*), the change in the 30-day Eurodollar deposit rate (*DEUIR*), and a constant term (*CONST*). We also include in the set of instrumental variables the MSCI regional index (*REGIN*) (including *PACIN* for the Pacific region, *EURIN* for the European region and *NAMRIN* for the North American region) to account for the regional effect on the dynamics of the risk prices. All the data are extracted from Datastream.

Table 1 presents the summary statistics for daily returns of country indexes, the world market index and the exchange rate changes as well as the information variables.[10] As it can be observed in Panel A, all the stock returns are negatively skewed and exhibit excess kurtosis, ranging from the lowest 2.531 in Taiwan to the highest 9.788 in Thailand. The Jarque-Bera test statistics for normality is extremely high in all cases, exceeding the 1% level of significance. In contrast, it is noted in Panel B that the exchange rate changes are both positively and negatively skewed, and also have much larger kurtosis than that of the stock returns for five countries, including Australia, Korea, Singapore, Taiwan and Thailand. Korea and Thailand have the largest excess kurtosis, amounting to 57.404 for Korea and 109.22 for

[10] We also performed the unconditional correlation analysis of these information variables. The results (available upon request) show that all the correlation coefficients are below 0.5 (except the value between REGIN (NAMRIN) and SPX), which are consistent with the previous studies and indicate that the selected instrumental variables contain sufficiently orthogonal information.

Thailand, respectively. As it can be seen in Panel C, the information variables are also both positively and negatively skewed with excess kurtosis ranging from 4.32 for REGIN to 22.99 for DEUIR. The Jarque-Bera test statistics in Table 1 are all significant at the 1% level, attesting to non-normal distribution of all the variables. Such empirical evidence of non-normality in stock returns and changes in exchange rates provides further justification for estimating parameters by the quasi-maximum likelihood method.

[Please insert Table 1 about here]

As it can be seen in Table 1, the augmented Dicky-Fuller test statistics suggest that the returns of stock indexes, the world market index and exchange rate changes are all stationary at the 5% level. The Ljung-Box statistics for returns with 20 lags (Q(20)) are statistically significant for all countries and the world market except Australia, indicating that stock returns are not free from linear dependencies. The similar results can be observed for exchange rate changes with the exception of the US and for the instrumental variables except *REGIN*. Moreover, the Ljung-Box test for squared returns at 20 lags ($Q^2(20)$) are significant at the 5% level for all the series, thereby indicating some degree of non-linear dependency. Our findings provide some empirical support for employing GARCH-type models to capture the time-varying conditional variance and covariance.

[Please insert Figure 1 about here]

[Please insert Table 2 about here]

We have also conducted a battery of tests for constancy in exchange rate exposure based on the OLS estimates of the conventional augmented market model.[11] These tests include the cumulative sum of squared recursive residuals (CSSRR) as suggested by Brown et al. (1975), the White's (1980) and ARCH-LM tests for heteroskedasticity. Figure 1 presents the results of the cumulative sum of CSSRR test. It is noted from Figure 1 that the CSSRR crosses the critical value boundaries in most

[11] This refers to the constant parameter version of the regression equation in (2)

of the cases at the 5% level of significance, suggesting parameter instabilities.[12] As it can be seen in Table 2, the White's and the ARCH LM test results are all significant at the 1% level, which provides further evidence that the parameters specified in equation (2) are likely to be unstable.

5. Empirical Findings

We now turn to the estimations of the time-varying parameters specified in the trivariate BEKK-GARCH-M specification with time-varying prices of risk and the time-varying currency betas and market betas, followed by an assessment of the stochastic structure of time-varying currency betas and its applications.

5.1 Conditional volatility, time-varying currency betas and market betas

We report in Table 3 the estimation results of the trivariate BEKK-GARCH model of Engle and Kroner (1995) as specified in equations (6)-(9) for the nine financial markets using the quasi-maximum likelihood method of estimation. The parameter estimates of the time-varying prices of risk are reported in Panel A, the parameter estimates for the conditional variance process are shown in Panel B, and Panel C reports the results of the hypothesis tests concerning the time-varying prices of risk. As it can be seen from Panel A of Table 3, the constant term associated with world market index (μ_m) is positive and statistically significant at the 5% level or better for all countries except Singapore. For the constant associated with country stock index (μ_i), it is positive and significant in six countries, and for the exchange rate associated constant (μ_x), only significant in three countries including Singapore, Taiwan and the US. It is found that most of the selected instrumental variables are statistically significant explaining the dynamics of the prices of risk, $\lambda_{m,t-1}$ and $\lambda_{x,t-1}$ for most countries. This is further supported by the joint hypothesis test results for the existence of time-varying risk premium reported in Panel C. We first conduct the

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[12] As two slope coefficients are involved in the regression, one may argue that this instability may stem from the market beta, but not from the exchange rate exposure beta. To address this issue, we have regressed country returns on exchange rate changes only and obtained the cumulative sum of squares of recursive residuals. The diagrams are very similar to those displayed in Figure 1. As such, it is more likely that the CSSRR crosses the critical value boundaries in all cases.

likelihood ratio test on the joint null hypothesis of zero prices on currency risk, and then on the hypothesis that the prices of currency risk are constant. As can be seen in Panel C, the *p*-value for the test statistics is equal to zero for all the sample countries. These test results imply that the currency risk is not only priced in these countries, but also time-varying. We conduct the same tests on market risk, and the results show that, with the exception of Korea, the market risk is both priced and time-varying in these countries. The results are consistent with De Santis and Gerard (1998) and Tai (2007) who find both currency and market risks are priced factors.[13] Furthermore, it is interesting to note from Panel A that the instrumental variables *DUSTP*, *SPX* and *MHDY* have significant predicting power in the time variation of prices on the currency risk in most of the countries, while *DUSTP*, *USDP*, *SPX* and *MHDY* are significant in most cases in predicting the time variation of prices on market risk. The regional index variable is only significant in explaining the time variation of currency risk prices in Canada, and for market risk prices in Australia, Canada and Taiwan.

[Please insert Table 3 about here]

We now turn to the volatility clustering and persistence. As it can be seen in Panel B of Table 3, most of the intercept terms associated with simple market and pair-market are significant in most countries, except c_m. All the estimates of GARCH parameters a_i, a_x, a_m, b_i, b_x and b_m are each statistically significant at the 1% level in all countries, thereby suggesting that the conditional variances are highly correlated with the previous ones and past shocks. The results imply the presence of strong persistence and volatility clustering in each stock market, the world market and the exchange rate markets. Furthermore, it is also interesting to note that there exist strong volatility spillover effects in these three markets. The significant coefficients of a_{ix}, a_{xm} and a_{im} indicate that the unexpected shocks originating in the stock market and exchange rate market spillover to other markets in most of the countries. Similarly,

[13] We also employed the trivariate BEKK-GARCH model to estimate the currency betas and market betas from the conditional second moments of various returns model by constraining the prices of risk to be time-invariant. In a sharp contrast to the results reported in Panel A of Table 3, the prices of both currency and market risk were found statistically significant only in Korea and the US (the results are available upon request). The poor performance of time-invariant prices of risk model in identifying the statistically significant relationship between excess return and risk is largely due to the assumption that the prices of currency and market risks are constant. We are grateful to the associate editor of this Journal for pointing out this.

stock and exchange rate volatility changes are found to spillover to the rest of the markets where the coefficients of b_{ix}, b_{xm} and b_{im} are statistically significant at the 5% level or better in most countries.

[Please insert Table 4 about here]

[Please insert Table 5 about here]

To further evaluate the relative performance of the model, we conduct the diagnostic tests of the residuals. Table 4 reports the summary statistics of the standardized residuals for stock returns and exchange rate changes. It can be seen that the Ljung-Box statistics for the standardized and squared standardized residuals at 20 lags ($Q(20)$ and $Q^2(20)$) have dropped significantly compared with the statistics reported in Table 1. In most cases the Ljung-Box $Q(20)$ and $Q^2(20)$ statistics are smaller than the critical value at the 5 % significant level. As such, the diagnostics suggest the absence of serial correlation, and that the proposed trivariate BEKK(1)-GARCH (1,1)-in-mean model is reasonably adequate to capture the conditional volatility of stock returns and changes in exchange rates. We then calculate the time-varying market betas and currency betas from the estimates of conditional variance and covariance matrix H_t using equations (11) and (12), and report the results in Table 5. As shown in Table 5, the average value of each market and currency beta is quite close to their corresponding OLS point estimate across countries except the currency beta in Australia, Korea and Thailand. All the market betas and their OLS estimates are positive, and the estimated currency betas associated with the bilateral exchange rate against the US dollar are also positive in most countries. It is also interesting to note that the US dollar exchange rate is found to be highly positively related to the returns on assets in some emerging markets, with a mean value ranging from 1.897 in Taiwan and 1.354 in Thailand to 1.118 in Korea and 0.322 in Singapore, but negatively related to returns on assets in Canada, Japan and UK.[14] These findings have important implication for firms' hedging strategies. Although it might be at a risk of over-simplification, one can interpret the results as follows: an exporter from

[14] We also find that the values of the time-varying market betas and currency betas are all increased in all countries (especially in Korea where the currency beta is almost doubled) when the prices of risk are time-variant, in comparison with the results assuming constant prices of risk (the results are available upon request),

the United States can hedge against his currency risk by investing in the UK assets as the latter's returns are negatively correlated with depreciation of the local currency. Importers or investors whose consumption basket consisting of imported goods from the concerned countries can hedge against their currency risk by investing in assets in any country other than the UK. The empirical results lend further support to the proposition by Campbell et al. (2010) that if stock returns and exchange rates are positively correlated, the investor can reduce portfolio return volatility by over-hedging, and if negatively correlated, the investor can reduce portfolio return volatility by under-hedging, that is, by holding foreign currency.

It is interesting to note that the estimated time-varying market betas and currency betas exhibit a very different pattern in mean value and volatility. As it can be seen in Table 6, the mean values of the currency betas in the developed markets are all negative with the exception of Australia, while the opposite can be observed in the emerging markets where the currency betas are all positive with much larger mean values. On the other hand, all the four emerging markets show a much high volatility in conditional currency betas in comparison with the developed markets. In a contrast, the market beta in most countries tends to be less volatile than the currency betas, especially in the emerging markets. This finding is consistent with our casual observation that the emerging markets are mostly characterized by high volatility largely associated with country-specific and region-specific political, social and economic events. It also lends a support to Lin et al. (2002) that there are different macroeconomic variables which contribute and lead to the fluctuating properties of currency betas in the developed countries and the emerging economies. It is also noted that the sample kurtosis of currency beta is greater than that of the corresponding market beta in six countries. This suggests that the distribution of currency betas tends to have thicker tails than that of the market beta. These features are further demonstrated in Figure 2 where the solid nearly flat line indicates the Hodrick-Prescott filtered trend. As can be seen from Figure 2, the fitted currency betas of Korea, Singapore, Taiwan and Thailand fluctuate within a wider range than those in Canada, Japan, the UK and the US.

[Please insert Table 6 about here]

[Please insert Figure 2 about here]

Next, we examine whether the time-varying currency betas are mean-reverting and stationary. We employ a widely used semi-nonparametric test proposed by Gewek and Porter-Hudak (1983) for such a purpose. We first perform a one-sided test to check the validity of the null hypothesis that the fractional differencing parameter (d) equals to 0 versus the alternative hypothesis that d is greater than 0, and then a second one-sided test under the null hypothesis that d is equal to 0 versus the alternative hypothesis that d is less than 1. The GPH test results are reported in Table 7.

[Please insert Table 7 about here]

As can be seen in Table 7, the null hypothesis is rejected at the 1% level (for Singapore it is rejected at the 5% level for $\alpha = 0.50$) for all cases at different value of α. All the time-varying currency betas series consistently reject both $I(0)$ and $I(1)$ processes. This implies that the betas series may follow a long memory process or an AFIMA process $I(d)$, with $0 < d < 1$. The GPH test results suggest that the currency betas for Taiwan, Thailand and UK are covariance stationary as well as mean-reverting, and the currency betas for Canada, Japan and Singapore are more likely to follow similar patterns, whereas currency betas for Australia, Korea and the US indicate covariance non-stationary, but mean-reverting dynamics. Our findings indicate that investors may exploit the mean-reverting feature of currency betas for forecasting purposes. The basic idea of mean reversion is that high or low currency betas in these markets are only temporary and they will eventually converge to the mean in the long-run. This could be very useful in formulating trading strategies against currency risk in the exchange rate markets.[15]

5.2 Usefulness of time-varying currency betas

We now turn to the discussion about the usefulness of the conditional time-varying betas series as a source of information for decision making. First, we compare currency betas among the concerned countries by using the stochastic dominance

[15] The mean reversion model can be exploited strategically to make extra gains. For instance, Foster and Stine (2003) introduced a test to determine whether a particular investment strategy can yield profits when they studied the incremental added-value of mean-reverting trading strategies, and Chua et al. (2006) developed their mean-reverting yield-curve strategies and tested the profitability of each of the strategies based on that the yield curve mean-reverts to an unconditional yield curve.

criterion. Then, we discuss the usefulness of time-varying currency premiums computed from the currency betas.

5.2.1 Dominance of currency betas among countries

The rules of stochastic dominance have been widely used to compare risk of stock returns.[16] However, in order to have a meaningful comparison of the distribution of currency betas, we have to modify[17] the conventional first order stochastic dominance inequalities. For instance, when an investor wants to identify the exchange rate exposure in the nine countries, he/she needs to consider both negative and positive values of time-varying currency betas for each country. This is because equal magnitudes of currency betas irrespective of their signs indicate similar risks. As such, it is more appropriate to compare distributions of currency betas in absolute values. Figure 3 plots the empirical cumulative distribution (ECD) of currency betas in absolute value. Apparently, the ECDs of currency betas in the emerging markets consistently lie below the right side of those ECDs for the rest of the countries, with Taiwan being the lowest. It is interesting to note that, among the four emerging markets, Singapore has the highest ECD curve, and so does her economic development level. These findings indicate that these emerging markets, especially Taiwan, have the highest currency exposure during the sample period in comparison with the developed economies, while the Singapore market is in between. Among the developed markets, Australia and Japan seem to be less exposed to the currency risk than Canada, UK and the US as their ECDs are located on top of the rest. However, the results based on the CDFs can't be fully reflected in the mean values of the time-varying exposure betas. For instance, Australia seems to be more exposed to exchange rate changes than Japan as the former has a mean value of 0.158 versus -0.19 for Japan in Table 5. But on the other hand, as shown in Figure 3, Japan seems to

[16] For example, Gonzales-Rivera (1996) applies the stochastic dominance criterion to compare risks associated with the time-varying market betas of firms, and Brooks et al. (2000) employ the same approach to analyzing impacts of regulatory changes on the risk and returns of the US banking industry.

[17] Let $F_x(\beta_{x,t})$ and $G_y(\beta_{x,t})$ be the cumulative distribution functions (CDFs) of the time-varying exchange rate exposure (currency betas) of two countries x and y, respectively. Country x's currency beta first order stochastic dominates country y's exposure beta, if two CDFs do not cross and $F_x(\beta_{x,t}) \geq G_y(\beta_{x,t})$ for all $\beta_{x,t}$ with at least one strict inequality, and country x's exposure beta is said to second order stochastic dominate country y's exposure beta, if $\int_{-\infty}^{\beta_{x,t}} (F_x(\beta_{x,t}) - G_y(\beta_{x,t}))d\beta_{x,t} \geq 0$ for all $\beta_{x,t}$ with at least one strict inequality.

have the same order as Australia, suggesting that both countries share the same level of exposure. Therefore, it is recommended to rank the cases by using the second order stochastic dominance as some of the CDFs cross over each other.

[Please insert Figure 3 about here]

[Please insert Figure 4 about here]

For practical consideration, consider an importer from the US looking for means of hedging against the currency risk through investment in foreign assets. It is clear now that the selection rule based on the absolute values of currency betas may not be helpful to choose the proper country for allocating funds. Our results suggest that, in this situation, the empirical distribution of nominal values of currency betas would be more preferred. As depicted in Figure 4, for an importer considering hedging against his currency risk, it would be more appropriate for him to consider investment in the emerging markets, which are highly positively exposed to the depreciation of the US dollar. By the same token, assets in country like UK would be an appropriate choice for exporters seeking means of hedging against currency risk.

5.2.2 Time-varying currency premiums

As discussed in Section 3, the time-varying market and currency betas can be estimated under the broad ICAPM framework using equations (6) to (9). It is natural to explore the relationship among currency, market and total risk premiums by country. For each country, the market premium (*MP*) and currency premium (*CP*) can be expressed as follows:

$$MP = \beta_{m,t-1} E(r_{m,t}) \quad (16)$$

$$CP = \beta_{x,t-1} E(r_{x,t}) \quad (17)$$

Here the market premium is proportional to the expected return of world market portfolio and the market beta, while the currency premium is proportional to the expected return of changes in exchange rates and the currency beta. According to our model, the conditional proportionality factors (market beta and currency beta) vary over time. Hence, the total risk premium can be computed as the sum of conditional market premium and currency premium.

Table 8 presents the computed mean values of conditional market, currency and total risk premiums (TP), and their standard deviations by country for the whole sample period and three sub-periods to assess the dynamics over time, especially the impacts on the risk premium of the recent global financial crisis.[18] We use data covering each of the sub-periods to estimate the parameters of the mean equation (6) and then calculate the corresponding risk premiums. For easy comparison, all risk premiums are expressed in percentage. As it can be seen in Table 8, the mean and standard deviation for the post global financial crisis (GFC) period in most countries are more than doubled that during the pre-GFC periods, and are reasonably similar to those of the entire period. In addition, the average currency premiums of assets during the entire sample period are positive in five cases and negative for Canada, Japan, UK and the US.

[Please insert Table 8 about here]

It is interesting to note from Table 8 that, with the exception of four negative currency premium countries, all the rest have a currency premium accounting for a minimum of about 20% of the total during the whole sample period. For the four emerging markets, the currency premium shows a much larger percentage in the total premium than that in the developed markets except Australia, ranging from the lowest at 16% in Singapore to the highest at 51% in Taiwan. It is also noted that the currency premium is in general more volatile in the emerging markets than in the developed markets, which is consistent with our early findings. The recent GFC is found to have a much profound impact on the currency risk premiums in the emerging markets, especially in Korea and Thailand. This finding is consistent with Lin (2011) who reports that exchange rate exposure became more significant or greater during the 2008 global crisis period. Our findings have important implication for investors' currency hedging strategies as the mean value and volatility of the currency premium

[18] We have also employed different specifications of the mean equation (such as excluding the constant term, adding a VAR(1) term, and so on) to estimate the parameters using data respectively covering the whole sample period and the post-financial crisis period for robustness test. The results (available upon request) show that the calculated means of the risk premiums are quite similar, but the volatility of the premiums varies substantially. This confirms the effect of structural break and the results reported in Table 8 are robust.

differ substantially between the developed and emerging markets. Investors in different markets need to balance the currency risk premium associated with each market and the benefits from choosing an asset as a means of hedging.

6. Concluding Remarks

In this paper we have employed a trivariate BEKK-GARCH-in mean model to examine the time-varying currency betas and market betas for the selected countries from the developed and emerging markets using a set of daily data including the returns of country indexes, the world market index and the exchange rate changes from 5 January 1999 to 25 July 2012. One notable feature of this study is that the time-varying currency betas are computed from the conditional variance and covariance of the return variables, thereby accommodating the conditional correlation between the bilateral exchange rate changes and market returns. As such, the estimated time-varying currency betas are more adequate than those estimates without taking the possible correlations into account. In addition, our model allows the prices of both world market and currency risks to be time-varying subject to a set of instruments.

The results show that most of the selected instrumental variables are statistically significant explaining the dynamics of the prices of risk. The joint hypothesis test results confirm that the currency risk is not only priced in the concerned countries, but also time-varying, and that, with the exception of Korea, the market risk is also both priced and time-varying in these countries. This finding is consistent with some existing studies that both currency and market risks are priced factors. The instrumental variables *DUSTP*, *SPX* and *MHDY* are found to be significant in predicting the time variation of prices on the currency risk, while *DUSTP*, *USDP*, *SPX* and *MHDY* are significant on market risk. We also find evidence that there exist strong volatility spillover effects in these markets.

Moreover, the results reveal that all the four emerging markets show a much high volatility in conditional currency betas in comparison with the developed markets, and the market beta in most countries tends to be less volatile than the currency betas, especially in the emerging markets. The US dollar exchange rate is found to be highly positively related to the returns on assets in some emerging markets, but negatively related to returns on assets in Canada, Japan and UK. These findings have important implication for firms' hedging strategies. The mean and standard deviation during the post-GFC period are found more than doubled that during the pre-GFC periods, and the recent GFC is found to have a much profound impact on the currency risk premiums in the emerging markets, especially in Korea and Thailand. Based on the GPH test we find evidence of long-memory of the estimated currency betas and mean-reverting, which has important implications for trading strategies against currency risk in the exchange rate markets. The two applications of the estimated time-varying currency betas further demonstrate the usefulness of the time-varying exposures in strategic investment.

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Tables:

Table 1Summary Statistics of Stock Returns, Exchange Rate Changes and Information Variables

Panel A: Returns of stock indexes by country

Coefficient	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA	World
Mean	0.011	0.018	-0.013	0.038	0.020	-0.002	0.035	-0.002	0.002	0.001
Maximum	6.101	9.723	13.062	11.722	6.928	9.172	15.860	9.265	11.043	9.097
Minimum	-8.679	-10.433	-10.435	-13.097	-9.833	-10.309	-18.085	-9.158	-9.514	-7.325
S D	1.069	1.282	1.400	1.913	1.340	1.631	1.780	1.267	1.329	1.096
Skewness	-0.379	-0.545	-0.316	-0.243	-0.165	-0.050	-0.012	-0.154	-0.167	-0.301
Kurtosis	8.466	11.107	9.689	6.949	7.217	5.531	12.788	8.731	10.321	9.932
J-B stat	4488.0	9861.7	6652.8	2333.3	2636.7	945.9	14119.6	4855.2	7915.6	7136.0
$Q(20)$	24.198	56.867	32.401	44.132	51.790	52.937	63.778	101.564	75.632	110.911
$Q^2(20)$	3873.7	4204.2	3883.8	1059.5	2621.7	1070.4	554.6	3848.2	4635.9	5237.1
ADF (ret)	-43.687	-45.269	-43.674	-43.328	-41.483	-40.468	-38.914	-45.276	-45.674	-42.068

Panel B: Exchange rate changes by country

Coefficient	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
Mean	0.014	0.011	0.010	0.001	0.008	0.002	0.004	-0.002	0.006
Maximum	6.701	5.046	4.610	13.265	2.290	2.621	6.925	4.474	4.152
Minimum	-8.828	-4.338	-3.077	-10.351	-2.139	-2.057	-9.133	-3.919	-2.277
S D	0.862	0.601	0.659	0.701	0.331	0.258	0.397	0.593	0.447
Skewness	-0.872	0.064	0.331	0.706	-0.055	0.166	-1.945	-0.035	0.310
Kurtosis	15.228	8.541	6.386	60.404	7.907	12.539	112.221	7.228	6.610
J-B stat	22483.2	4526.5	1754.4	485932.0	3549.8	13426.0	1760301.0	2635.5	1976.7
$Q(20)$	51.943	47.016	33.539	127.617	49.939	43.285	84.569	53.777	25.204
$Q^2(20)$	3576.1	2356.7	345.5	1764.0	1008.8	146.2	43.8	1707.6	211.1
ADF(rate) [a]	-42.675	-43.317	-43.289	-40.862	-43.454	-39.961	-45.900	-41.989	-43.491
ADF(chan)[b]	-70.758	-74.399	-72.642	-67.862	-48.065	-45.574	-76.690	-70.618	-74.344

Panel C: Preliminary statistics of information variables

Coefficient	DUSTP	USDP	SPX	MHDY	DEUIR	PACIN	EURIN	NAMRIN
Mean	0.0003	1.1004	0.0024	0.0015	-0.0009	0.0051	-0.0036	0.0031
Maximum	0.740	3.500	10.957	7.787	0.630	9.831	10.778	10.428
Minimum	-0.560	0.510	-9.470	-7.112	-0.430	-9.182	-10.584	-9.505
S D	0.075	0.487	1.327	1.011	0.046	1.319	1.455	1.316
Skewness	0.277	2.795	-0.152	-0.134	0.335	-0.325	-0.129	-0.230
Kurtosis	13.236	11.780	10.343	11.282	25.988	7.318	9.431	10.234
J-B stat	15486.07	15965.51	7959.65	10120.16	77944.31	2810.10	6104.59	7742.27
$Q(20)$	153.811	67888.101	79.020	104.452	219.521	24.527	83.486	67.303
$Q^2(20)$	2064.69	67172.18	4649.71	5198.01	317.32	3664.24	3781.44	4847.93
ADF(rate) [a]	-42.890	-1.553	-45.822	-43.013	-49.506	-43.821	-43.543	-45.258
ADF(cha)[b]	-67.495	-36.359	-76.317	-70.591	-43.196	-48.747	-70.488	-75.782

Notes: Q (20) and Q^2 (20) are Ljung-Box statistics of returns and squared returns for 20 lags. They follow a χ^2 distribution and the critical value at the 5% level of significance with 20 degrees of freedom is 31.41. [a] and [b] - Augmented Dikey-Fuller statistics for variable in level and changes, respectively.

Table 2: Results of Heteroskedasticity test using OLS estimates by country

Test statistic	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
White's test[a]	124.1***	363.4***	134.4***	46.4***	149.7***	202.9***	53.73***	264.2***	202.3***
ARCH- LM (5) [a]	141.0***	87.41***	99.69***	30.63***	37.81***	28.02***	15.41***	419.6***	385.7***

Notes: Regression equation used: $r_{i,t} = \beta_0 + \beta_m r_{m,t} + \beta_x r_{x,t} + \xi_i$; Both White's Heteroskedasticity (with cross terms) and ARCH LM test statistics are assumed to follow χ^2 distribution; [a] Critical valueat the 1% level with 5 degrees of freedom is 15.09; *** indicates significance at the 1% level.

Table 3: Estimation results for the trivariateMGARCH(1,1)-M model

	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
Panel A: Conditional mean process									
$C_{0,i}$	0.041*** (2.97)	0.048*** (3.17)	0.024 (1.23)	0.068*** (2.98)	0.028 (1.53)	0.039 (1.62)	0.086*** (3.05)	0.033** (2.26)	0.039** (2.38)
$C_{0,x}$	0.008 (0.35)	0.007 (0.51)	0.01 (0.32)	0.006 (0.55)	0.018* (1.81)	0.012* (1.93)	0.010 (1.50)	0.009 (0.46)	0.045** (2.27)
$C_{0,m}$	0.032** (1.99)	0.031** (2.26)	0.038*** (2.97)	0.035*** (2.64)	0.012 (0.60)	0.038*** (2.84)	0.032** (2.34)	0.042*** (2.94)	0.063*** (3.90)
$\delta_{x,0}$	0.014 (0.18)	0.018 (0.19)	−0.041 (0.36)	0.068 (0.80)	−0.245 (−1.38)	0.036 (0.21)	−0.039 (0.33)	−0.035 (0.31)	−0.337** (2.07)
$\delta_{x,1}$	−0.191 (−1.11)	0.763*** (2.76)	−1.163** (5.68)	−0.013 (−0.07)	−2.330** (−4.22)	−0.906 (−1.27)	−1.259** (−2.46)	−1.511*** (−5.71)	−1.683*** (−4.07)
$\delta_{x,2}$	0.013 (0.38)	0.005 (0.13)	0.016 (0.34)	−0.028 (−0.84)	0.087 (1.12)	−0.116 (−1.32)	0.028 (0.26)	0.014 (0.32)	0.107* (1.69)
$\delta_{x,3}$	0.168*** (10.45)	0.870*** (4.07	−0.137** (−4.77)	0.016 (1.23)	0.328*** (6.22)	0.265*** (4.42)	0.188*** (3.75)	0.174*** (5.06)	−0.101 (−0.28)
$\delta_{x,4}$	−0.096*** (−4.48)	−0.17*** (−4.68)	0.170*** (4.44)	0.063*** (3.09)	−0.215** (−3.35)	0.06 (0.72)	−0.074 (−1.26)	−0.156** (−2.43)	−0.066 (−1.17)
$\delta_{x,5}$	0.684 (1.55)	0.236 (0.40)	−0.665** (−1.17)	−0.677 (1.50)	0.021 (0.02)	0.876 (0.72)	−0.167 (−0.17)	−0.427 (−0.67)	−0.293 (−0.37)
$\delta_{x,6}$	−0.01 (−0.79)	−0.611** (−2.75)	0.006 (0.32)	−0.017 (−1.44)	0.020 (0.53)	0.066 (1.54)	0.023 (0.83)	0.043 (1.37)	0.302 (0.80)
$\delta_{m,0}$	−11.018 (−0.44)	−30.33** (−2.38)	−0.615 (−0.06)	−0.230 (−0.03)	−0.853* (−1.80)	−118.6 (−1.57)	−68.5*** (−48.55	−12.77*** (−6.39)	−52.52*** (−11.23)
$\delta_{m,1}$	−40.724 (−0.50)	−37.428 (−0.45)	−60.87** (−3.41)	−63.71** (−3.41)	0.635 (0.42)	−1267*** (−30.74)	83.26*** (49.87)	−68.13*** (−13.06)	−71.18 (−0.39)
$\delta_{m,2}$	−26.221* (−1.65)	−23.106 (−0.28)	−41.459* (−13.68	−41.99** (−17.81	−1.81*** (−3.11)	−776.5*** (−12.02)	8.72*** (3.72)	−26.06*** (−14.55)	−39.8*** (−26.68)
$\delta_{m,3}$	1.752 (0.07)	0.668 (0.00	6.673*** (5.34)	6.682*** (8.06)	0.351** (2.25)	−53.6*** (−6.88)	4.74*** (5.80)	0.331 (0.11)	−33.53 (−0.46)
$\delta_{m,4}$	−1.908*** (−0.05)	−11.091 (−0.04)	−11.14** (−5.37)	−11.09** (−7.37)	−0.019 (−0.08)	−3.468 (−0.21)	−4.601** (−1.98)	−5.915* (−1.91)	−2.56 (−0.11)
$\delta_{m,5}$	10.373 (0.01)	20.839 (0.00)	−77.146 (−1.44)	−76.89** (−3.04)	4.188 (1.58)	845.9*** (22.27)	49.278 (0.64)	60.13*** (11.55)	10.926 (0.10)
$\delta_{m,6}$	7.303*** (8.43)	11.127*** (11.58)	−1.364 (−0.81)	−1.378 (−1.09)	−0.198 (−1.57)	−101.8*** (−10.74)	0.536 (0.63)	−0.982 (−0.14)	24.50 (0.40)
Panel B: Conditional variance process									
c_i	0.074*** (8.17)	−0.091** (−9.89)	0.228*** (13.90)	0.061*** (4.20)	0.119*** (11.97)	0.124*** (10.36)	0.332*** (28.25)	0.113*** (11.97)	0.113*** (14.90)
c_x	0.064*** (8.29)	0.001 (0.01)	0.044*** (7.02)	0.048*** (9.31)	−0.033** (−11.26	−0.048*** (−13.23)	0.062*** (19.18)	−0.036*** (−6.32)	−0.035 (−0.63)
c_m	0.000 (0.00)	0.0001 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.0001 (0.00)	0.0002 (0.00)
c_{ix}	0.015** (1.69)	−0.015** (−3.45)	0.001 (0.12)	0.030*** (3.34)	0.008*** (2.66)	0.034*** (6.93)	0.033*** (4.57)	−0.011** (−2.36)	−0.012 (−0.08)
c_{xm}	0.079*** (5.99)	−0.062 (−0.01)	0.081*** (3.55)	−0.022** (−1.03)	−0.066** (−6.53)	0.036*** (2.85)	0.109 (0.80)	−0.077*** (−4.36)	−0.024 (−0.11)
c_{im}	0.032** (2.42)	−0.055** (−6.33)	0.032** (2.51)	0.085*** (3.80)	−0.001 (−0.07)	0.062*** (5.24)	0.055 (0.24)	0.045*** (4.63)	0.126 (0.81)
b_i	0.974*** (462.9)	0.971*** (506.9)	0.945*** (221.7)	0.977*** (668.8)	0.963*** (372.2)	0.975*** (511.7)	−0.955** (−343.3	0.957*** (3332.4)	0.967*** (422.1)
b_x	0.981*** (521.9)	0.987*** (753.2)	0.990*** (757.1)	0.959*** (513.8)	0.978*** (474.1)	0.905*** (261.6)	−0.899** (−216.1	0.985*** (605.9)	−0.986*** (−603.6)
b_m	0.971*** (462.3)	0.972*** (447.6)	0.967*** (364.0)	0.970*** (435.1)	0.975*** (520.3)	0.976*** (568.7)	0.971*** (388.52)	0.959*** (352.6)	−0.951*** (−266.0)
b_{ix}	−0.012*** (−7.05)	−0.003** (−3.69)	−0.000 (−0.27)	−0.000 (−0.21)	−0.001** (−2.06)	0.001 (1.38)	0.002 (1.46)	−0.002** (−2.18)	0.000 (0.02)
b_{im}	−0.006** (−2.27)	−0.001 (−0.57)	0.003 (0.91)	−0.003** (−3.09)	−0.000 (−0.04)	−0.007*** (−4.83)	−0.179** (−6.29)	0.010*** (3.28)	1.36*** (77.34)

b_{xm}		−0.01*** (−2.74)	0.004 (1.45)	−0.008** (−2.23)	−0.005 (−1.04)	−0.025** (−3.18)	−0.037** (−2.09)	−0.262** (−4.89)	−0.001 (−0.38)	−0.02*** (−4.90)
a_i		0.222*** (26.18)	0.227*** (29.92)	0.281*** (26.71)	0.218*** (30.08)	0.260*** (27.21)	0.214*** (26.37)	0.229*** (24.67)	0.280*** (28.90)	0.241*** (28.13)
a_x		0.162*** (21.84)	0.160*** (21.08)	0.116*** (16.13)	0.267*** (38.41)	0.181*** (23.54)	0.385*** (43.26)	0.418*** (44.75)	0.158*** (18.83)	−0.137*** (−15.60)
a_m		0.232*** (27.17)	0.217*** (26.44)	0.238*** (25.71)	0.230*** (26.44)	0.216*** (28.09)	0.204*** (29.14)	0.211*** (23.92)	0.256*** (29.09)	−0.281*** (−28.06)
a_{ix}		0.065*** (10.73)	0.009*** (2.74)	−0.005 (−1.24)	0.002 (0.86)	0.006*** (2.77)	−0.002 (−1.44)	0.003 (1.26)	0.013*** (3.36)	−0.009*** (−3.37)
a_{im}		0.034** (3.21)	0.006 (0.77)	−0.012 (−1.56)	0.012** (2.16)	0.017** (1.99)	0.027*** (4.29)	0.019*** (3.39)	−0.019** (−2.08)	0.351*** (35.27)
a_{xm}		−0.001 (−0.05)	−0.003 (−0.23)	−0.004 (−0.31)	0.003 (0.19)	0.028 (0.93)	0.143** (3.22)	0.047*** (2.83)	−0.009 (−0.66)	0.071*** (5.81)
Panel C: Hypothesis tests										
Test1	χ^2 p-value df=7	319.0*** 0.000	301.5*** 0.000	40.9*** 0.000	161.6*** 0.000	214.6*** 0.000	54.4*** 0.000	82.0*** 0.000	238.6*** 0.000	43.7*** 0.000
Test 2	χ^2 p-value df=6	298.2*** 0.000	299.0*** 0.000	36.2*** 0.000	157.2*** 0.000	214.0*** 0.000	48.8*** 0.000	20.2*** 0.001	237.8*** 0.000	38.0*** 0.000
Test 3	χ^2 p-value df=7	294.1*** 0.000	29.9*** 0.000	235.1*** 0.000	7.6 0.379	180.1*** 0.000)	393.9*** 0.000	87.6*** 0.000	41.4*** 0.000	31.2*** 0.000
Test 4	χ^2 p-value df=6	294.1*** 0.000	30.0*** 0.000	232.8*** 0.000	7.5 0.277	179.6*** 0.000	392.3*** 0.000	86.6*** 0.000	40.8*** 0.000	30.0*** 0.000

Test1: Is the price of exchange rate risk equal to zero?
H_0: $\delta_{x,j}$ =0, for j=0,1,…,6.
Test2: Is the price of exchange rate risk constant?
H_0: $\delta_{x,j}$ =0, for j=1,…,6.
Test3: Is the price of world market risk equal to zero?
H_0: $\delta_{m,j}$ =0, for j=0,1,…,6.
Test4: Is the price of world market risk constant?
H_0: $\delta_{m,j}$ =0, for j=1,…,6.

Notes: Notes: The subscript *j* of $\delta_{x,j}$ and $\delta_{m,j}$ (j=0,1,…6) denotes respectively the instrumental variable CONST, DUSTP, USDP, SPX, MHDY, DEUIR, and REGIN. The t-statistics are in parentheses. The Wald test follows a χ^2 distribution. ***,** and * denote respectively significance at the 1% level, the 5% level and the 10% level.

Table 4: Diagnostics for return on stock indexes and bilateral exchange rate changes

Panel A: Stock returns by country

Coefficient	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
Mean	-0.038	-0.029	-0.033	-0.027	-0.026	-0.019	-0.031	-0.040	-0.039
Maximum	3.601	4.231	4.606	4.030	4.188	5.129	8.762	4.180	3.452
Minimum	-5.805	-5.850	-6.223	-7.556	-5.576	-5.058	-14.462	-5.045	-6.089
S D	0.971	0.992	0.985	0.982	0.979	0.978	0.981	0.984	0.977
Skewness	-0.359	-0.361	-0.307	-0.344	-0.230	-0.213	-0.658	-0.315	-0.358
Kurtosis	4.311	4.179	4.363	4.835	4.348	4.382	19.081	3.758	4.411
J-B Stat	329.2	281.9	329.4	565.9	299.0	308.0	38355.4	143.0	368.7
$Q(20)$	15.3	18.7	17.7	25.4	36.2	33.7	59.1	25.0	27.7
$Q^2(20)$	49.2	28.6	21.4	16.1	43.5	42.8	7.6	40.3	59.4

Panel B: Bilateral exchange rate changes by country

Coefficient	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
Mean	-0.013	-0.003	0.015	-0.019	-0.005	-0.010	-0.011	-0.005	0.004
Maximum	3.835	4.080	5.728	5.293	7.562	12.486	7.251	5.224	5.634
Minimum	-5.962	-5.110	-5.263	-5.990	-4.757	-9.499	-8.405	-3.878	-4.539
S D	0.987	0.985	0.999	0.981	0.987	0.986	0.982	0.989	0.994
Skewness	-0.407	-0.023	0.234	-0.382	0.163	0.235	-0.079	0.021	0.139
Kurtosis	4.454	3.506	5.305	5.637	5.780	19.282	8.079	3.684	3.989
J-B Stat	409.0	38.1	815.2	1110.2	1154.4	39091.6	3804.9	69.2	155.6
$Q(20)$	15.1	13.6	15.9	27.4	39.5	59.0	68.2	15.6	14.8
$Q^2(20)$	58.5	37.2	23.8	36.6	13.5	6.6	14.4	19.3	16.1

Notes: $Q(20)$ and $Q^2(20)$ are Ljung-Box statistics of residuals and squared residuals for 20 lags. They follow a χ^2 distribution and the critical value at the 5% level of significance with 20 degrees of freedom is 31.41.

Table 5: Comparison between OLS point estimates of betas and mean time-varying currency betas by country

Country	Currency beta		Market beta	
	OLS β_x	Mean of $\beta_{x,t}$	OLS β_m	Mean of $\beta_{m,t}$
Australia	0.2714	0.1579	0.2480	0.2663
Canada	-0.2388	-0.2200	0.9141	0.8799
Japan	-0.2006	-0.1902	0.4553	0.5024
Korea	0.8210	1.1176	0.3974	0.4162
Singapore	0.3378	0.3222	0.4780	0.4472
Taiwan	1.6308	1.8970	0.3046	0.3252
Thailand	0.6795	1.3538	0.4376	0.3493
UK	-0.2942	-0.3759	0.9249	0.8857
US	-0.5995	-0.5569	1.1434	1.1473

Notes: Time-varying market and exchange rate exposure betas are computed using equations (11) and (12), respectively.

Table 6: Summary statistics of time-varying currency betas and market betas by country

Panel A: Time-varying currency betas by country

Coefficient	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
Mean	0.1579	-0.2200	-0.1902	1.1176	0.3222	1.8970	1.3538	-0.3759	-0.5569
Maximum	1.3977	1.9546	0.4349	5.6998	3.4964	8.0467	6.6096	0.9506	0.4956
Minimum	-0.4168	-1.6193	-2.3597	-4.6416	-1.6875	-2.7328	-2.3926	-1.4541	-1.8660
S D	0.2698	0.2782	0.2724	1.1512	0.6324	1.2833	1.1199	0.2363	0.2699
Skewness	0.8664	0.1944	-2.4120	0.6450	0.7274	0.3251	0.3659	0.5750	-0.4309
Kurtosis	3.7608	13.2835	14.7319	5.7648	5.9401	3.8811	3.6005	6.8205	4.5397
J-B stat	527.7	15602.7	23707.1	1371.4	1585.4	176.7	132.0	2345.3	458.7

Panel B: Time-varying market betas by country

Coefficient	AUS	CAN	JPN	KOR	SGP	TWN	THA	GBR	USA
Mean	0.2663	0.8799	0.5024	0.4162	0.4472	0.3252	0.3493	0.8857	1.1473
Maximum	0.9968	1.8795	2.2728	1.8764	1.4133	1.4231	4.5555	1.5768	1.4965
Minimum	-0.2947	0.4086	-0.3046	-1.1570	-0.1077	-0.5921	-0.4419	0.1814	0.6879
S D	0.1780	0.2106	0.2636	0.3199	0.2497	0.2616	0.3586	0.1757	0.1055
Skewness	0.7294	0.8017	0.4445	0.4937	0.7149	0.2171	3.8442	0.0480	-0.2145
Kurtosis	4.2450	4.1568	3.5019	3.9830	3.6571	4.1412	33.4584	3.5902	3.6665
J-B stat	541.9	575.9	153.5	286.0	364.8	219.7	145392.0	52.7	92.6

Table 7: GPH test results for estimates of time-varying currency betas by country

Country	Value of differencing parameter d		
	$\alpha = 0.50$	$\alpha = 0.55$	$\alpha = 0.60$
Australia	0.5378*** (7.28)	0.5978*** (9.18)	0.6989*** (12.56)
Canada	0.4531*** (4.47)	0.5305*** (6.50)	0.5969*** (9.88)
Japan	0.2328*** (2.94)	0.4086*** (5.70)	0.5385*** (8.62)
Korea	0.6167*** (7.01)	0.6922*** (9.47)	0.7403*** (11.98)
Singapore	0.2629** (2.54)	0.3928*** (5.02)	0.5647*** (8.24)
Taiwan	0.3060*** (3.06)	0.2808*** (6.06)	0.3940*** (7.21)
Thailand	0.3555*** (4.35)	0.3907*** (6.30)	0.4457*** (8.67)
UK	0.3725*** (3.56)	0.4076*** (4.74)	0.4312*** (7.08)
US	0.6211*** (7.68)	0.7298*** (10.12)	0.8244*** (13.62)

Notes: *d* refers to the differencing parameter in the fractional integration process $\Phi(L)(1-L)^d Y_t = c + \Theta(L)\upsilon_t$ and is represented by ϕ in the regression: $\ln I(\omega_j) = c - \phi \ln\left(4\sin^2(\omega_j/2)\right) + \zeta$.

Values of *t*-statistics are in parentheses; *** indicates significance at least at the 1% level.

Table 8
Mean and volatility of risk premiums by country in various sub-sample periods

		1/5/1999 ---- 6/30/2003			7/1/2003 ---- 12/31/2007			1/1/2008 ---- 7/25/2012			1/5/1999 ---- 7/25/2012		
		CP	MP	TP	CP	MP	TP	CP	MP	TP	CP	MP	TP
Australia	mean	0.278	0.694	0.972	0.247	1.310	1.557	1.115	1.319	2.434	0.550	1.109	1.659
	sd	3.698	1.197	4.532	3.210	1.524	4.173	32.099	8.118	38.231	18.840	4.849	22.472
Canada	mean	-0.233	3.318	3.085	-0.240	2.783	2.543	-0.669	4.212	3.543	-0.382	3.441	3.059
	sd	1.812	9.156	8.633	1.464	2.593	1.996	10.856	56.723	49.210	6.443	33.368	29.006
Japan	mean	-0.008	2.118	2.110	-0.056	2.576	2.520	-0.170	1.676	1.506	-0.078	2.121	2.043
	sd	2.337	8.567	8.653	3.490	1.472	3.685	18.671	9.889	27.438	11.100	7.619	16.819
Korea	mean	2.231	1.827	4.058	0.950	2.307	3.258	1.784	1.004	2.788	1.655	1.709	3.364
	sd	5.381	10.973	11.230	1.873	1.113	2.275	28.973	6.795	33.729	17.135	7.487	20.656
Singapore	mean	0.360	4.069	4.429	0.434	1.192	1.626	0.564	1.656	2.220	0.453	2.300	2.754
	sd	2.472	7.683	8.364	2.748	3.076	5.112	14.373	17.256	28.979	8.607	11.157	17.775
Taiwan	mean	1.706	0.897	2.603	1.346	1.774	3.120	0.306	0.545	0.851	1.114	1.070	2.184
	sd	8.943	1.784	9.063	2.733	1.778	3.768	11.246	4.989	14.710	8.477	3.278	10.279
Thailand	mean	0.947	1.171	2.118	1.142	1.511	2.653	1.803	1.437	3.241	1.300	1.373	2.674
	sd	5.006	1.610	5.474	3.181	1.712	3.365	6.393	14.794	16.753	5.054	8.691	10.410
UK	mean	-0.179	3.627	3.448	-0.194	3.483	3.289	-0.171	4.434	4.263	-0.181	3.851	3.670
	sd	2.553	4.040	4.560	1.662	3.310	3.013	7.583	29.340	33.538	4.736	17.292	19.716
US	mean	-0.335	6.127	5.792	-0.072	4.917	4.845	-0.325	5.478	5.153	-0.244	5.506	5.262
	sd	1.737	2.463	2.199	1.582	1.839	1.062	10.556	22.019	22.511	6.273	12.907	13.142

Notes: “sd” is short for standard deviation.

Figures:

Figure 1: Cumulative sum of squared recursive residuals (CSSRR) test results

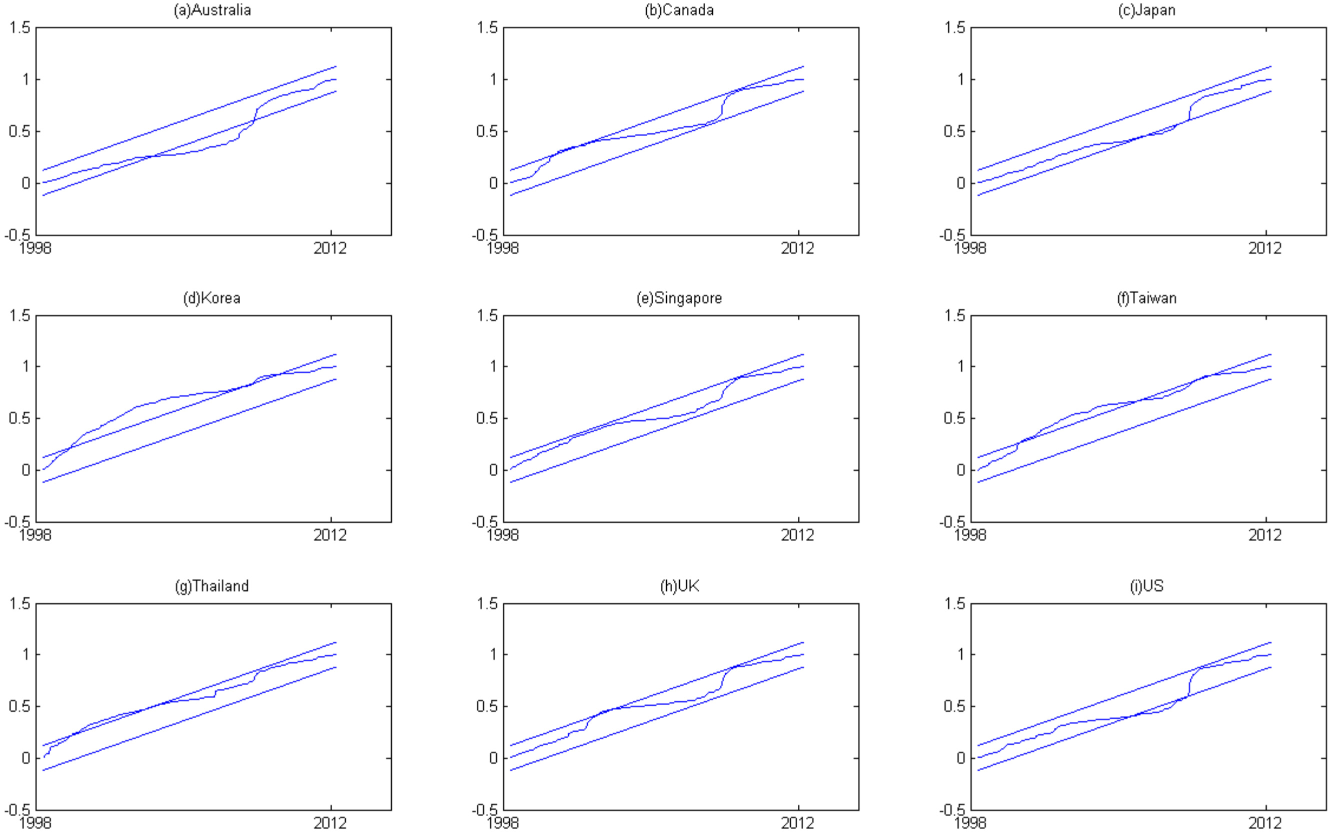
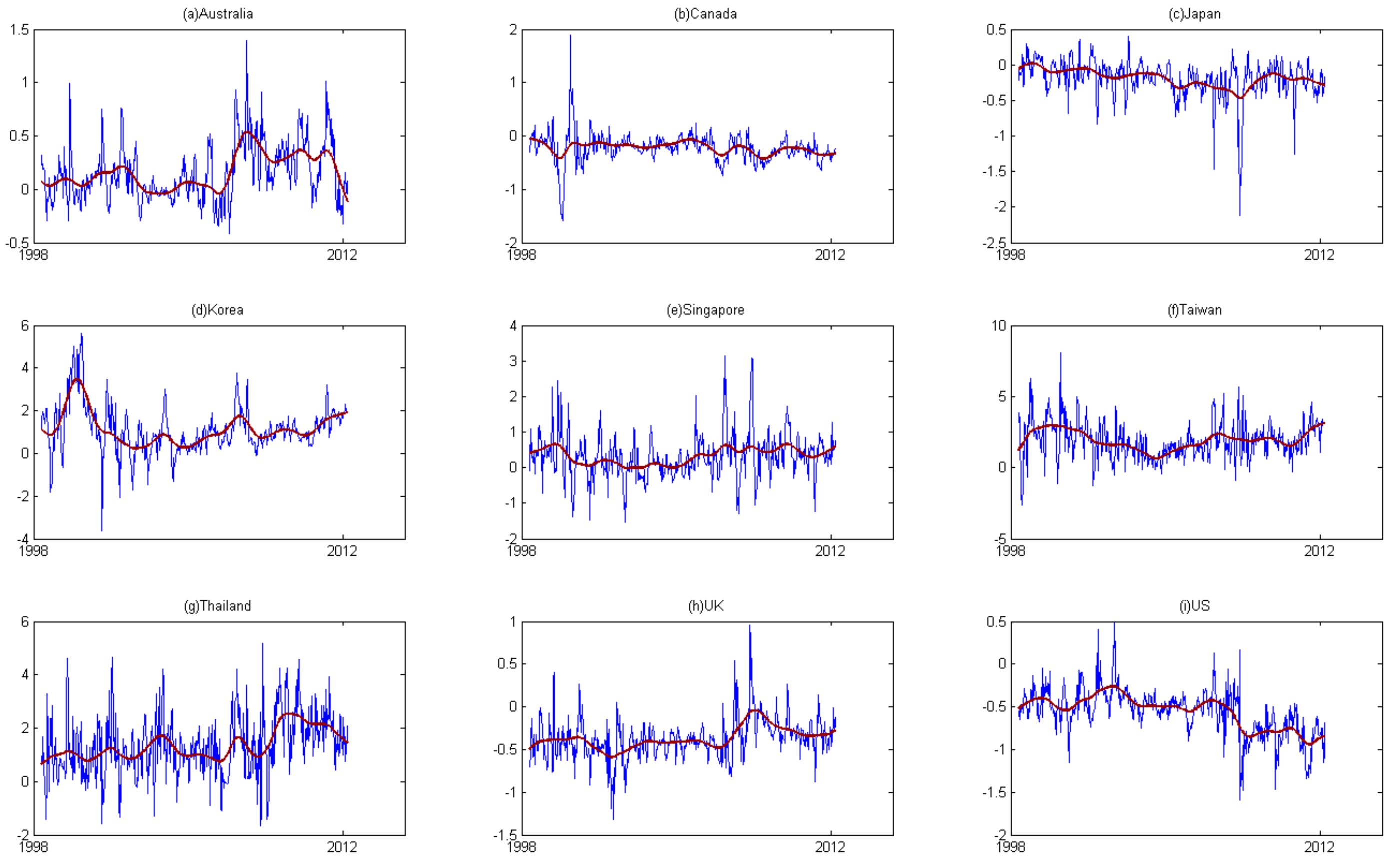


Figure 2: Time-varying currency betas by country



Note: The near flat line across the time-varying currency betas represents the Hodrick-Prescott filtered trend computed for each currency betas series.

Figure 3: Cumulative distribution of absolute time-varying currency betas by country

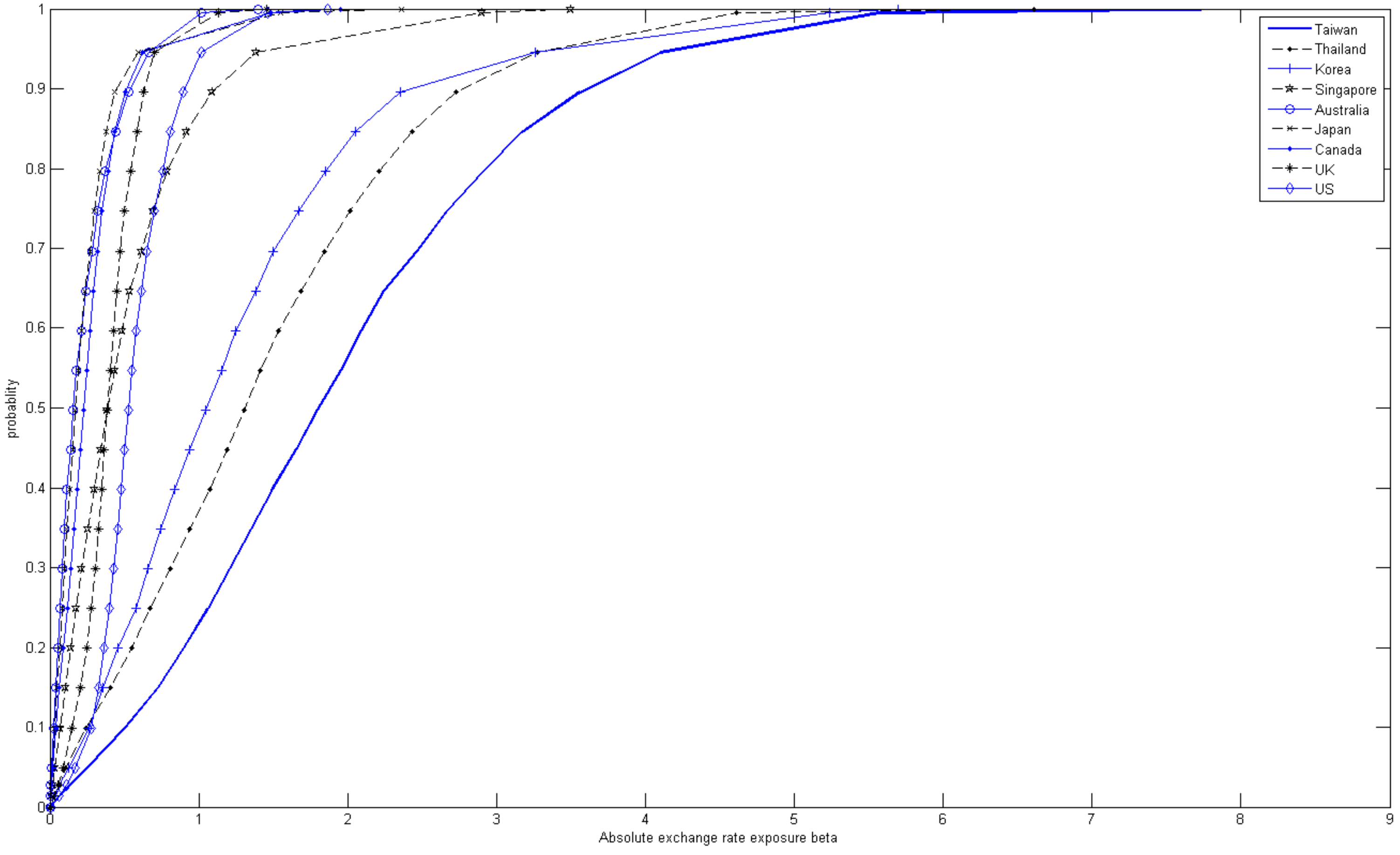


Figure 4: Cumulative distribution of time-varying currency betas by country