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Abstract

The effects of exchange rate risk have interested researchers, since the collapse of fixed exchange rates. Little consensus exists, however, regarding its effect on exports. Previous studies implicitly assume symmetry. This paper tests the hypothesis of asymmetric effects of exchange rate risk with a dynamic conditional correlation bivariate GARCH(1,1)-M model. The asymmetry means that exchange rate risk (volatility) affects exports differently during appreciations and depreciations of the exchange rate. The data include bilateral exports from eight Asian countries to the US. The empirical results show that real exchange rate risk significantly affects exports for all countries, negative or positive, in periods of depreciation or appreciation. For five of the eight countries, the effects of exchange risk are asymmetric. Thus, policy makers can consider the stability of the exchange rate in addition to its depreciation as a method of stimulating export growth.

Journal of Economic Literature Classification: C32, F14, F31, F41

Keywords: depreciation, exchange rate risk, exports, bivariate GARCH-M model

Does Exchange Rate Risk Affect Exports Asymmetrically? Asian Evidence

I. Introduction

The relationship between exchange rate risk and exports has received considerable attention since the collapse of fixed exchange rates in the early 1970s. Ethier (1973) argues that exchange rate risk could lower exports due to profit risk. De Grauwe (1988), however, suggests that exporters might increase exports to offset potential revenue losses. Broll and Eckwert (1999) note that the price of an option to export increases with risk. Pozo (1992) uncovers a negative effect of exchange rate risk on UK exports to the US. Chowdhury (1993) and Arize (1995, 1996, 1997) find negative effects of exchange rate risk on US, European, and G7 exports. Weliwita, Ekanayake, and Tsujii (1999) and Fang and Thompson (2004) provide evidence of negative effects for Sri Lanka and Taiwan. Arize, Osang, and Slottje (2000) and Arize, Malindretos, and Kasibhatla (2003) conclude that exchange rate risk generates a negative effect on LDC exports, using a moving sample standard deviation model. In contrast, Asseery and Peel (1991) find positive effects for multilateral exports except for the UK. Kroner and Lastrapes (1993) discover positive effects for France, Germany, and Japan, but negative effects for the UK and the US. McKenzie and Brooks (1997) report positive effects for Germany and the US. Finally, Klaassen (2004) reports no effect of monthly bilateral US exports on other G7 countries.

While a variety of theoretical and empirical models attempt to isolate quantitatively important effects of exchange rate risk on exports, all work proceeds under the assumption of symmetry, meaning that no difference exists between the risk effects of exchange rate appreciation and depreciation. Tse and Tsui (1997) find that a depreciation shock produces a greater effect on future volatility in exchange rates than an appreciation shock of the same magnitude. Risk-averse exporters behave differently when facing different degrees of foreign exchange market volatility. Thus, different risk effects emerge under conditions of exchange rate depreciation and appreciation. This paper tests the hypothesis of asymmetric effects of exchange rate risk on exports, where the asymmetry measures possible differences in the exchange rate risk (volatility) effect when the exchange rate appreciates and depreciates.

No empirical studies directly test whether exchange rate risk acts symmetrically or asymmetrically. Some inferences emerge from the research on export price adjustments to exchange rate changes (Krugman 1987, Sercu 1992, Knetter 1994, Kanas 1997, and Mahdavi 2000). These papers establish the hypothesis that the risk profile of economic exposure exhibits asymmetry. That is, changes in the export price differ between real depreciations and real appreciations. Our paper considers whether we observe different exchange rate risk effects on exports between depreciations and appreciations.

Whether asymmetric risk effects exist proves important to policy makers. Conventional wisdom argues that depreciation increases exports, but exchange rate risk induced by the depreciation can hurt exports. Thus, market intervention to stimulate exports may fail, if the authorities ignore the effects of exchange rate risk. Fang and Thompson (2004) show that exports respond positively to depreciations and negatively to risk effects, but the net effect only adds noise to export fundamentals. The existence of asymmetric risk effects further complicates and increases the uncertainty of trade policy. Thus, successful trade policy requires a full understanding and control of exchange risk during periods of depreciation and appreciation.

To study the effects of exchange rate risk requires a measure of the unobservable exchange rate risk. Hodrick and Srivastava (1984) identify exchange risk as conditional and time varying. Moving standard deviations of the exchange rate maintain the hypothesis of homoskedascity while serving as a proxy for heteroskedastic risk in Chowdhury (1993), Arize, Osang, and Slottje (2000), and Arize, Malindretos, and Kasibhatla (2003). This approach raises a logical inconsistency and probably proves inadequate to capture fully exchange rate risk dynamics. Generalized autoregressive conditional heteroskedasticity (GARCH) models can successfully model relationships between means and variances as in Bollerslev (1986, 1990), Engle et al. (1987), and Bollerslev et al. (1992). This paper specifies exchange rate risk as time-varying exchange rate volatility constructed with a GARCH (1, 1) process following Bollerslev (1986), such that a larger estimated conditional variance indicates more risk.

This paper contributes to the literature by using the bivariate GARCH-M model with dynamic conditional correlation (DCC) (Engle 2002) in measuring the exchange rate risk effect on exports and testing for asymmetry. Engle's DCC approach allows time-varying correlations between exports and the exchange rate. It differs from previous studies that implicitly assume a constant correlation. This paper uses monthly time-series data on bilateral exports from eight Asian countries -- Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand -- to the US for 1979 to 2003. The majority of existing studies consider developed countries, but the eight Asian countries, except Japan, industrialized during this period. Klaassen (2004) suggests that developing countries provide a better laboratory to study the effect of exchange risk on exports. Table 1 reports that the US accounts for a substantial portion of exports from these Asian countries. The average US share of total exports over the sample ranges from 16 percent for Indonesia to 34 percent for the Philippines. The bilateral approach can avoid asymmetric responses across exchange rates in highly aggregated data, and then focus on the asymmetric effects of the exchange rate risk.

After testing the time-series properties of the variables and identifying the GARCH or ARCH effects of the exchange rates, the empirical results of our bivariate GARCH-M DCC model provides some support for the asymmetry hypothesis. In each country, positive depreciation effects exist along with negative or positive exchange risk effects during depreciations or appreciations. For five of the eight countries, significant asymmetric effects of the exchange risk on exports occur. The evidence supports the uncertainty of exchange rate policies designed to influence exports.

The rest of this paper is organized as follows. Section 2 specifies the analytical framework, which includes the main elements of the time-varying correlation bivariate GARCH-M model designed to test for the asymmetric hypothesis of the exchange risk. Section 3 describes that data, analyzes the time-varying variances of exports and the exchange rates, and presents empirical results. Section 4 investigates the asymmetric effects of exchange rate risk on exports. Section 5 summarizes the empirical findings and provides concluding remarks.

II. The Bivariate GARCH-M Model and Testing for Asymmetric Effects

The nonstructural reduced-form export equation of Rose (1990), Pozo (1992), and Klaassen (2004) provides the building block for our empirical analysis of the asymmetric effects of exchange rate risk on Asian exports to the United States. Real export revenue (x) depends on real foreign income (y), the real exchange rate (q), and real exchange rate risk (h_q). Real export revenue equals nominal export revenue in domestic currency deflated by the consumer price index (CPI). Foreign income, the US industrial production index, should produce a positive effect on exports. The real exchange rate, the domestic currency price of the US dollar times the ratio of US to domestic CPIs, should exhibit a positive effect on exports. The real exchange rate eliminates potential ambiguity from adjusting price levels. The effect of exchange rate risk proves uncertain theoretically and empirically.

To capture dynamic adjustments, the following eclectic bivariate GARCH-M-DCC model provides the framework for investigating and testing the asymmetric hypothesis.

$$\Delta lx_t = a_0 + \sum_{i=1}^{2} a_i \, \Delta lx_{t-i} + \sum_{i=0}^{2} b_i \, \Delta ly_{t-i} + \sum_{i=0}^{2} c_i \, \Delta lq_{t-i} + \sum_{i=0}^{2} d_i \, h_{q,t-i}^{1/2} + \varepsilon_{x,t} \tag{1}$$

$$\Delta lq_t = s_0 + s_1 \, \varepsilon_{t-1} + \sum_{i=1}^{2} \gamma_i \, MD_i + \varepsilon_{q,t} \tag{2}$$

$$\varepsilon_t \mid \Psi_{t-1} \sim Student - t(v) \tag{3}$$

$$h_{x,t} = \alpha_0 + \alpha_1 \varepsilon^2_{x,t-1} + \alpha_2 h_{x,t-1} \tag{4}$$

$$h_{q,t} = \beta_0 + \beta_1 \varepsilon^2_{q,t-1} + \beta_2 h_{q,t-1} + \sum_i^2 \lambda_i VD_i \tag{5}$$

$$D_t^2 = \begin{bmatrix} h_{q,t} & 0 \\ 0 & h_{x,t} \end{bmatrix} \tag{6}$$

$$\eta_t = D_t^{-1} \varepsilon_t \tag{7}$$

$$Q_t = \bar{\rho}_{xq}(1 - \theta_1 - \theta_2) + \theta_1 \eta_{t-1}\eta'_{t-1} + \theta_2 Q_{t-1} \tag{8}$$

$$R_t = diag\{Q_t\}^{-1} Q_t \, diag\{Q_t\}^{-1} \tag{9}$$

where $\Delta lx_t \equiv 100\times(\ln x_t - \ln x_{t-1})$, $\Delta ly_t \equiv 100\times(\ln y_t - \ln y_{t-1})$, and $\Delta lq_t \equiv 100\times(\ln q_t - \ln q_{t-1})$. The lag structure of the mean equation of Δlx_t is selected by the Schwartz Information Criteria (SIC) and $\varepsilon_{x,t}$ is a white noise. $h_{q,t}$ is time varying exchange rate volatility estimated by the GARCH(1,1) process. The presence of the square root of $h_{q,t}$, $h_{q,t}^{1/2}$, in the mean equation of Δlx_t constitutes the bivariate GARCH-M model. The MA component picks up serial dependence of Δlq_t to ensure that $\varepsilon_{q,t}$ is white noise. The residual matrix, ε_t, conditional on the information set Ψ_{t-1} available at time $t-1$ follows a bivariate Student-t distribution with degrees of freedom v. Our sample includes the Asian financial crisis in 1997, which exhibited dramatic movements in exchange rates in most Asian countries. MD_i and VD_i are dummy variables employed to capture extraordinary exchange rate changes in the mean and the variance equations for Δlq_t. $h_{x,t}$ measures the conditional variance of exports. Conditions, α_i >0, β_i >0, λ_i >0, $\alpha_1 + \alpha_2 < 1$ and $\beta_1 + \beta_2 < 1$, imply positive and stable conditional variances of $\varepsilon_{x,t}$ and $\varepsilon_{q,t}$. If α_2 or β_2 equal zero, the process reduces to an ARCH(1). The matrix D_t^2

contains $h_{x,t}$ and $h_{q,t}$ along the principle diagonal and thus, η_t is the standardized residual matrix. Q_t is the covariance matrix of η_t, following a GARCH(1,1) process. $\bar{\rho}_{xq}$ is the unconditional correlation of exports and the exchange rates over the sample period. θ_1 and θ_2 positive and $\theta_1 + \theta_2 < 1$ ensure that Q_t is positively defined and mean-reverting. R_t is the conditional correlation matrix composed of time-varying correlations. Equations (1) to (9) constitute the DCC estimator proposed by Engle (2002). If $\theta_1 = \theta_2 = 0$, then it reduces to the Bollerslev (1990) constant conditional coefficient estimator.

Let Φ denote the parameters in D_t^2 that includes all parameters in equations (1) to (5) and Θ denote the parameters in R_t that includes θ_1 and θ_2. Then, the log likelihood function of bivariate t-distribution in the maximization procedure is

$$L(\Phi,\Theta) = \sum_{t=1}^{T} L_t(\Phi,\Theta)$$

where $L_t(\Phi,\Theta) = \ln\Gamma(\frac{v+2}{2}) - \ln\Gamma(\frac{v}{2}) - \ln\left[\pi(v-2)\right] - \frac{1}{2}\ln\left|D_t R_t D_t\right| - \frac{v+2}{2}\ln(1+\frac{\eta_t' D_t^{-1} R_t^{-1} D_t^{-1}\eta_t}{v-2})$ and $\Gamma(\bullet)$ represents the Gamma function.

The model focuses on the effects of exchange rate movements on exports and the reduced-form export equation includes depreciation and exchange rate risk as well as the rate of change of foreign income as explanatory variables. The signs, magnitudes, and significance of the estimated coefficients (c_i) in equation (1) provide a straightforward test of the relationship between exports and depreciation, where $\sum c_i > 0$ implies that depreciation improves exports. Also of interest are the signs, magnitudes, and significance of the estimated coefficients of exchange rate risk ($h_{q,t}^{1/2}$) in equation (1). If exporters reduce their exports to minimize profit uncertainty during periods of exchange rate fluctuations, then $\sum d_i < 0$. If, however, exporters intend to offset potential losses or use options markets as a hedge, then $\sum d_i > 0$. As the equation constrains the d_i s to remain constant for the exchange risk variable during both appreciations and depreciations, equation (1) implicitly assumes a symmetric response of the export revenue to the exchange rate risk.

To test for asymmetric effects, we test the hypothesis that d_i differs between appreciations and depreciations. Let $d_i = d_{1i} + d_{2i}D$, where the dummy $D = 1$ for $\Delta lq_t < 0$ (i.e. an appreciation) and 0 for $\Delta lq_t \geq 0$ (i.e. a depreciation). Equation (1) becomes

$$\Delta lx_t = a_0 + \sum_{i=1}^{2} a_i \Delta lx_{t-i} + \sum_{i=0}^{2} b_i \Delta ly_{t-i} + \sum_{i=0}^{2} c_i \Delta lq_{t-i} + \sum_{i=0}^{2} d_{1i} h_{q,t-i}^{1/2} + \sum_{i=0}^{2} d_{2i} (D h_{q,t-i}^{1/2}) + \varepsilon_{x,t} \quad \text{(1a)}$$

The estimated relations are as follows:

$$\text{Depreciation: } \Delta lx_t = \hat{a}_0 + \sum_{i=1}^{2} \hat{a}_i \Delta lx_{t-i} + \sum_{i=0}^{2} \hat{b}_i \Delta ly_{t-i} + \sum_{i=0}^{2} \hat{c}_i \Delta lq_{t-i} + \sum_{i=0}^{2} \hat{d}_{1i} h_{q,t-i}^{1/2} + \varepsilon_{x,t} \quad \text{and}$$

$$\text{Appreciation: } \Delta lx_t = \hat{a}_0 + \sum_{i=1}^{2} \hat{a}_i \Delta lx_{t-i} + \sum_{i=0}^{2} \hat{b}_i \Delta ly_{t-i} + \sum_{i=0}^{2} \hat{c}_i \Delta lq_{t-i} + \sum_{i=0}^{2} (\hat{d}_{1i} + \hat{d}_{2i}) h_{q,t-i}^{1/2} + \varepsilon_{x,t} ,$$

where $\sum \hat{d}_{2i}$ measures the difference in the effects of the exchange rate risk between appreciations and depreciations. Equation (1a) replaces equation (1) in estimating our bivariate GARCH-M model. Statistical evidence consistent with an asymmetric effect exists, if either $\sum \hat{d}_{1i}$, or $\sum (\hat{d}_{1i} + \hat{d}_{2i})$, (or both) significantly differs from zero and the two sums differ significantly from each other (or $\sum \hat{d}_{2i}$ differs significantly from zero). If both sums prove statistically insignificant, then the exchange rate risk causes no effect on exports.

III. Data and Empirical Results

For each of the eight countries, the bilateral export variable equals monthly seasonally adjusted real export revenue for the US from January 1979 to April 2003 with a base year of 1995. All data come from the *International Financial Statistics and Direction of Trade* of the IMF, except for Taiwan, where the data come from *AREMOS*. Table 2 reports preliminary statistics for the natural logarithmic differences of exports and the real exchange rate. Every country experienced depreciation and export growth over the sample, on average. Thailand exhibits the highest average export growth at 1.031 percent with a depreciation of 0.196 percent. Indonesia exhibits the highest monthly depreciation at 0.336 percent and an export growth of 0.486 percent. Thus, depreciation positively associates with exports, on average.

The unconditional risk measured by standard deviations shows that Indonesia exhibits the most volatile exchange rate and exports while Japan and Singapore exhibit the least volatile exports and exchange rates, respectively. Export volatility exceeds exchange rate volatility in every country. A general pattern of volatility's effect on exports does not emerge from standard deviations and the extreme values.

Skewness statistics reject Δlx_t symmetry at the 5-percent level for Taiwan and Δlq_t symmetry for every country, except Singapore and Taiwan. Kurtosis statistics for Δlx_t and Δlq_t imply that all series are leptokurtic with fat tails. Jarque-Bera tests reject normality for all variables and countries, suggesting the use of the Student-t distribution in model estimation. The Ljung-Box Q-statistic tests for autocorrelation, where the number of lags (k) affects its power. Tsay (2002) suggests choosing $k = \ln(T)$ where T equals the number of observations (291), implying k=5.67. Thus, the autocorrelations tests run up to 6 lags. Ljung-Box Q-statistics indicate autocorrelation in Δlx_t and Δlq_t for all countries. Ljung-Box Q-statistics for squared Δlx_t and Δlq_t suggest time-varying variances for both series in all countries, except for Δlq_t in the Philippines and Taiwan. An ARMA process for mean and variance equations captures the dynamic structure to generate white-noise residuals. In the model, we employ an AR(2) process for the mean equation of Δlx_t; an MA(1) process for the mean equation of Δlq_t; and GARCH(1,1) processes for equations (4) and (5), the two variance equations.

Valid inference in GARCH models requires stationary variables. After selecting lag lengths by the Schwartz Information Criterion (SIC), the augmented Dickey-Fuller (ADF) test shows that Δlx_t and Δlq_t are individually stationary [I(0)] series at the 5-percent level.

The correlation coefficient between the two monthly log differenced series ranges from 0.018 in Taiwan to 0.259 in the Philippines. Figure 1 shows the sample correlation coefficient using a moving window of 12 observations (i.e., 1 year). The horizontal line denotes the correlation coefficient. The correlations change over time and, except for Japan, appear to increase in recent years for most countries, especially Indonesia and Korea. Engle (2002), Tsay (2002), and Tse and Tsui (2002) provide evidence that the estimation of a time-varying correlation GARCH model improves over that of a constant correlation model. This paper applies Engle's (2002) dynamic conditional correlation bivariate GARCH modeling approach. The bivariate GARCH model consists of two sets of equations. The first set of equations consists of a bivariate GARCH (1,1) model for the conditional variances in equations (1a) to (5) and the second set, a GARCH (1,1) model for the correlation coefficient in equations (6) to (9).

Preliminary examination shows that the standard univariate GARCH(1,1) model for Δlq_t performs adequately for Japan, Singapore, and Taiwan.[1] Unstable variance processes emerge, however, in Indonesia, Korea, Malaysia, the Philippines, and Thailand because the Asian financial crisis increased exchange market volatility immediately. Neglecting structural breaks may bias upward GARCH estimates of the persistence in variance, vitiating the use of GARCH to estimate the mean equation. Perron (1989, 1997) suggests identifying break points by examining data and using dummy variables to capture shifts in mean or variance processes. Figure 2 shows time plots of the eight exchange rates, marking the break dates.

[1] This result appears reasonable, since Japan, Singapore, and Taiwan were not significantly affected by the Asian financial crisis (see Figure 2).

One-time shocks appear as single pulses in the depreciation series and as mean shifts in volatility. Dummy variables enter the mean equation for Indonesia and Thailand and the variance equations for Indonesia, Korea, Malaysia, the Philippines, and Thailand. In the mean equations, dummies for Indonesia are $MD_1 = 1$ for t = 1983:04, $MD_2 = 1$ for t = 1986:09, and 0 otherwise; for Thailand, $MD_1 = 1$ for t = 1981:07, $MD_2 = 1$ for t = 1984:11, and 0 otherwise. In the variance equations, dummies for Indonesia are VD_1=1 for t $\geq$ 1997:07, and 0 otherwise; for Korea VD_1 = 1 for t $\geq$ 1997:07, and 0 otherwise; for Malaysia $VD_1 = 1$ for 1997:07 ≤ t ≤ 1998:12, and 0 otherwise; for the Philippines $VD_1 = 1$ for 1983:01 ≤ t ≤ 1984:12, $VD_2 = 1$ for 1997:07 ≤ t ≤ 1998:12, and 0 otherwise; for Thailand $VD_1 = 1$ for t $\geq$ 1997:07, and 0 otherwise. The 1997 Asian crisis raised exchange rate volatility in Indonesia, Korea, Malaysia, the Philippines, and Thailand. The Philippines also experienced another volatile period from 1983 through 1984.

The properties of the time varying variance and correlation in exports and exchange rates suggest the bivariate GARCH(1,1)-M model with dynamic conditional correlation specified in equations (1a) to (9) to investigate the asymmetric effect of exchange rate risk. The general model is estimated first. Although neither autocorrelation nor heteroskedasticity exist, insignificant coefficients make it difficult to gauge the effect of the risk. Table 3 reports estimated coefficients and standard errors for a parsimonious version with insignificant variables deleted. The advantages of the parsimonious specification include higher precision of estimates from reduced multicollinearity, increased degrees of freedom, more reliable estimates, and greater power of tests. The insignificant likelihood ratio statistic, LR(k), at the 5-percent level suggests no difference between the general and the parsimonious models for each country.

All estimates of the ARMA components and dummy variables in mean equations (1a) and (2) are significant and the parameters in the two variance equations are positive. Every country exhibits time-varying variances for exports and exchange rates, suggesting the bivariate GARCH model. The significance of λ_1 and λ_2 in equation (5) confirms the use of dummy variables to alleviate the effect of structural breaks. Volatility persistence for Δlx_t varies from 0.177 in Taiwan to 0.981 in Indonesia, and for Δlq_t from 0.186 in Taiwan to 0.885 in Thailand. The two variance processes converge. Joint estimates of the degrees of freedom of the t-distribution are significant, the hypothesis of the multivariate Student-t distribution is not rejected.

Both θ_1 and θ_2 in the GARCH(1,1) process of Q_t are significantly positive and $\theta_1 + \theta_2 < 1$. The sum of $\theta_1 + \theta_2$ lie between 0.662 in the Philippines and 0.962 in Malaysia. Table 4 reports statistics of conditional correlation coefficients between Δlx_t and Δlq_t, using the bivariate GARCH(1,1)-M-DCC model of equations (1a) to (9). The average of the coefficients ranges from 0.011 in Malaysia to 0.201 in Japan. The mean or the median is close to the unconditional coefficient in Table 2. Values of the maximum, the minimum, and the standard deviation show that the coefficient is not constant. Figure 3 plots the fitted conditional correlation coefficient between Δlx_t and Δlq_t. The plot illustrates that the correlation coefficient fluctuates over time, similar to that of Figure 1. This characteristic along with the non-zero estimates for θ_1 and θ_2 suggests the use of the time-varying correlation coefficient model for each country.

Bivariate Ljung-Box $Q_2(k)$ statistics (Hosking, 1980) for standardized residuals and squared standardized residuals of Δlx_t and Δlq_t do not detect remaining autocorrelation or conditional heteroskedasticity at the 5-percent level. The bivariate GARCH-M DCC model in equations (1a) to (9) adequately represent each country.

The marginal effect of US manufacturing income on exports proves significantly positive for all countries. Seven of the eight Asian countries experience contemporaneous effects, three experience one-month-lagged, and two experience two-month-lagged effects. The cumulative effect ranges from 1.745 for Malaysia, 2.371 for Japan, to 3.282 for Thailand. Different countries respond differently to the US economy. Generally, quick adjustments and large estimates reflect the small open-economy property of these economies.

Depreciation exhibits the expected positive effect on exports for the eight countries studied, but these effects prove insignificant only in Malaysia and Singapore.[2] The cumulative depreciation effect ranges from 0.226 for Singapore to 2.477 for Korea. Every country exhibits lower individual or cumulative depreciation effect than the US income effect, except Korea.

Exchange rate risk possesses significant effects on exports for all countries, negative or positive in periods of depreciation or appreciation.

IV. Asymmetric Effects of Exchange Rate Risk

Table 5 reports results of the sum tests for the asymmetric effect of the exchange rate risk. The likelihood ratio (LR) statistic with a χ^2 distribution and one degree of freedom tests the significance of the sum $\sum d_{1i}$, $\sum(d_{1i}+d_{2i})$, or $\sum d_{2i}$, whether the total influence of exchange rate risk on exports equals zero for depreciations, for appreciations, or for the differences between the two sums. We define weal asymmetry if either $\sum d_{1i}$ or $\sum(d_{1i}+d_{2i})$ differ significantly from zero and strong asymmetry if $\sum d_{2i}$ differs significantly from zero.

The sum of the coefficients of exchange rate risk in depreciation is significant for all countries except Singapore and Thailand. Five countries exhibit significant negative effects; one exhibits a significant positive effect. The magnitude of the sum ranges from 0.614 in Malaysia to -3.479 in Taiwan. The coefficient sum in appreciation is significant for Japan, Korea, Philippines,

[2] Fang and Miller (2004) report similar findings for Singapore, using a bilateral GARCH-M model with constant variance. Abeysinghe and Yeok (1998), using OLS, find that appreciation does not diminish Singapore's exports due to their high import content. Lower import prices reduce the cost of export production.

Singapore, and Thailand. Three countries exhibit a significantly negative sum; two exhibit a significantly positive sum. The magnitude ranges from 0.494 for the Philippines to -3.671 for Singapore. Generally, the exchange rate risk affects exports for all countries. The effect proves negative for depreciations or appreciations in four countries -- Indonesia, Japan, Singapore, and Taiwan. It exhibits a mixed negative or positive effect for depreciations or appreciations for the other four countries -- Korea, Malaysia, the Philippines and Thailand. In sum, all eight countries exhibit weak asymmetry.

An asymmetric effect of exchange rate risk on exports exists, if either $\sum d_{1i}$ or $\sum(d_{1i} + d_{2i})$ (or both) significantly differs from zero and $\sum d_{2i}$ also differs significantly from zero. Since the exchange rate risk exhibits significant effects on exports either in depreciation or appreciation (or both), the difference between the two coefficient sums, $\sum d_{2i}$, determines the test. $\sum d_{2i}$ significantly differs from zero for Japan, Korea, Malaysia, the Philippines, and Singapore. In sum, these five countries exhibit strong asymmetry. The difference between the two coefficient sums insignificantly differs from zero in Indonesia, Taiwan, and Thailand. Nonetheless, these three countries still exhibit weak asymmetry.

Exchange rate depreciation (appreciation) exhibits the expected positive (negative) effect on exports (i.e., c_i coefficients) in each country, except for Malaysia and Singapore. The effect of exchange rate risk can complement or offset such exchange rate effects, depending on the country, whether the exchange rate depreciates (appreciates), and whether the exchange rate risk increases (decreases). Assuming that larger exchange rate adjustments associate with higher exchange rate risk, we can draw the following inferences from our estimates. If these Asian countries try to stimulate their exports by depreciating their currencies, those attempts to stimulate exports receive significant reinforcement from the exchange rate risk in Malaysia, but offsetting effects in Indonesia, Japan, Korea, the Philippines, and Taiwan.

Previous empirical results on the effects of exchange rate risk without distinguishing asymmetric responses provide mixed results. As a comparison, we also estimate the symmetric-effect GARCH model in equations (1) to (9). Table 6 reports estimates. Diagnostic tests support the statistical appropriateness of the dynamic conditional correlation bivariate GARCH-M model. First, the positive effects of US manufacturing income of the two models produce a reasonable match. Second, significant positive depreciation effects exist for all eight countries in the symmetric effect model. Although they exhibit similar patterns in the two models, the effect proves insignificant in the asymmetric model for Malaysia and Singapore. That is, the symmetric model provides more evidence of positive depreciation effects than the asymmetric model. Third, the cumulative exchange rate risk effect in the symmetric model proves significantly negative for three countries -- Indonesia, Japan, and Taiwan – and not significant for the other five countries. These findings agree with the majority of prior studies, which conclude with either a negative exchange rate risk effect or no effect. In contrast, the asymmetric model identifies significant negative exchange rate risk effects for all countries, except Malaysia, for appreciations, depreciations, or both. Malaysia along with Korea and the Philippines exhibit significant positive effects for appreciations or depreciations. The asymmetric model that allows different responses during depreciations and appreciations provides more evidence of the effect of exchange rate risk on exports.

More recently, Klaassen (2004) finds no exchange rate risk effect on monthly bilateral US exports to other G7 countries, arguing that the exchange rate risk does not exhibit sufficient variability to uncover its effect on exports, and suggests studying the effect, using data on developing countries, for which much more volatile exchange rate risk may exist. The present paper uses data on monthly bilateral exports from eight Asian countries to the US -- seven developing and one developed. Applying the newly developed dynamic conditional correlation bivariate GARCH(1,1)-M model and allowing asymmetric responses, we find significant exchange rate risk effects for all countries studied.

V. Summary and Discussion

This paper applies dynamic conditional correlation bivariate GARCH-M model to examine the asymmetric effects of exchange rate risk on exports, using monthly bilateral exports from eight Asian countries to the US over the period 1979 to 2003. The empirical results summarize as follows. For all the eight countries, foreign income affects exports positively and significantly with contemporaneous, one-month-lagged or two-month-lagged effects. Exchange rate depreciation exhibits the normal positive effect, but proves insignificant in two countries. Real exchange rate risk (volatility) produces significant effect on exports for all countries, negative or positive. Moreover, all countries also exhibit either weak or strong asymmetry with respect to exchange rate risk during appreciations and depreciations of the exchange rates. For Japan, Korea, Malaysia, the Philippines, and Singapore, the effects of exchange rate risk prove strongly asymmetric. The pattern of weak or strong asymmetry shows the following results. Indonesia, Japan, and Taiwan respond negatively to exchange rate risk during depreciations. Korea and the Philippines respond negatively to exchange rate risk during appreciations and positively in appreciations. Malaysia exhibits only a positive exchange rate risk effect during depreciations.

In sum, the conventional assumption of a symmetric effect of exchange rate risk at the aggregate level appears invalid. Given our asymmetric effects, then unfavorable effects of exchange rate risk on exports prove significant in five countries – Indonesia, Japan, Korea, the Philippines, and Taiwan – during depreciations, but in only three countries – Japan, Singapore, and Thailand – during appreciations. Unfavorable effects of exchange rate risk exist during depreciations and favorable effect during appreciations for Korea and the Philippines. The role of the exchange rate in determining export revenue may prove less predictable, given asymmetric effects. Consider the effect of depreciations in Korea and the Philippines. In Figure 2, their currencies depreciated substantially against the dollar in recent years, especially after the Asian crisis of 1997. Although both countries possess strong positive depreciation effects (the highest estimates among the eight countries in Table 3), the asymmetric effect generates a negative exchange rate risk effect, leading to an uncertain net effect of the depreciation on exports. This last statement assumes that the recent depreciation associates with higher exchange rate risk, which appears to be the case from Figure 2. The negative exchange rate risk effect could offset or even dominate the positive depreciation effect. For Malaysia, however, the asymmetric exchange rate risk effect reinforces the positive effect of depreciation.

Table 1: US share of total exports

Country	Share (%)Ratio
INDONESIA	16.0
JAPAN	30.5
KOREA	26.5
MALAYSIA	17.6
PHILIPPINES	34.1
SINGAPORE	18.7
TAIWAN	32.8
THAILAND	18.7

Note: The data are obtained from Direction of Trade of the IMF, exports to the US/total exports.

Table 2: Preliminary statistics for exports and the exchange rate

	INDONESIA		JAPAN		KOREA		MALAYSIA	
	Δlx_t	Δlq_t	Δlx_t	Δlq_t	Δlx_t	Δlq_t	Δlx_t	Δlq_t
Sample size	291	291	291	291	291	291	291	291
Mean	0.486	0.336	0.218	0.020	0.542	0.123	0.617	0.254
SD	23.561	6.257	5.263	2.792	10.886	2.785	9.815	2.085
Maximum	112.428	56.678	15.506	6.801	41.158	34.325	36.894	14.890
Minimum	-120.641	-26.884	-18.577	-10.068	-42.280	-8.509	-32.974	-15.417
Skewness	-0.166	3.026	-0.035	-0.609	-0.186	6.678	0.049	0.348
	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)
Kurtosis	8.475	32.407	3.787	3.757	5.013	82.118	4.118	26.085
	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)
J-B N	364.801*	10929.82*	7.573*	24.945*	50.807*	78061.06*	15.278*	6467.65*
$Q(3)$	70.030*	11.934*	52.199*	27.323*	70.169*	59.985*	68.233*	13.182*
$Q(6)$	77.207*	29.785*	66.728*	28.284*	90.065*	64.426*	70.957*	14.315*
$Q^2(3)$	62.163*	55.883*	14.311*	8.800*	44.415*	13.136*	19.944*	139.630*
$Q^2(6)$	62.257*	87.651*	16.013*	17.596*	47.158*	13.622*	26.883*	188.000*
ADF(m)	-21.005*(1)	-14.494*(0)	-9.673*(2)	-12.641*(0)	-19.635*(1)	-12.047*(1)	-18.864*(1)	-13.875*(0)
ρ_{xq}	0.213		0.206		0.215		0.081	

	PHILIPPINES		SINGAPORE		TAIWAN		THAILAND	
	Δlx_t	Δlq_t	Δlx_t	Δlq_t	Δlx_t	Δlq_t	Δlx_t	Δlq_t
Sample size	291	291	291	291	291	291	291	291
Mean	0.622	0.186	0.487	0.095	0.283	0.053	1.031	0.196
SD	9.528	2.702	12.145	1.411	8.956	1.560	11.542	2.609
Maximum	35.601	21.006	55.490	6.380	37.592	9.020	49.175	16.295
Minimum	-38.113	-8.687	-54.574	-4.995	-25.208	-6.546	-43.237	-15.911
Skewness	-0.050	2.577	-0.218	0.069	0.407	0.109	-0.144	1.872
	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)	(0.144)
Kurtosis	5.418	20.495	6.618	4.950	4.645	7.954	6.404	24.106
	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)	(0.287)
J-B N	71.019*	4033.18*	160.985*	46.330*	40.824*	298.168*	141.504*	5570.93*
$Q(3)$	64.406*	8.400*	100.780*	17.620*	89.918*	14.133*	38.784*	23.865*
$Q(6)$	66.996*	9.516	101.580*	20.500*	90.098*	22.365*	58.018*	28.645*
$Q^2(3)$	31.870*	6.203	59.289*	48.710*	36.352*	3.324	53.417*	129.850*
$Q^2(6)$	35.351*	8.823	59.721*	86.074*	39.742*	6.538	109.77*	187.150*
ADF(m)	-18.787*(1)	-14.335*(0)	-19.291*(1)	-13.543*(0)	-20.683*(1)	-13.980*(0)	-14.982*(1)	-12.766*(0)
ρ_{xq}	0.259		0.046		0.018		0.110	

Note: SD represents standard deviation; J-B N denotes Jacque-Bera normality test; $Q(k)$ and $Q^2(k)$ are Ljung-Box statistics for the level and squared terms for autocorrelations up to k lags; and ADF(m) is the augmented Dickey-Fuller unit root test with lags m selected by the SIC criterion.

* denotes significance at the 5-percent level.

** denotes significance at the 10-percent level.

Table 3: Estimates for dynamic conditional correlation bivariate GARCH-M model (1a)-(9)

	INDONESIA		JAPAN		KOREA		MALAYSIA		PHILIPPINES		SINGAPORE		TAIWAN		THAILAND	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
a_0	1.832*	0.413	4.901*	0.123	1.007**	0.557	0.439	0.403	0.401	0.286	4.555*	0.277	4.622*	0.358	1.182*	0.316
a_1	-0.649*	0.048	-0.574*	0.044	-0.600*	0.050	-0.628*	0.048	-0.629*	0.046	-0.697*	0.049	-0.712*	0.047	-0.654*	0.051
a_2	-0.354*	0.046	-0.269*	0.038	-0.302*	0.046	-0.254*	0.050	-0.241*	0.044	-0.251*	0.048	-0.292*	0.044	-0.329*	0.045
b_0	2.988*	0.674	1.387*	0.303	1.749*	0.742			1.621*	0.484	2.651*	0.596	1.295*	0.579	2.075*	0.739
b_1							1.745*	0.600	1.401*	0.429			1.554*	0.562		
b_2			0.984*	0.282											1.207*	0.572
c_0	0.362*	0.053			0.708*	0.128			1.229*	0.181	0.226	0.215			0.554*	0.086
c_1			0.304*	0.063	1.032*	0.115			0.738*	0.115			0.820*	0.228	0.540*	0.072
c_2	0.210*	0.074	0.286*	0.077	0.737*	0.090	0.288	0.205	0.215**	0.123					0.286*	0.087
d_{10}					-1.461*	0.145	1.240*	0.184	-0.446**	0.240						
d_{11}			-1.410*	0.036	-1.723*	0.262			0.706*	0.156			-3.479*	0.233	0.199*	0.030
d_{12}	-0.376*	0.072			2.392*	0.216	-0.626*	0.184	-0.996*	0.243	-2.339*	0.153				
d_{20}	0.579*	0.096	-0.627*	0.075					0.632*	0.250					0.372*	0.118
d_{21}	-0.400*	0.109	-0.334*	0.080			-0.783*	0.239	0.598*	0.202	-1.332*	0.075	0.758*	0.350	-0.813*	0.050
d_{22}					1.011*	0.187									-0.422*	0.092
s_0	0.069	0.057	0.187	0.185	0.033	0.070	0.113**	0.063	0.005	0.095	0.043	0.071	0.087	0.091	-0.042	0.059
s_1	0.207*	0.065	0.308*	0.060	0.351*	0.052	0.177*	0.067	0.357*	0.059	0.235*	0.054	0.212*	0.061	0.211*	0.061
γ_1	30.261*	1.508													6.072*	0.643
γ_2	16.552*	0.495													15.066*	0.329
α_0	1.642*	0.609	13.189*	1.496	36.998*	4.438	5.713*	1.277	8.213*	3.289	7.257*	1.082	42.448*	5.102	1.464*	0.504
α_1	0.079*	0.012	0.204*	0.094	0.404*	0.077	0.143*	0.028	0.249*	0.086	0.271*	0.013	0.177*	0.090	0.085*	0.008
α_2	0.901*	0.010			0.303*	0.023	0.793*	0.021	0.721*	0.073	0.675*	0.028			0.887*	0.007
β_0	0.251*	0.043	6.112*	0.317	0.108*	0.020	0.796*	0.097	0.695*	0.178	0.268*	0.008	1.834*	0.182	0.078*	0.011
β_1	0.451*	0.074	0.191*	0.043	0.094*	0.017	0.333*	0.088	0.338*	0.104	0.086*	0.009	0.186*	0.060	0.087*	0.003
β_2	0.309*	0.047			0.781*	0.021			0.425*	0.070	0.766*	0.016			0.798*	0.013
λ_1	12.008*	4.216			0.713*	0.255	42.343*	20.030	9.095**	4.961					12.431*	4.790
λ_2									16.388**	9.253						
v	5.951*	1.074	6.835*	1.729	4.051*	0.409	5.170*	0.831	3.018*	0.202	7.315*	1.814	4.822*	0.704	6.433*	1.047
θ_1	0.135*	0.061	0.024*	0.004	0.111*	0.051	0.032*	0.001	0.200*	0.058	0.056**	0.029	0.073*	0.026	0.029*	0.014
θ_2	0.717*	0.131	0.670*	0.024	0.712*	0.008	0.930*	0.001	0.462*	0.116	0.695*	0.171	0.755*	0.198	0.891*	0.022
$\rho_{xq,t}$	0.110		0.201		0.112		0.011		0.169		0.044		0.014		0.064	
$Q_2(6)$	35.167		19.255		30.017		28.935		32.510		11.301		28.691		31.584	
$Q_2^2(6)$	12.090		20.064		16.656		9.593		29.215		21.853		22.378		25.184	
$LR(k)$	3.360(6)		4.510(7)		2.916(4)		10.166(8)		1.726(2)		2.002(8)		4.714(9)		5.926(3)	

Note: $Q_2(6)$ and $Q_2^2(6)$ are the bivariate Ljung-Box statistics (Hosking,1980) of the standardized and squared standardized residuals for autocorrelations up to 6 lags. $LR(k)$ is the likelihood ratio statistic following a χ^2 distribution with the degree of freedom k (in the parentheses) that tests that the restricted simple model has the same explanatory power as the unrestricted general model when we eliminate the k insignificant estimates.

* denotes significance at the 5-percent level.
** denotes significance at the 10-percent level.

Table 4: Statistics for dynamic conditional correlations

	INDONESIA	JAPAN	KOREA	MALAYSIA	PHILIPPINES	SINGAPORE	TAIWAN	THAILAND
Mean	0.110	0.201	0.112	0.011	0.169	0.044	0.014	0.064
Median	0.106	0.202	0.134	0.021	0.183	0.053	-0.001	0.063
Maximum	0.609	0.305	0.396	0.155	0.494	0.246	0.420	0.220
Minimum	-0.413	0.094	-0.453	-0.155	-0.392	-0.185	-0.270	-0.104
Std. Dev.	0.197	0.029	0.127	0.065	0.118	0.066	0.116	0.052

Table 5: Tests of asymmetric effect of exchange rate risk

	$\sum d_{1i}$	$\sum (d_{1i} + d_{2i})$	$\sum d_{2i}$
INDONESIA	-0.376 *	-0.198	0.178
LR statistic	5.434	1.687	0.600
	(0.020)	(0.194)	(0.439)
JAPAN	-1.411 **	-2.371 *	-0.960 *
LR statistic	3.444	7.385	9.327
	(0.063)	(0.007)	(0.002)
KOREA	-0.793 **	0.218 *	1.011 **
LR statistic	3.693	15.107	3.509
	(0.055)	(0.000)	(0.061)
MALAYSIA	0.614 *	-0.169	-0.783 *
LR statistic	3.951	0.243	4.274
	(0.047)	(0.622)	(0.039)
PHILIPPINES	-0.735 **	0.494 **	1.229 *
LR statistic	3.249	3.154	5.432
	(0.071)	(0.076)	(0.020)
SINGAPORE	-2.339	-3.671 *	-1.332 *
LR statistic	2.087	4.635	4.277
	(0.149)	(0.031)	(0.039)
TAIWAN	-3.479 **	-2.722	0.757
LR statistic	3.323	1.968	1.070
	(0.068)	(0.161)	(0.301)
THAILAND	0.199	-0.663 *	-0.862
LR statistic	0.256	4.657	1.840
	(0.613)	(0.031)	(0.175)

Note: *LR statistic* is the likelihood ratio statistic following a χ^2 distribution with one degree of freedom that tests $\sum d_{1i} = 0$, $\sum (d_{1i} + d_{2i}) = 0$ and $\sum d_{2i} = 0$. *P-values* are in parentheses.

* denotes significance at the 5-percent level.
** denotes significance at the 10-percent level.

Table 6: Estimates for dynamic conditional correlation bivariate GARCH-M model (1)-(9)

	INDONESIA		JAPAN		KOREA		MALAYSIA		PHILIPPINES		SINGAPORE		TAIWAN		THAILAND	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
a_0	1.691 *	0.415	3.937 *	0.240	0.761 **	0.427	0.442	0.408	0.128	0.305	3.366 *	0.099	10.165 *	0.241	1.314 *	0.370
a_1	-0.643 *	0.048	-0.570 *	0.044	-0.577 *	0.049	-0.625 *	0.047	-0.617 *	0.042	-0.684 *	0.049	-0.736 *	0.070	-0.645 *	0.047
a_2	-0.353 *	0.047	-0.272 *	0.041	-0.277 *	0.042	-0.250 *	0.050	-0.230 *	0.043	-0.257 *	0.035	-0.324 *	0.047	-0.321 *	0.045
b_0	2.865 *	0.667	1.212 *	0.347	1.521 *	0.651			1.176 *	0.471	2.618 *	0.566	1.539 *	0.554	2.446 *	0.570
b_1							1.828 *	0.604	1.550 *	0.415			1.579 *	0.524		
b_2			1.066 *	0.336												
c_0			0.298 *	0.082	0.562 *	0.118			0.936 *	0.106					0.474 *	0.131
c_1	0.280 *	0.069	0.453 *	0.079	0.924 *	0.195	0.380 *	0.188	0.395 *	0.133	0.419 **	0.215	0.590 *	0.256	0.780 *	0.166
c_2	0.148 **	0.076	0.325 *	0.078											0.485 *	0.130
d_0	0.421 *	0.083			-0.088	0.229	1.189 *	0.188	0.664 *	0.122	1.579 *	0.071				
d_1	-0.653 *	0.086	-1.476 *	0.080					0.741 *	0.123			-1.959 *	0.097	-0.253 *	0.122
d_2							-0.962 *	0.199	-1.308 *	0.124	-3.804 *	0.084	-4.973 *	0.103		
s_0	0.072	0.056	0.174	0.189	0.033	0.069	0.117 **	0.063	0.004	0.094	0.037	0.088	0.106	0.093	-0.042	0.059
s_1	0.202 *	0.068	0.310 *	0.058	0.351 *	0.055	0.183 *	0.068	0.356 *	0.057	0.236 *	0.053	0.218 *	0.060	0.212 *	0.062
γ_1	30.258 *	1.483													6.065 *	1.206
γ_2	16.037 *	0.598													15.069 *	1.198
α_0	1.839 *	0.701	13.528 *	1.892	40.966 *	6.764	5.722 *	1.275	8.397 *	1.820	4.106 *	0.053	44.521 *	5.117	1.559 *	0.479
α_1	0.096 *	0.015	0.182 **	0.097	0.363 *	0.118	0.139 *	0.027	0.240 *	0.053	0.173 *	0.006	0.092	0.069	0.082 *	0.012
α_2	0.887 *	0.011			0.282 *	0.075	0.797 *	0.020	0.725 *	0.028	0.793 *	0.005			0.890 *	0.010
β_0	0.251 *	0.044	6.164 *	0.479	0.118 *	0.023	0.796 *	0.099	0.713 *	0.146	0.309 *	0.023	1.823 *	0.083	0.083 *	0.016
β_1	0.489 *	0.087	0.172 *	0.055	0.101 *	0.027	0.357 *	0.099	0.333 *	0.067	0.099 *	0.023	0.164 *	0.031	0.100 *	0.021
β_2	0.299 *	0.048			0.761 *	0.024			0.401 *	0.059	0.732 *	0.016			0.787 *	0.017
λ_1	10.869 *	4.018			0.799 *	0.307	34.865 *	15.375	16.632 *	5.160					10.868 *	3.659
λ_2									18.962	11.580						
v	5.691 *	0.934	7.131 *	1.858	4.143 *	0.461	5.069 *	0.795	3.023 *	0.170	7.174 *	0.579	5.164 *	0.946	6.105 *	1.257
θ_1	0.160 **	0.082	0.057 **	0.032	0.099 *	0.030	0.011	0.018	0.204 **	0.110	0.061 **	0.034	0.049 *	0.023	0.040 *	0.006
θ_2	0.592 *	0.198	0.730 *	0.073	0.828 *	0.005	0.984 *	0.037	0.441 *	0.120	0.649 *	0.155	0.859 *	0.115	0.952 *	0.013
$Q_2(6)$	32.658		20.294		30.200		28.275		36.108		8.848		28.183		36.001	
$Q_2^2(6)$	13.299		20.950		14.066		10.643		15.949		20.672		16.552		23.231	
$\sum d_i$	-0.232*		-1.476**		-0.088		0.227		0.097		-2.226		-6.932*		-0.253	
x^2	(4.624)		(3.273)		(0.082)		(0.642)		(0.263)		(1.968)		(6.889)		(2.478)	
$LR(k)$	4.788 (4)		3.414 (5)		5.621 (5)		7.844 (5)		1.962 (2)		3.606 (5)		2.874 (4)		5.858 (4)	

Note: See Table 3. LR χ^2 statistics are in parentheses testing for the significance of $\sum d_i$.

* denotes significance at the 5-percent level.
** denotes significance at the 10-percent level.

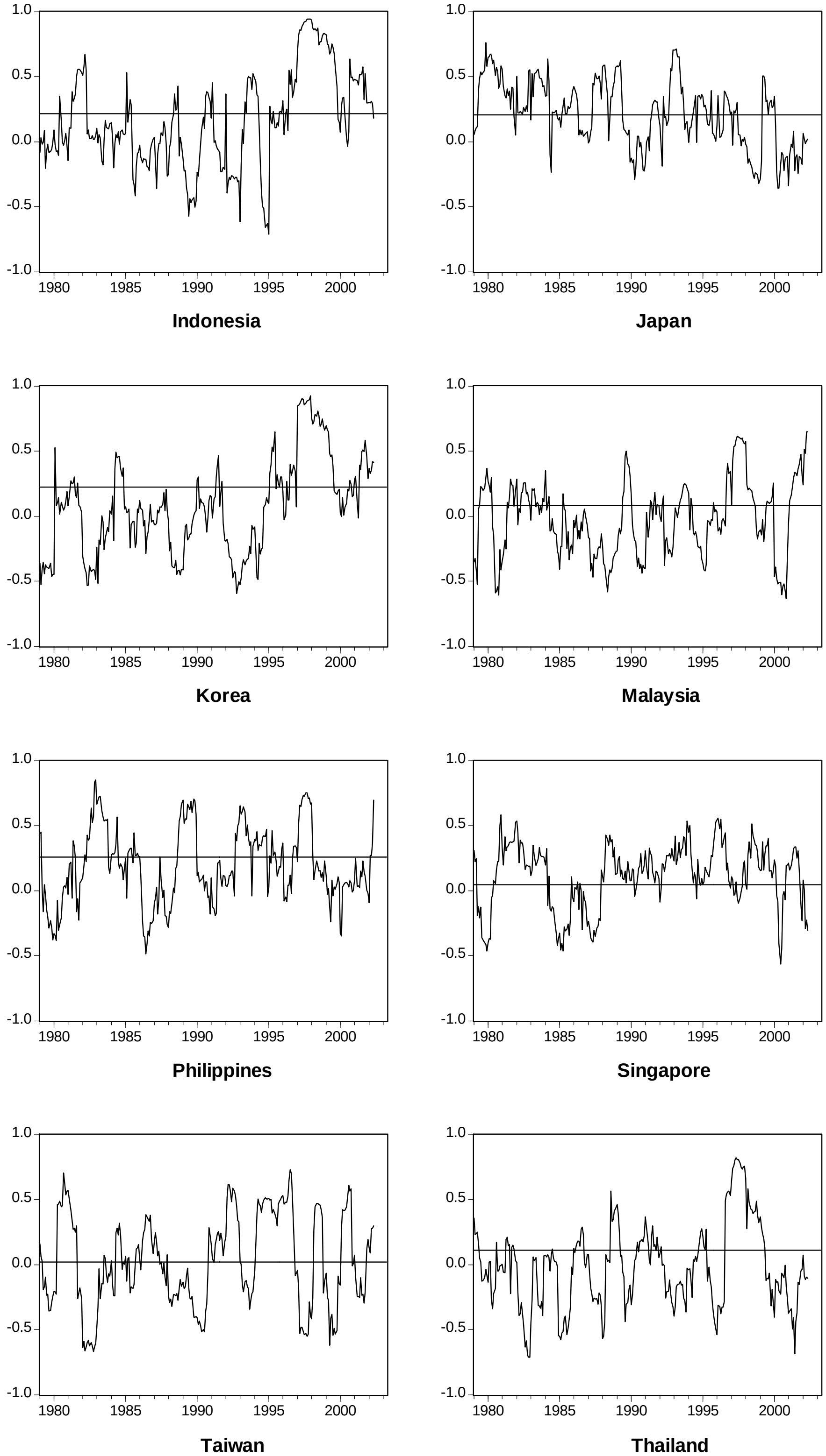

Figure 1. 12-period rolling correlations

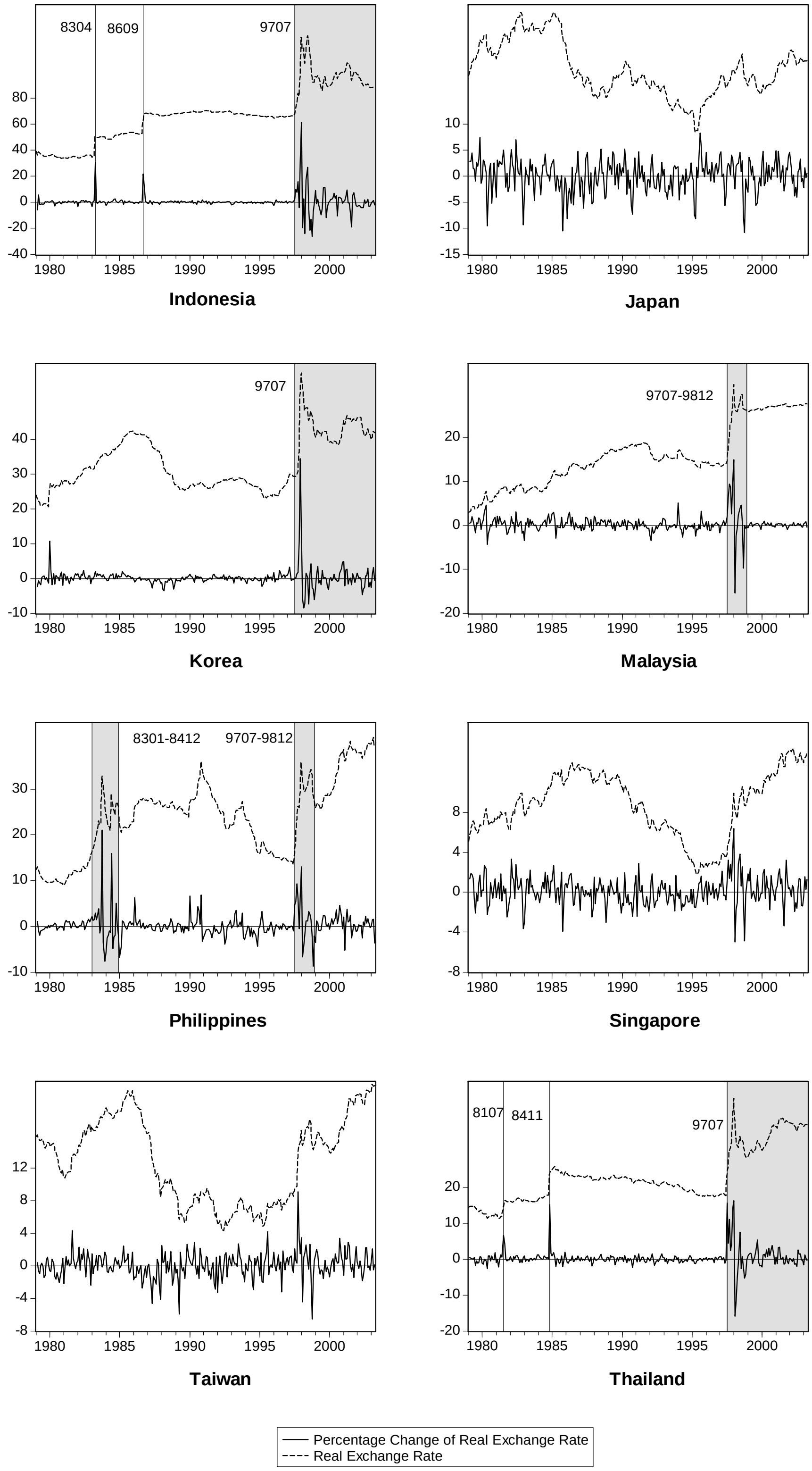

Figure 2. Structural changes for exchange rates

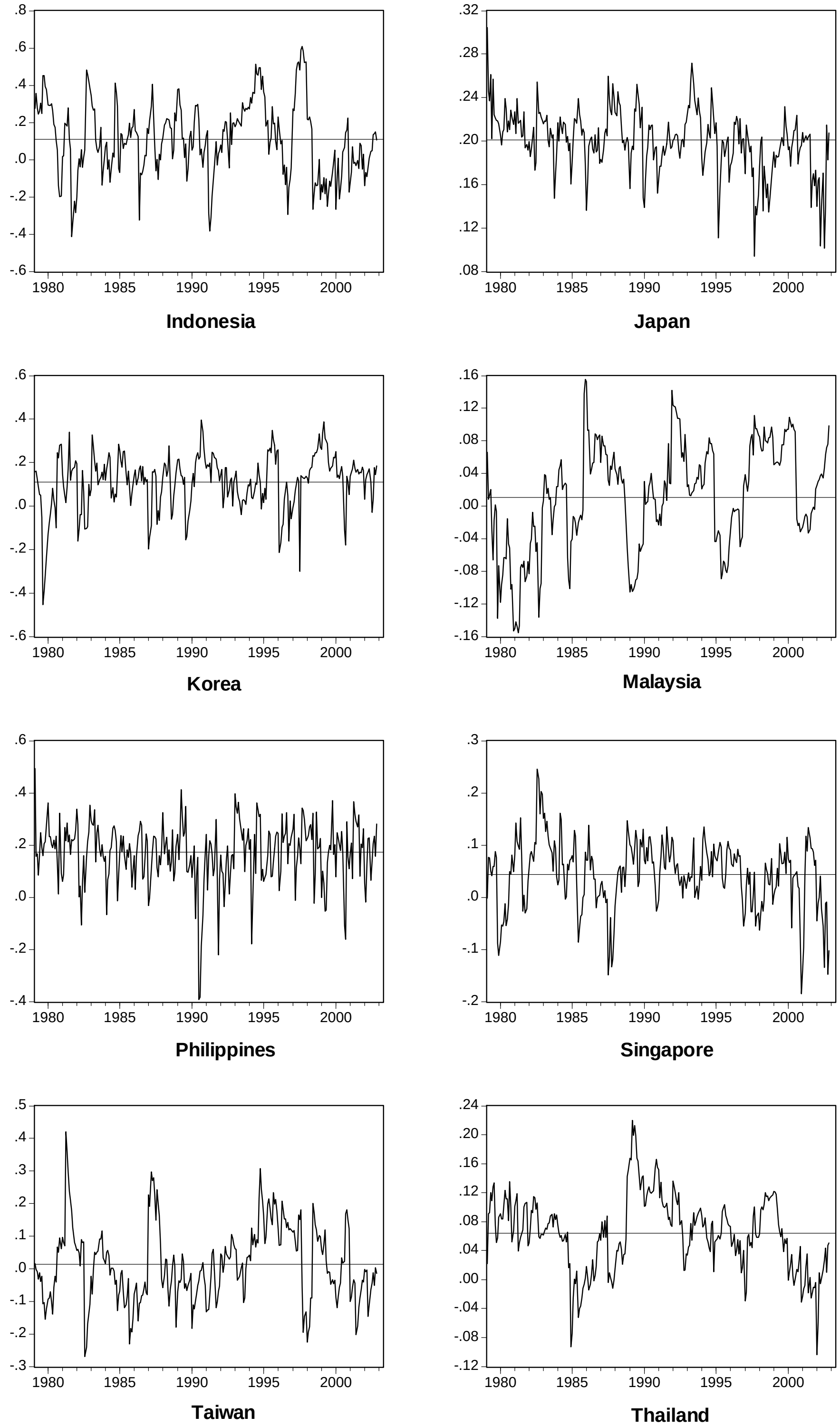

Figure 3. Dynamic conditional correlations

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