The Exchange Rate and Interest Rate Differential Relationship: Evidence from Two Financial Crises

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Abstract

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Abstract

This paper examines the contemporaneous and inter-temporal interaction between real exchange rate and real interest rate differential in the two financial crises of 1997 and 2008 by using data from thirteen countries from different world regions. The empirical result shows that negative contemporaneous relationship exists in most countries. In addition, there is little evidence on a systematic inter-temporal relationship between the real interest rate differential and the real exchange rate, and an absence of consistent result in supporting a negative relationship among the thirteen economies. An extremely low change in the conditional correlation between real interest rate differential and real exchange rates can be found in small countries.

Keywords: Contemporaneous, inter-temporal relationship, exchange rate, interest rate differential, financial crisis

JEL Classification: C22, E43, F32, O57.

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I Introduction

It has been argued that an increase in the real interest rate of the home country will lead to a positive real interest rate differential that attracts capital inflow, which would in turn impose an upward pressure on the home economy's real exchange rate. However, given the contagious movement of the real interest rate across economies, and when the real interest rate of other economies have caught up to eliminate the real interest rate differential, capital inflow might not have taken place and remove the upward pressure on the real exchange rate. Thus, the real interest rate differential and real exchange rate relationship may behave differently between contemporaneous and inter-temporal situations.

Both the sticky-price and flexible-price approaches have been used to explain the relationship between real interest rate differential and real exchange rate. The sticky-price approach predicted a negative relationship between exchange rate and nominal interest rate differential (Dornbusch, 1976). It argued that the higher interest rate in the home country relative to the foreign country will attract capital inflow, and hence the home currency will appreciate instantly. On the contrary, the flexible-price approach argued for a positive relationship between nominal interest rate differentials and exchange rate, and that a change in nominal interest rate reflected a change in the expected inflation rate. Given that the nominal interest rate equals to the sum of the real interest rate and the expected inflation rate, an increase in nominal interest rate in the home country relative to the foreign nominal interest rate will result in a depreciation of the home currency as expected inflation rises. The demand for the domestic currency will therefore fall and the exchange rate will then depreciate (Frankel, 1976; Bilson, 1978).

In addition, rather than the international demand for flows of goods, Frankel (1979) incorporated the international demand for stocks of assets into exchange rate analysis and highlighted the importance of expectation and rapid adjustment in capital markets. Hooper and Morton (1982) further examined large and prolonged changes in real exchange rate, and empirically found that over half of the variance of real exchange rate during the 1970s was related to the shifts in the current account and changes in real interest rate differentials. Other literatures provided empirical evidence that real interest rate differential is a key determinant of exchange rate movement (Obstfeld and Rogoff, 1984; Boughton, 1987).

Recent studies have applied cointegration technique to study the linkage between real exchange rate and real interest rate differential (Coughlin and Koedijk, 1990; Blundell-Wignall and Brown, 1991; MacDonald, 1998; Edison and Melick, 1999). For example, the cointegration techniques and error-correction models used in Meese and Rogoff (1988) and Edison and Pauls (1993) did not show a long run relationship between real exchange rate and real interest rate differential. Sollis and Wohar (2006) used the threshold cointegration methodology and found some evidence of a nonlinear long-run relationship between real exchange rate and real interest rate differential. Hoffmann and MacDonald (2009) used the bivariate VAR method to model the relationship of real interest rate differentials and real exchange rate, and considered the long-run change in real exchange rate as the sum of period-to-period changes. Bautista (2006) has provided empirical finding on the inter-temporal relationship between real exchange rate and real interest differential in six East Asian economies, and found a large decline in the conditional correlation structure during the Asian Financial Crisis (AFC) period.

The world has experienced at least two financial crises that have strong contagious effects within the decade of 1997/98 and 2007/08. The AFC in 1997/98 began in mid-1990s with a fall in exports in a number of Asian economies sparked off in July 1997 with the devaluation of the Thailand currency. The fear of a global fund withdrawal following the closure of key financial institutions in South Korea and Japan led eventually to a collapse of financial markets and regional currency depreciations. Both the financial-panic hypothesis that argued for a substantial downward shift in market expectation and confidence, and the fundamental-based hypothesis that argued for an unsustainable deterioration in macroeconomic fundamentals have been put forward as alternative explanations for the AFC (Eichengreen et al., 1998; Kaminsky *et al*., 1998; Krugman, 1998a, 1998b; Radelet and Sachs, 1998a, 1998b; Corsetti *et al*., 1999). Other studies have considered the herd behavior and the drop in capital inflow as additional explanations (Chari and Kehoe, 2003; Calvo, 1998; Rigoborn, 1998; Pan *et al*., 2001).

The 2008 financial crisis that began with the collapse of the US subprime mortgage industry in March 2007 and the subsequent emergence of a worldwide credit crunch as many international hedge funds and banks have invested heavily in sub-prime mortgage-backed securities. The situation heightened in September 2008 when the US Federal Reserve (Fed) took over the two largest mortgage-based security companies and the subsequent closure of Lehman Brothers in New York had led to a financial meltdown that generated a tsunami-like sequence of contagious effects on other international financial centers in Europe and Asia.

Responses to the 2008 financial crisis including the two G20 meetings in 2009 have identified two fundamental schools of thought. The financial market fundamental school advocated for the correction in such financial fundamentals as regulations, bank liquidity, moral hazard and corporate government (for example, International Monetary Fund, 2009; Financial Services Authority, 2009). On the contrary, the monetarist school believed that the role of monetary policy and the interest rate are the underlying factors (Meltzer, 2009; Gokhale and Van Doren, 2009; Schwartz, 2009). Because of the highly integrated worldwide financial markets, the monetary policy adopted by the US can swiftly influent other world economies though interest rate and exchange rate mechanisms. Prior to the 2008 financial crisis, for example, the Fed's expansionary monetary policy and a prolonged low interest rate regime were highly contagious from the US to major EU and Asia economies.

This paper examines the possibility of a contemporaneous relationship between real interest rate differential and change in real exchange rate by using a bivariate structural vector autoregressive (SVAR) method. Armed with the assumption of rational expectation and efficient market, the hypothesis is that real exchange rate changes that result from the adjustment of real interest rate differential will happen in a very short horizon. This means that the information on real interest rate differential shall only have an immediate impact on the change in real exchange rate, and hence future exchange rate movement will reflect only future information and will be independent to current change in real exchange rate. The paper will then consider the inter-temporal interactions between real interest rate differential and real exchange rate. Engle (2002) has proposed the dynamic conditional correlation (DCC) model that allowed for the correlation matrix time dependent by formulating the conditional correlation as a weighted sum of past correlations. The DCC model can be regarded as nonlinear combinations of univariate generalized autoregressive conditional heteroskedasticity (GARCH) models.

The dynamic conditional correlations between real interest rate differential and real exchange rate will be considered. To begin with, the univariate GARCH models will not be limited to the standard first order GARCH (1, 1) process (Bautista, 2006). Instead, a functional coefficient autoregression of order $\psi(AR(\psi))$ with the conditional variance specified as a higher order univariate GARCH (p, q) model for each series in the estimation process will be considered. The accurate standardized residuals can then be obtained for estimating the time varying correlation matrix. Such a specification ensured that the relevant dynamics can be captured in the correlation structure.

The empirical study shows the experience of thirteen world countries for a period that covered the two financial crises of 1997/98 and 2007/08, and the performances of the twelve countries are expressed relative to the performance of the US, which is considered as the "foreign" country. The twelve world countries include, in the case of Europe, the United Kingdom, Germany, Greece and Iceland. In general, European countries did not suffer much in the AFC, but are faced with different degree of difficulties in the 2008 crisis. Iceland has suffered severely soon after the 2008 financial crisis due obviously to the lack of funds. Greece's financial problem took longer and resurfaced in mid-2010 as a result of the inability to contain public debts. The two countries in the Americas are Canada and Chile. The four AFC-affected countries in Asia are Japan, South Korea, Singapore and Thailand, while China and India represent the two emerging countries. A relatively short horizon data have been used in order to lower the effect of “unquantifiable news” from the market. Monthly data is used in the analysis.

The rest of this paper is organized as follows. Section II discusses the theoretical underpinnings between changes in the real exchange rate and real interest rate differential relative to the foreign country. Section III shows the general data description and the results of descriptive statistics of the sample economies. Sections IV and V show, respectively, the empirical results of the contemporaneous and inter-temporal relationship between real interest rate and real exchange rate. The last section concludes the paper.

II The Real Interest Rate and Real Exchange Rate Link

Consider the following uncovered interest parity relation:

$$E_t(e_{t+1} - e_t) = i_t - i_t^*, \tag{1}$$

where E_t is the conditional expectation operator, i_t (i_t^*) is the domestic (foreign) nominal interest rate and e_t is the nominal exchange rate expressed in domestic currency per US dollar. Equation (1) shows that nominal exchange rate adjustment is expected once the nominal interest rate differential between home and foreign country exists. The real exchange rate (q_t) is constructed from the nominal exchange rate and consumer price indices as:

$$q_t = e_t + p_t^* - p_t, \tag{2}$$

where p_t^* (p_t) represents the foreign (home) currency price of the goods produced aboard (domestically). The real interest rate (r_t), expressed in the Fisher equation format, is equal to the nominal interest rate minus the expected inflation rate:

$$r_t = i_t - (E_t p_{t+1} - p_t). \tag{3}$$

The uncovered interest parity relation with real exchange rate and real interest rate can then be expressed as:

$$E_t(q_{t+1} - q_t) = r_t - r_t^* \ . \tag{4}$$

According to Obstfeld and Rogoff (1984), the real exchange rate could adjust monotonically at the same constant rate to its flexible price value. The real exchange rate adjustment mechanism can be defined as:

$$E_{t+1}(q_{t+1} - \bar{q}_{t+1}) = \theta(q_t - \bar{q}_t), \quad 0 < \theta < 1 \, , \tag{5}$$

$$E_t \bar{q}_{t+1} = \bar{q}_t \, , \tag{6}$$

where E_{t+1} represents the conditional expectations operator at time t+1. θ is the speed of adjustment parameter and $\bar{q}_t$ is the real exchange rate that prevails at time *t* if all prices were fully flexible. Equation (5) implies that real exchange rate adjusts to its flexible price value ($\bar{q}_t$), while Equation (6) suggests that the *ex-ante* purchasing power parity holds under perfect price flexibility and assumes that $\bar{q}_t$ follows a random walk process. Substituting Equation (6) into (5) and rearranging the equation, we get:

$$q_t = \alpha[E_t(q_{t+1} - q_t)] + \bar{q}_t \, , \tag{7}$$

where $\alpha = 1/(\theta - 1) < 0$. Substituting Equation (4) into Equation (7), we have:

$$q_t = \alpha(r_t - r_r^*) + \bar{q}_t \ . \tag{8}$$

Equation (8) shows a linear relationship between real exchange rate, real interest rate differential and flexible-price real exchange rate. Equation (8) will be used for both contemporaneous and inter-temporal relationships analysis. In accordance with the traditional Mundell–Fleming–Dornbusch (MFD) model (Mundell, 1961; Fleming, 1962; Dornbusch, 1976), the real exchange rate and real interest rate differential should be negatively related. The coefficient of the real interest rate differential (α) in Equation (8) should be negative. The real exchange rate would move to the opposite direction if a positive deviation of the real interest rate differential exists.

III Statistical Performance

The monthly data are obtained from the International Financial Statistics (IFS) CD ROM issued by the International Monetary Fund (IMF) and DataStream. The sample covered the period from January 1994 to June 2009, with the exception of Thailand whose sample period began from June 1994. The real exchange rate is expressed in logarithm and calculated by adjusting the nominal end-of-period domestic exchange rate against the US dollar by the domestic and US CPI, as shown in Equation (2). The real interest rate is calculated by the nominal interest rate minus the *ex-post* one month realized inflation rate as shown in Equation (3). The real interest rate differentials are measured by subtracting the real interest rate for the US from the real interest rate of each country. The lending rate is used as a proxy of nominal interest rate for China, Chile and Japan, while the money market rate is adopted for all the other countries.

Figure 1 plots the relative performance of the real interest rate differential (right axis) and real exchange rate (left axis) for the twelve economies. One observation is that although the short-term movement of these two variables showed a deviation, their overall movement seemed to show a correlation. In the case of real interest rate differential, there are not much significant changes among the sample countries, with the exception of the Asian countries during the AFC period. The governments of South Korea, Singapore and Thailand during the

AFC have increased their interest rates sharply in order to drive away the speculators. In the case of the real exchange rate, the sudden capital outflow has caused a sharp depreciation in real exchange rate in most Asian economies, especially in South Korea, Thailand and Singapore. The pegged exchange regime in Thailand and the managed floating exchange regime in South Korea have been replaced by a free-floating exchange rate arrangement in 1997 and 1998 respectively.

The 2008 financial crisis started with the collapse of the US sub-prime mortgage industry in March 2007, the Federal Open Market Committee (FOMC) has lowered on a stepwise scale the Federal Fund Rate, and hence caused an apparent rising trend in the real interest rate differential that began from late 2007, with the exception of Iceland, Chile and Singapore due probably to their increase in inflation expectation. The increase in the real exchange rate trend that started in late 2008 represented depreciation in the domestic currency of the sample economies against the US dollar, with the only exception of Japan with the yen serving as a shelter currency. Due to the deterioration in the US economy, the strength of US dollar against all depreciated currencies basically reflected a situation of capital fund repatriation by international investors.

Table 1 shows the descriptive statistics of the real interest rate differential and change in the real exchange rate. The performance in the real exchange rate showed that many countries have exhibited a left-skewed distribution in their data series, with the exception of Germany, Greece, Iceland, Chile and South Korea. As expected, the standard deviation of Thailand and South Korea is relatively higher than other countries, due probably to the shift in exchange rate regime during the AFC period. Though India adopted a market determined exchange rate regime, the Reserve Bank of India has actively traded in the foreign exchange market in order to influence the market price of the Rupee, and hence, the standard deviation of India's exchange rate is the lowest among other countries. As for the real interest rate differential, China has the highest standard deviation as a result of a significant change in inflation rate between 1994 and 1996. The five countries of Iceland, Chile, Thailand, China and India exhibited a leptokurtic distribution since their excess Kurtosis coefficients are closed to or larger than 3.

The Jarque-Bera tests for normality are statistically strong and significant, with the exception of the real exchange rate in Iceland and the real interest rate differential in United Kingdom, Japan and Singapore. For both real exchange rate and real interest rate differential, the Box-Pierce test for the raw series, Q(5), suggested that serial correlation existed in all countries. The results of Box-Pierce test for squared raw series indicated that a strong presence of ARCH-structure in all real exchange rate and real interest rate differential with the exception of Iceland.

The statistic results of the Augmented Dickey-Fuller (ADF) test, the Lagrange Multiplier test (LM) and the Constant Conditional Correlation test (Engle and Sheppard, 2001) are reported in Table 2. The ADF result shown in Panel A indicated that all real interest rate differentials are stationary, and the real exchange rates for all countries are stationary after first difference. The LM test for the ARCH effect shown in Panel B cannot reject the null that all the coefficients of the squared residual of real exchange rates of Greece, Canada, Chile, China and Japan are equal to zero, while only Iceland cannot be rejected in the case of real interest rate differential. We also test for the constant correlation among the series with the null hypothesis of constant correlation against the alternative hypothesis of time varying correlation. The null of constant correlation generally cannot be rejected except Greece. However, Engle and Shepard (2001) stated that the conditional correlation test result is not easy to interpret because the correlation structures could be time-varying, and the significance depended on the number of the lags selected. The dynamic conditional correlation model can, therefore, be applied to determine the significance of the conditional correlation test based on the estimated parameters of the DCC model.

IV The Contemporaneous Relationship

In order to measure the contemporaneous relationship and the inter-relationship between real interest rate differential and real exchange rate, the country is described by a Structural Vector Autoregressive (SVAR) system that expressed the contemporaneous interactions between real interest rate differential and real exchange rate in the following structural form:

$$B(L)Y_t = \gamma_0 + e_t , \tag{9}$$

where $B(L)$ is a 2 x 2 matrix polynomial in the lag operator, L; Y_t is a 2 x 1 vector of variables which included two endogenous variables in the vector:

$$Y_t = \begin{bmatrix} r_t - r_t^* \\ \Delta q_t \end{bmatrix}, \tag{10}$$

and e_t is a 2 x 1 vector structural disturbances which is identical independent normal and var(e_t) = Λ. Λ is a diagonal matrix and the diagonal elements are the variances of structural disturbances such that each structural disturbance can be assigned explicitly to particular equations. $r_t - r_t^*$ represented the real interest rate differential at the current level, and the change in real exchange rate (Δq_t) is defined by using the formula $\Delta q_t = q_t - q_{t-1}$.

Let B_0 be the contemporaneous coefficient matrix on L^0 in the structural form, and let $B^0(L)$ be the coefficient matrix in $B(L)$ without contemporaneous coefficient B_0. The matrix polynomial in the lag operator, L, can be expressed as follow:

$$B(L) = B_0 + B^0(L) . \tag{11}$$

Consider the following reduced form VAR equation:

$$Y_t = \alpha_0 + A(L)Y_t + u_t , \tag{12}$$

where $A(L)$ is a matrix polynomial in lag operator, L, and u_t is a vector of reduced-form disturbances with no structural interpretation. We begin with the SVAR equation, and multiply B_0^{-1} to the structural form equation:

$$Y_t = B_0^{-1}\gamma_0 + B_0^{-1}B(L)Y_{t-1} + B_0^{-1}e_t = \alpha_0 + A(L)Y_{t-1} = u_t. \tag{13}$$

Note that the parameters of reduced form VAR equation are related to the parameters of the SVAR equation:

$$\mathrm{A(L)} = B_0^{-1}B^0(L) . \tag{14}$$

The reduced form residuals are related to the structural disturbances:

$$u_t = B_0^{-1}e_t, \tag{15}$$

and the covariance matrix is:

$$\mathrm{E}(u_t u_t') = \Sigma = B_0^{-1}\Lambda B_0^{-1'}. \tag{16}$$

The reduced form residuals become linear combinations of the structural disturbances. Equation (16) suggests that the covariance matrix of the reduced form residuals is not diagonal, and the right hand side of the equation has $n \times (n+1)$ free parameters to be estimated. Since Σ contains $n \times (n+1) / 2$ parameters, the parameters in the SVAR equation cannot be identified without restriction. To achieve identification, $n \times (n+1) / 2$ restrictions are therefore needed. By normalizing the diagonal elements in B_0 to unity, the identification requires at least $n \times (n+1) / 2$ restrictions on B_0.

In the SVAR analysis, a constant variable is included and the number of lag length in each model is based on the Akaike information criterion. Table 3 gives the contemporaneous coefficients of the twelve countries. As expected, nine out of twelve estimated coefficients are negative though they are mostly statistically insignificant. An interesting phenomenon found in the European region is that a negative relationship between real interest rate differential and real exchange rate can be found in Iceland and Greece, while the coefficient of Germany is positive and significant. On the contrary, the estimated coefficient of most Asian countries is statistically significant, with the exception of China and India. It suggests that government intervention on exchange rate would affect the contemporaneous relationship between real interest rate differentials and real exchange rate.

Figure 2 illustrates the Choleski-decomposition impulse response functions of the interest rate differential shock (shock 1) and real exchange rate shock (shock 2). The vertical axis represents the real interest rate differential in panels a) and b), and real exchange rate in panels c) and d), respectively. The horizontal axis denotes time horizon in months. The upper and lower dashed line plotted in each graph show the two standard-error bands generated by using the Monte Carlo techniques.

The impact of real exchange rate to a positive interest rate shock (panel c) is examined to see how real interest rate differential influences real exchange rate. In the case of European countries, the overall impression in their panel c) graphs show that a positive interest rate differential shock can generate a positive effect on real exchange rate in a short time horizon, with the exception of Germany. The impact in general peaked at the second month, but declined in the third months. An apparent positive initial impact on real exchange rate can be seen among the Asian countries, and the responses in real exchange rate peaked at the first month but declined thereafter. The downturn came to a completion around the third or fourth month before it stabilized. As for Canada, Chile and the two emerging countries of China and India, the overall results are inconsistent, as the initial effect of real interest rate differential shock on real exchange rate is negative in Canada and China but positive in Chile and India.

The impulse response analysis provided a quantitative measure on the dynamic effects of real exchange rate to a real interest rate differential shock. In our response analysis, there are only three economies with a negative initial effect consistent with the traditional view that a transitory appreciation of the real exchange rate is associated with an increase in real interest rate differential. Although one could argue that the dynamic response of the real exchange rate started to drop at the second month in most cases, the results cannot satisfy the condition of interest rate parity and the traditional view that expected change in real exchange rate is generated by the current real interest rate differential. There is little and weak evidence for supporting the relationship between real interest rate differential and real exchange rate.

V The Dynamic Conditional Correlation Model

Lacking robust evidence that supported the linkage between real interest rate differential and real exchange rate, the analysis is extended to study the dynamic relationship between these two variables. The dynamic conditional correlation (DCC) model in Engle (2002) is used to examine the relationship between changes in real exchange rate and real interest rate differential. The DCC model formulated the conditional correlation as a weighted sum of past correlations and allowed the conditional correlation matrix time dependent. Assume that the multivariate GARCH model with *2 x 1* vector of series y_t exhibited a conditional normal distribution of zero mean and covariance matrix H_t :

$$y_t | \Omega_{t-1} \sim N(0, H_t) , \tag{17}$$

where Ω_{t-1} is the information set at time *t*-1. Under the DCC-GARCH framework, the covariance matrix is defined as:

$$H_t \equiv D_t R_t D_t , \tag{18}$$

where $D_t = diag\left\{\sqrt{h_{it}}\right\}$ is a *k* x *k* diagonal matrix of time varying standard deviations from univariate GARCH models with $\sqrt{h_{it}}$ on the *i*th diagonal, and $R_t \equiv \left\{\rho_{ij}\right\}_t$ is the time varying correlation matrix containing conditional correlation coefficients. The univariate GARCH (*p, q*) is given as:

$$h_{it} = w_i + \sum_{q=1}^{q_i} \alpha_{ip} \varepsilon_{it-p}^2 + \sum_{p=1}^{p_i} \beta_{iq} h_{it-q} \ . \tag{19}$$

The estimation of the DCC-GARCH model is obtained by:

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1} , \tag{20}$$

where the evolution of the correlation in the model is given by:

$$Q_t = (1 - \sum_{m=1}^{M} \alpha_m - \sum_{n=1}^{N} \beta_n) \bar{Q} + \sum_{m=1}^{M} \alpha_m (\xi_{t-m} \xi_{t-m}^{'}) + \sum_{n=1}^{N} \beta_n Q_{t-n} \ . \tag{21}$$

$\xi_t = \dfrac{\varepsilon_{it}}{\sqrt{h_{it}}}$ is a vector that included the standardized residuals and $\varepsilon_t \sim N(0, R_t)$. $\bar{Q}$ is the unconditional covariance of ξ_{t-m} , and $Q_t \equiv \left\{q_{ij}\right\}_t$ is regarded as a conditional covariance matrix. Q_t^* is a *k* x *k* diagonal matrix containing the square root of the diagonal elements of Q_t :

$$Q_t^* = \begin{bmatrix} \sqrt{q_{11}} & 0 & \cdots & 0 \\ 0 & \sqrt{q_{22}} & \cdots & 0 \\ \vdots & \cdots & \ddots & 0 \\ 0 & 0 & \cdots & \sqrt{q_{kk}} \end{bmatrix}. \quad (22)$$

The time varying conditional correlation is expressed as $\rho_{i,j,t} = \frac{q_{i,j,t}}{\sqrt{q_{i,i,t}q_{j,j,t}}}$, which is included in R_t. The general restriction of non-negativity and stationarity of variances is assumed. The estimation of DCC model is estimated using a three-stage procedure. Firstly, the univariate GARCH (p, q) models are fitted into the two series to obtain the estimated standard residuals. The second stage involves the estimation of the intercept parameters of conditional correlation. Finally, the coefficients governing the dynamics of correlation are estimated using the intercept parameters of conditional correlation.

The univariate GARCH model for each of the 24 data series (include real exchange rates and real interest rate differentials of the 12 countries) are first estimated, and the standardized residuals are then used to estimate the correlation parameters. In order to obtain a consistent correlation estimate, the specification of univariate GARCH model in our estimation is not limited to the standard first order GARCH (1, 1) process. All the univariate model used in the estimation is *AR(Ψ)-GARCH(p,q)*, where the conditional mean and conditional variance equation are selected by finding the minimum of the AIC allowing for $\rho < 2$, $P < 3$ and $Q < 2$. The student-t distribution is assumed in the estimation. Table 4 reports the estimated parameters of the *AR(Ψ)-GARCH(p,q)* process. The three parameters of w, α and β are the GARCH parameters from Equation (18), and Ψ_i are the coefficients of the AR process. A total of five economies (United Kingdom, Greece, Japan, China and India) are specified as AR (2) process in the conditional mean equation. As for the conditional variance equation, the weights of α_t and β_t satisfy the non-negativity constrains and the $\alpha_t + \beta_t < 1$ restriction in all economies.

Table 5 shows that some of the DCC estimates of α_D and β_D are nonnegative scalar parameters, satisfying the condition $\alpha_t + \beta_t < 1$ and are significantly different from zero. However, one can note that most of the α_D equal to zero, suggesting that the constant conditional correlation may be more appropriate for these series. On the other hand, there is little evidence for supporting the relationship between the real interest rate differential and change in the real exchange rate as the estimated unconditional correlations (ρ_{21}) are statistically insignificant in most cases. With the exception of Chile, the statistic results of student distribution (*df*) are highly significant in all series and the vector normality test gave the identical results that these series do not follow a multivariate normal distribution. The multivariate portmanteau test in Hosking (1980) is used to detect the misspecification in the conditional mean equation and the variance matrix. The results of portmanteau test (*MQ*) on standardized residuals are all statistically insignificant, indicating that the serial correlations in conditional mean have successfully been eliminated by the AR filter. In addition, no serial correlation in the variance matrix is detected as the results of portmanteau test on squared standardized residuals (MQ^2) are mostly statistically insignificant with 5% significant level. The diagnostic tests suggested that the model for each economy in general is well specified.

Figure 3 to Figure 6 show the conditional correlation structure between the real interest rate differential and the change in the real exchange rate for the four European countries (United Kingdom, Germany, Greece and Iceland), the two countries in the Americas (Canada and Chile), the four Asian countries (Japan, South Korea, Singapore and Thailand) and the two emerging countries (China and India), respectively. Among the twelve countries, there are a total of six countries (Iceland, Greece, Canada, Chile, Japan and China) that have a negative dynamic correlation structure, implying that their negatively correlated performance between real interest rate differential and real exchange rate is consistent with the theoretical argument.

Contrary to the result shown by Bautista (2006) that an abrupt decline in the conditional correlation structure appeared in six East Asian countries during the AFC period, our empirical results show an apparent increase in conditional correlation structure in all Asian countries. The higher correlation is driven by the higher variances in real exchange rate and real interest rate differential during the AFC period. The large and sudden change in capital flow did cause severely depreciation in many Asian countries in 1997. In order to combat against international speculators, a tightened monetary policy pursued by the Asian governments helped to defend the exchange rate. A large increase in conditional correlation should, therefore, be found as a result of a sharp increase in interest rate accompanied by a clear depreciation of the currency. The observation from the AFC is the sharp increase in the conditional correlation structure resulted from the increase in interest rate differential and real depreciation of the home currency among the Asian countries.

During the 2008 financial crisis, the empirical result shows that the conditional correlation structure of most economies has also increased. Since the real interest rate differential is the difference between the US and home country real interest rate, each country in the sample has passively increased its real interest rate differential as the US Fed started to lower its interest rate in late 2007. In fact, the repatriation of capital by international investors started in March 2008.

One important finding in the DCC analysis is that a very slight change in dynamic conditional correlation structure is found in Iceland[1], Iceland can be regarded as a small country in Europe, and any change in Iceland's interest rate shall not generate any impact on the Euro currency. Besides Iceland, the change in dynamic conditional correlation of Greece, Singapore, Thailand and India moved within a small range. This finding suggests that the interest rate movement is not a crucial concern of capital flows in small economies. Although India is one of the major emerging markets in the world, the active trading in the foreign exchange market conducted by the Reserve Bank of India resulted only in a slight change in the conditional correlation.[2] As expected, the dynamic conditional correlation of China is constant over time. This makes sense since any change in interest rate will not affect the exchange rate under a fixed exchange rate regime.

VI Conclusion

This paper examines the contemporaneous and inter-temporal relationship performance between real interest rate differential and real exchange rate in twelve world countries in the two financial crisis periods. The SVAR model is used to study the contemporaneous between these two variables. Nine out of twelve countries have a negative estimated contemporaneous coefficient and only three of them are statistically significant. In the impulse response analysis,

[1] The value of conditional correlation of Iceland shown in Figure 2 only gives the changes after 10 decimal places. Indeed, we do find clear and larger changes in the dynamic conditional correlation structure in most economies when the estimation process is based on the standard first order DCC – GARCH (1, 1) model. Moreover, the multivariate portmanteau test in Hosking (1980) indicates that there is misspecification error in both conditional mean equation and the variance matrix.

[2] The value of conditional correlation of India shown in Figure 5 only gives the change after 13 decimal places.

there are only three countries that a positive real interest rate differential shock can generate a negative initial effect to the real exchange rate.

In addition, the dynamic conditional correlations method is used to study the time-varying conditional correlation structure of these twelve economies with univariate *AR(Ψ)-GARCH(p,q)* specification in the first stage of DCC estimation. We find little evidence that there is a systematic relationship between the real interest rate differential and change in the real exchange rate, and are unable to find consistent results among these twelve countries in supporting their negative relationship.

Our empirical results showed that the inter-temporal relationship between these two variables is weak as the DCC estimates are not statistically significant in most countries. A sharp increase in the conditional correlation, however, can be found during the two financial crises. In the AFC period, the large increase in conditional correlation has clearly appeared in the Asian countries, while the result of the 2008 financial crisis has covered more regions. The reason for the sharp increase in conditional correlation is due to the severe depreciation in the real exchange rate accompanied by a tightened monetary policy pursued by the Asian governments during AFC, but a more passive increase in real increase rate differential during the 2008 financial crisis.

One encouraging finding is that the inter-temporal relationship between real interest rate differential and real exchange rates in Iceland, Singapore, Thailand and India is extremely low. The change in their monetary policy did not generate a significant impact on their capital movement. This suggests that return from interest earning is not a crucial factor for international capital fund investing in smaller countries. In addition, a constant conditional correlation structure can be found. Due to the fixed exchange rate regime and the non-convertibility of the Renminbi in China, there is no significant dynamic relationship between real interest rate differential and real exchange rate. In fact, it seems that the 2008 financial crisis has made little influence on the China economy. It can be concluded that exchange rate stability is crucial in the period of financial crisis.

The empirical findings seem to give a new dimension to the discussion on the negative relationship between real exchange rate and real interest rate differential. The argument that a rise in domestic interest rate would attract capital inflow with the ultimate outcome of a currency appreciation may apply only to a single country, because the rise in the interest rate of a single country could easily contagion to other countries, resulting in the inter-temporal rise in the interest rate of other countries. When other countries have caught up with the rise in interest rate in the next time period, there may not be any capital flow large enough to influence the price of the currency. As such, there is no pressure for the value of any currency to change. Hence, real interest rate differential at most has a very temporary effect on real exchange rate across countries. Once the interest rate of other countries has efficiently been adjusted, there will not be any impact on real exchange rate.

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Table 1 Descriptive Statistic of Real Interest Rate Differential and Real Exchange Rate

	United Kingdom	Germany	Iceland	Canada	Chile	Japan	Korea	Singapore	Thailand	China	India
Real exchange rate											
mean	-0.508	0.472	4.335	0.276	6.279	4.614	6.993	0.394	3.574	1.955	3.812
std.dev	0.105	0.146	0.150	0.115	0.144	0.156	0.162	0.122	0.177	0.125	0.075
Skewness	-0.495	0.462	0.383	-0.433	0.460	-0.799	0.222	-0.663	-0.482	-1.188	-0.823
Kurtosis	-0.640	-0.492	-0.026	-0.500	-0.773	0.031	-0.868	-0.983	-0.959	0.411	0.767
min	-0.751	0.205	4.026	-0.026	6.046	4.162	6.740	0.155	3.269	1.632	3.597
max	-0.337	0.798	4.739	0.462	6.606	4.877	7.476	0.550	3.976	2.107	3.942
Jarque-Bera	10.713	9.263	4.538	7.696	11.123	19.684	7.327	20.989	13.865	44.827	25.422
	(0.005)**	(0.01)**	(0.103)	(0.021)**	(0.004)**	(0.000)**	(0.026)**	(0.000)**	(0.001)**	(0.000)**	(0.000)**
$Q(5)$	757.788	839.572	704.667	828.435	704.667	775.143	704.997	1362.600	809.718	850.825	768.815
	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
$Q^2(5)$	765.736	844.67	701.751	836.255	701.751	774.384	697.889	1336.490	802.936	853.418	768.953
	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
Real interest rate differential											
mean	1.018	0.398	3.975	0.721	6.069	0.845	3.129	-0.318	0.316	1.404	4.890
std.dev	1.347	1.498	3.512	1.323	3.141	1.874	1.546	1.635	3.143	5.796	3.447
Skewness	-0.187	0.541	4.269	0.627	1.841	-0.466	0.036	-0.225	1.440	-2.085	-1.286
Kurtosis	-0.254	-0.089	30.509	0.187	6.774	-0.413	-0.257	-0.559	2.869	3.585	2.981
min	-2.510	-2.510	-3.260	-1.870	1.080	-4.000	-0.680	-4.330	-5.540	-19.400	-9.800
max	4.210	4.760	32.470	4.460	24.940	4.290	7.310	3.100	13.930	6.970	10.190
Jarque-Bera	1.573	9.841	7736	12.402	458.26	6.945	125.99	3.856	119.29	233.1	119.52
	(0.456)	(0.007)**	(0.000)**	(0.000)**	(0.000)**	(0.031)**	(0.000)**	(0.145)	(0.000)**	(0.000)**	(0.000)**
$Q(5)$	478.273	654.073	66.49	557.744	190.388	754.447	494.363	801.125	471.645	785.98	570.788
	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
	267.373	393.124	0.816	452.156	106.94	639.309	274.015	236.721	362.73	686.888	410
$Q^2(5)$	(0.000)**	(0.000)**	(0.976)	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**

Note: ** represents statistical significance at 5%.

Table 2 General Statistic of Real Interest Rate Differential and Real Exchange Rate

	United Kingdom	Germany	Iceland	Canada	Chile	Japan	Korea	Singapore	Thailand	China	India
Panel A: Augmented Dicky-Fuller Test											
Real exchange rate											
Δq_t	-3.561**	-3.034**	-3.253**	-3.910**	-3.585**	-3.616**	-3.958**	-3.502**	-4.519**	-2.190**	-3.870**
Real interest rate differential											
$r_t - r_r^*$	-2.526**	-2.706**	-2.828**	-3.742**	-2.298**	-2.218**	-2.076**	-3.037**	-3.093**	-4.433**	-3.491**
Panel B: LM ARCH Effect Test											
Real exchange rate											
Δq_t	5.048	7.699	19	0.509	1.284	1.043	8.048	7.430	7.845	1.18	2.921
	(0.000)**	(0.000)**	(0.000)**	(0.769)	(0.273)	(0.394)	(0.000)**	(0.000)**	(0.000)**	(0.321)	(0.015)
Real interest rate differential											
$r_t - r_r^*$	42.09	180.09	0.132	186	20.46	282.9	91.96	4.093	56	1306	180
	(0.000)**	(0.000)**	-0.985	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**	(0.000)**
Panel C: Constant Correlation Test											
E-S Test(5)	1.602	4.419	3.578	1.379	9.926	11.952	11.968	6.942	8.057	2.166	8.992
	(0.952)	(0.620)	(0.734)	(0.967)	(0.128)	(0.063)	(0.063)	(0.326)	(0.234)	(0.904)	(0.174)

Notes: Figures in parenthesis represent the p-values; ** and * represent statistical significance at 5% and 10%, respectively.

Table 3 Contemporaneous Coefficients in Structural Models

	Coefficients	Standard Error
United Kingdom	-0.0004	0.003
Germany	0.0076	0.005*
Greece	-0.0018	0.002
Iceland	-0.0004	0.001
Canada	0.0018	0.004
Chile	-0.0010	0.001
Japan	-0.0083	0.005*
Korea	-0.0228	0.005**
Singapore	-0.0097	0.002**
Thailand	-0.0049	0.002**
China	0.0035	0.003
India	-0.0006	0.001

Note: ** and * represent statistical significance at 5% and 10%, respectively.

Table 4 Univeriate AR(p) – GARCH(p , q) Models

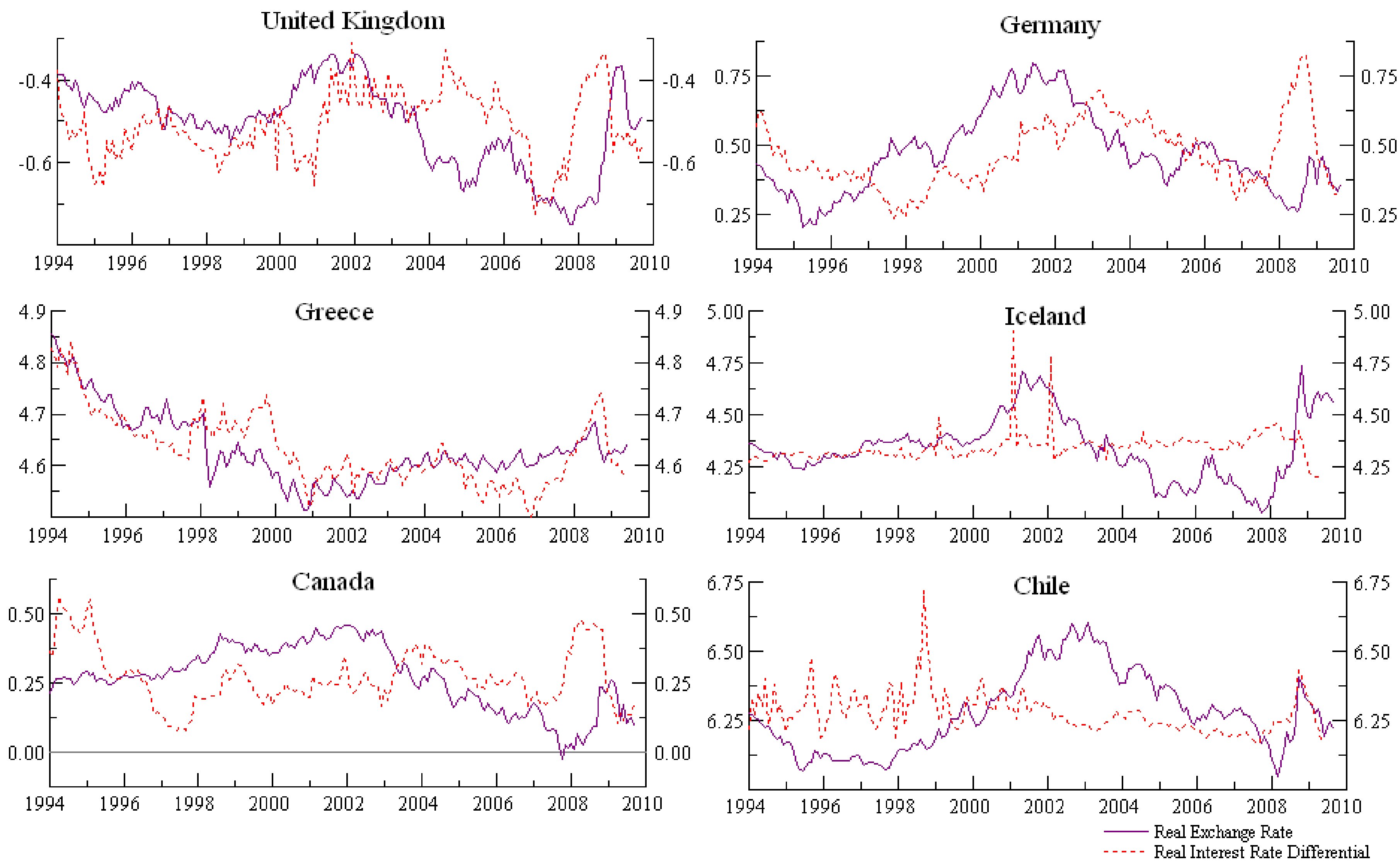
	ψ_0	*Std.Error*	ψ_1	*Std.Error*	ψ_2	*Std.Error*	w_I	*Std.Error*	$\Sigma\alpha_i$	$\Sigma\beta i$
Real exchange rate										
United Kingdom	-0.001	(0.001)	0.031	(0.079)	-0.099	(0.090)	0.899	(0.654)	0.083	0.757
Germany	-0.002	(0.002)	0.123	(0.071) *	-	-	0.515	(0.093)**	0.013	0.918
Iceland	0	(0.003)**	0.184	(0.078)**	-	-	0.521	(0.170)**	0.171	0.807
Canada	0.001	(0.001)	-0.008	(0.069)	-	-	0.032	(0.023)	0.045	0.955
Chile	0.001	(0.002)	0.221	(0.084)**	-	-	0.431	(0.471)	0.327	0.662
Japan	0.003	(0.003)	0.138	(0.082)*	0.053	(0.076)	7.400	(1.791)**	0.22	0.071
Korea	-0.001	(0.001)	0.123	(0.089)	-	-	0.935	(0.447)**	0.72	0.358
Singapore	-0.001	(0.001)	0.005	(0.074)	-	-	0.307	(0.143)**	0.185	0.723
Thailand	0.001	(0.003)	0.116	(0.109)	-	-	2.189	(1.710)**	0.236	0.58
China	0.002	(0.002)	0.606	(0.501)	-0.448	(0.645)	0.0678	(0.019)	0.055	0.928
India	-0.002	(0.001)	0.103	(0.057) *	-0.049	(0.049)	0.246	(0.181)	0.214	0.743
Real interest rate differential										
United Kingdom	0.793	(0.458) *	0.695	(0.084)**	0.204	(0.080)**	0.045	(0.042)	0.056	0.852
Germany	0.415	(5.990)	0.978	(0.040)**	-	-	0.177	(0.129)	0.164	0.034
Iceland	0.012	(0.135)	-0.4	(0.107)**	-	-	1.560	(1.407)	0.144	0.73
Canada	0.23	(0.826)	0.963	(0.023)**	-	-	0.043	(0.019)**	0.013	0.745
Chile	3.756	(0.536)	0.866	(0.046)**	-	-	0.018	(0.012)	0.152	0.856
Japan	0.385	(1.107)	1.114	(0.055)**	-0.144	(0.058)**	0.035	(0.014)**	-0.072	0.919
Korea	3.035	(0.440)**	0.892	(0.032)**	-	-	0.202	(0.075)**	0.268	0.328
Singapore	-0.402	(0.628)	0.922	(0.032)**	-	-	0.147	(0.040)**	0.144	0.566
Thailand	-0.009	(0.619)	0.902	(0.036)**	-	-	0.039	(0.023)*	0.32	0.672
China	3.343	(3.120)	1.227	(0.189)**	-0.247	(0.176)	0.761	(0.293)**	0.054	0.95
India	4.72	(0.973)**	1.216	(0.070)**	-0.29	(0.065)**	0.092	(0.049)*	0.104	0.81

Notes: Figures in parenthesis represent the standard errors of the coefficients in univariate GARCH models; ** and * represent statistical significance at 5% and 10%, respectively.

Table 5 DCC (1,1) Model and Diagnostic Test

	United Kingdom	Germany	Iceland	Canada	Chile	Japan	Korea	Singapore	Thailand	China	India
DCC parameters											
ρ_{21}	0.030	0.025	-0.010	-0.008	-0.086	-0.116	0.163	0.265	0.014	-0.211	0.056
	(0.074)	(0.115)	(0.058)	(0.070)	(0.064)	(0.160)	(0.106)	(0.087) **	(0.059)	(0.065) **	(0.076)
α_D	0.129	0.209	0.000	0.004	0.031	0.016	0.038	0.000	0.000	0.000	0.000
	(0.062) **	(0.527)	(0.000)	(0.025)	(0.012) **	(0.012)	(0.037)	(0.000)	(0.000)	(0.000)	(0.000) **
β_D	0.000	0.000	0.513	0.938	0.969	0.984	0.868	0.566	0.744	0.834	0.810
	(0.606)	(1.845)	(0.460)	(0.041) **	(0.016) **	(0.026) **	(0.077) **	(0.658)	(1.079)	(0.498) *	(0.201) **
Df	5.895	13.095	2.941	7.042	15.906	7.260	4.704	6.589	3.810	4.015	5.602
	(1.273) **	(7.879) *	(0.185) **	(2.003) **	(10.213)	(1.894) **	(0.862) **	(2.017) **	(0.420) **	(0.650) **	(1.387) **
MQ (8)	37.854	40.047	25.274	32.669	25.052	35.013	40.566	24.245	27.554	49.339	37.855
	(0.154)	(0.128)	(0.755)	(0.385)	(0.765)	(0.242)	(0.117)	(0.800)	(0.644)	(0.015) *	(0.154)
MQ^2 (8)	43.342	34.575	16.403	49.478	22.970	24.170	35.077	42.392	30.921	43.102	32.889
	(0.055)	(0.183)	(0.971)	(0.007) *	(0.687)	(0.764)	(0.240)	(0.066)	(0.369)	(0.057)	(0.327)
Normality	47.439	18.937	1922.500	47.846	9.105	34.589	47.150	45.134	213.670	327.360	42.407
	(0.000) **	(0.001) **	(0.000) **	(0.000) **	(0.059)	(0.000) **	(0.000) **	(0.000) **	(0.000) **	(0.000) **	(0.000) **

Notes: Figures in parenthesis represent the standard errors of the coefficients in DCC model, and p-value in diagnostic test. ** and * represents the series statistically significant at 5% and 10%, respectively.


United Kingdom
Germany
Greece
Iceland
Canada
Chile
Real Exchange Rate
Real Interest Rate Differential

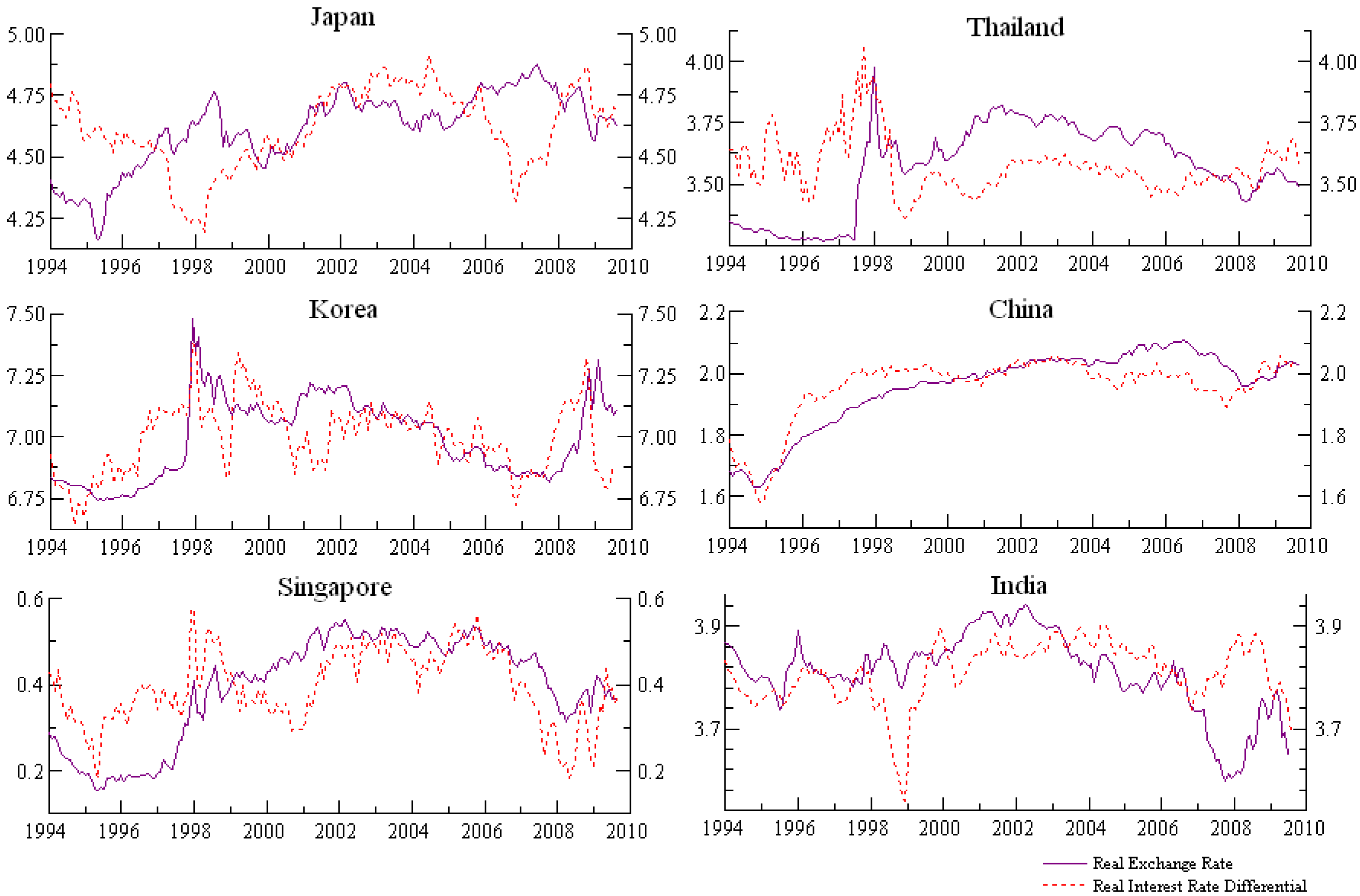
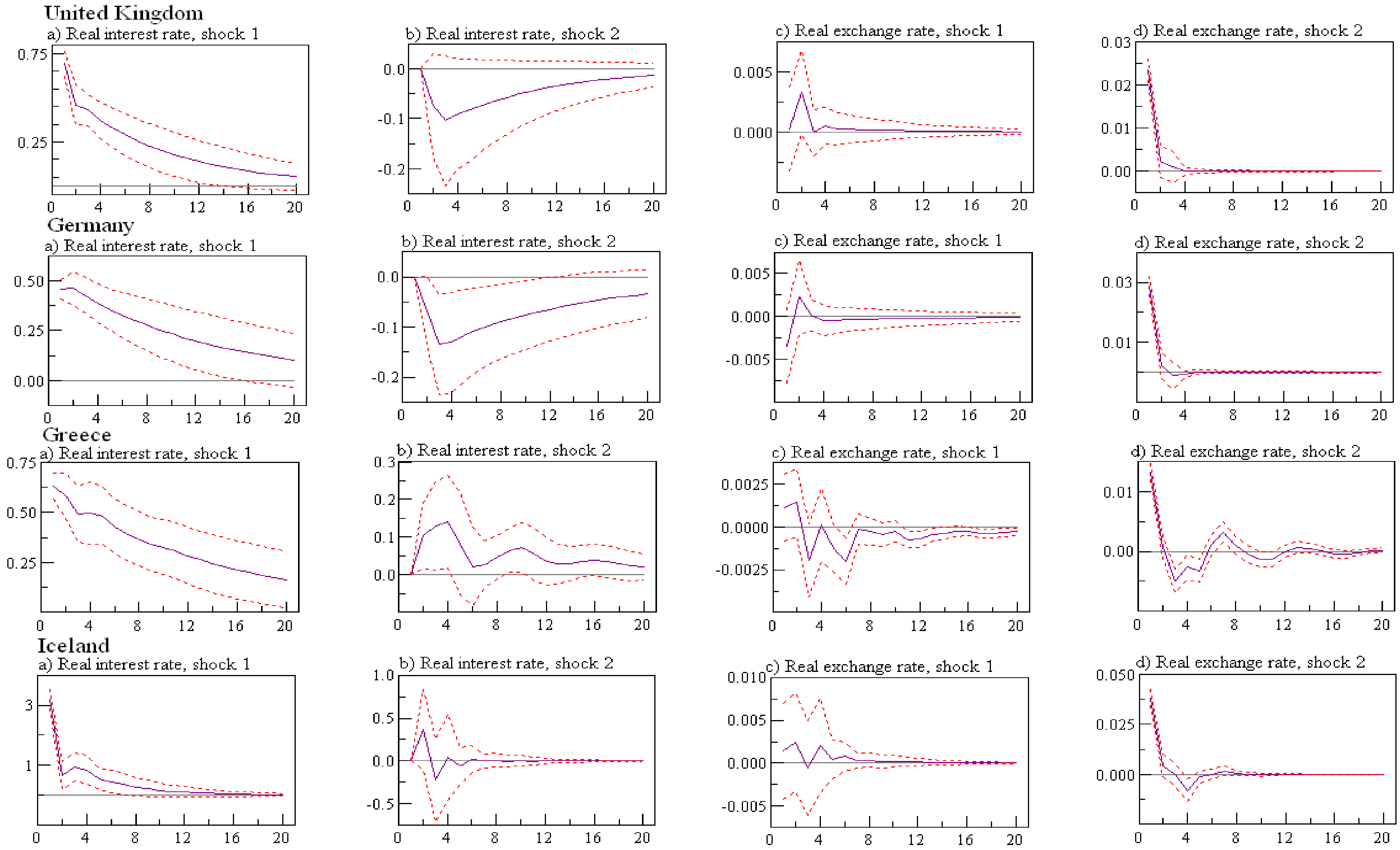
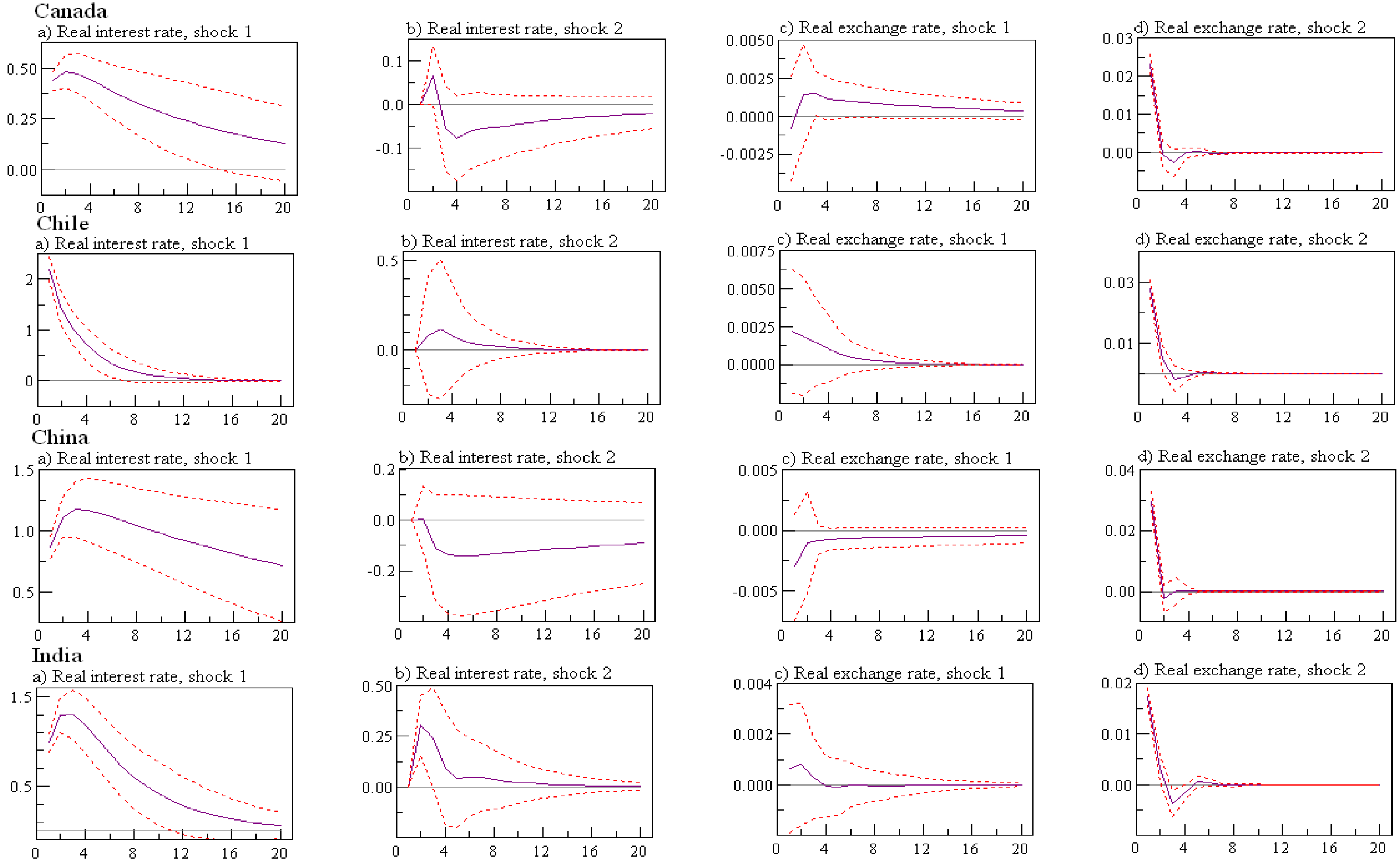


Figure 1 Time Series of Real Interest Rate Differential and Real Exchange Rate


United Kingdom
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2
Germany
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2
Greece
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2
Iceland
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2


Canada
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2
Chile
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2
China
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2
India
a) Real interest rate, shock 1
b) Real interest rate, shock 2
c) Real exchange rate, shock 1
d) Real exchange rate, shock 2

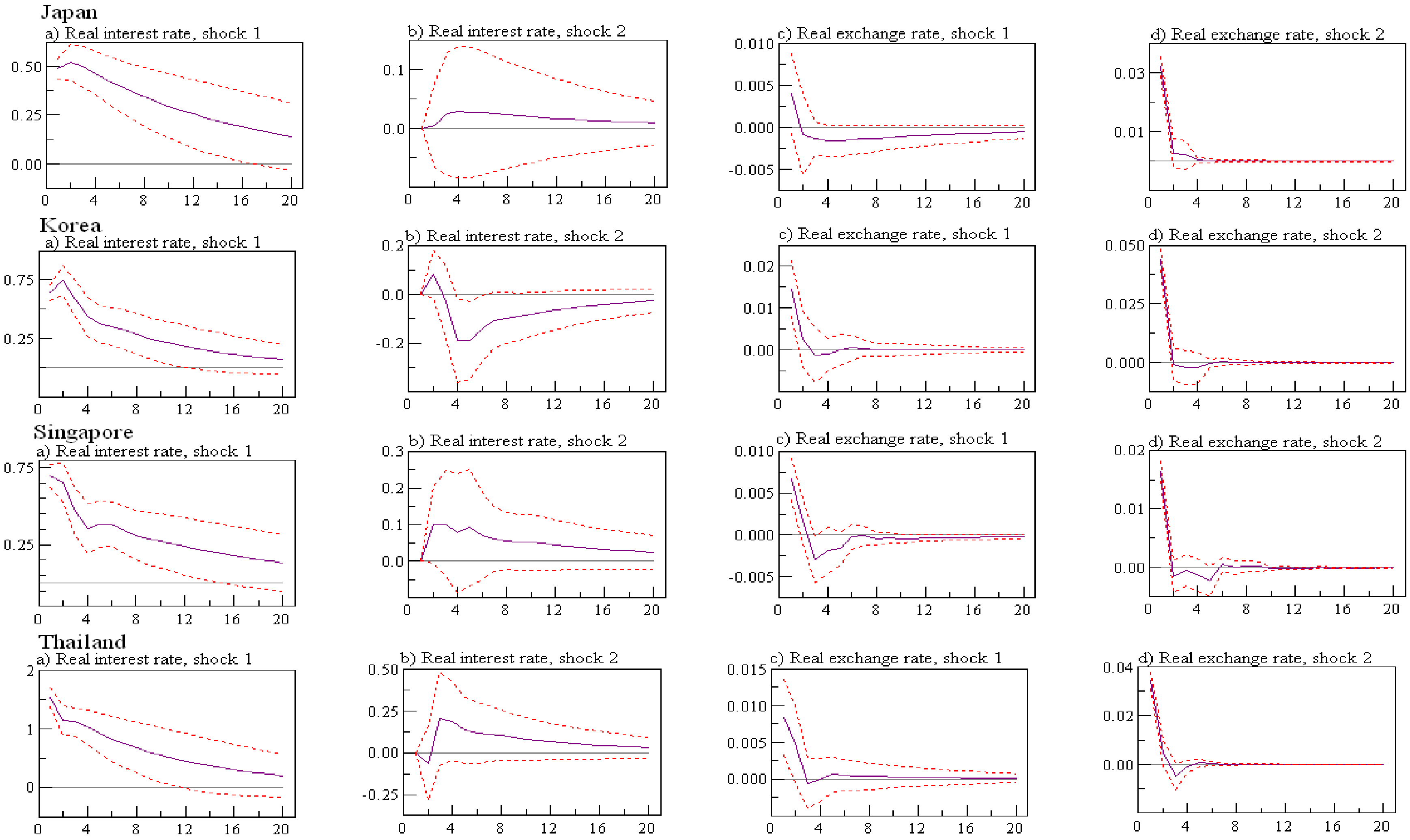


Figure 2 Impulse Responses Obtained from Choleski decompositions

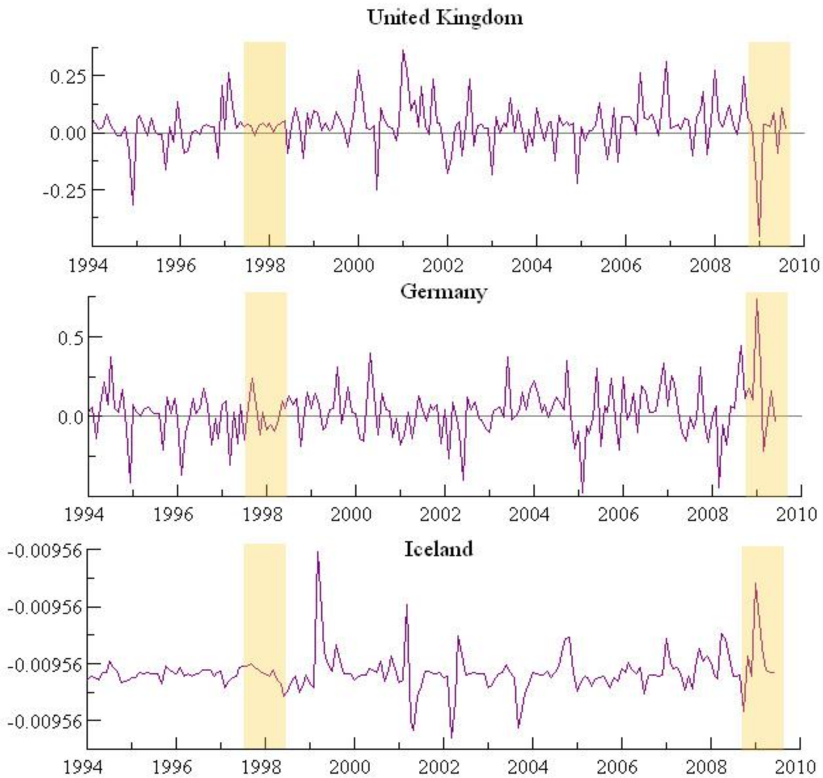


Figure 3 The Dynamic Conditional Correlation Structure between Relative Interest Rate Differentials and Real Exchange Rates: Europe

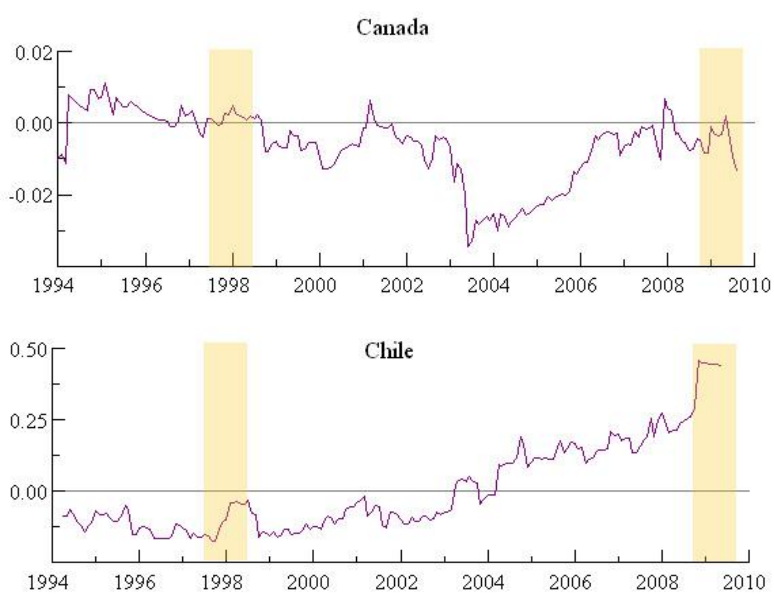


Figure 4 The Dynamic Conditional Correlation Structure between Relative Interest Rate Differentials and Real Exchange Rates: Canada and Chile

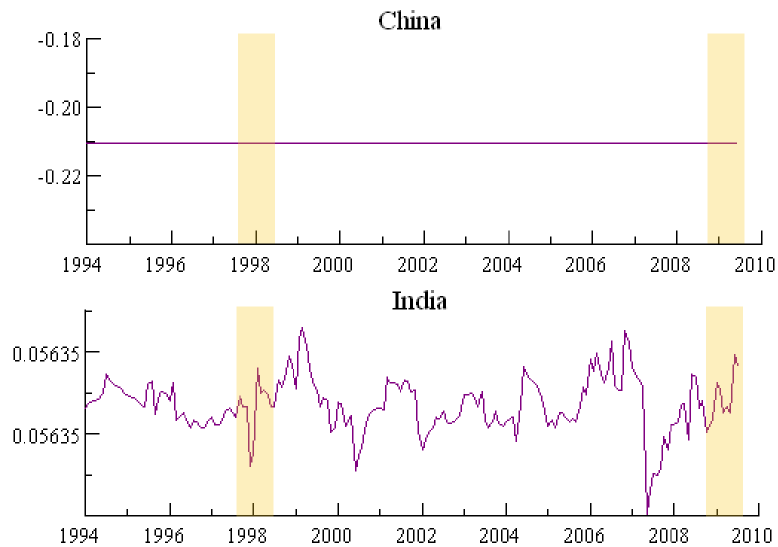


Figure 5 The Dynamic Conditional Correlation Structure between Relative Interest Rate Differentials and Real Exchange Rates: Emerging Markets

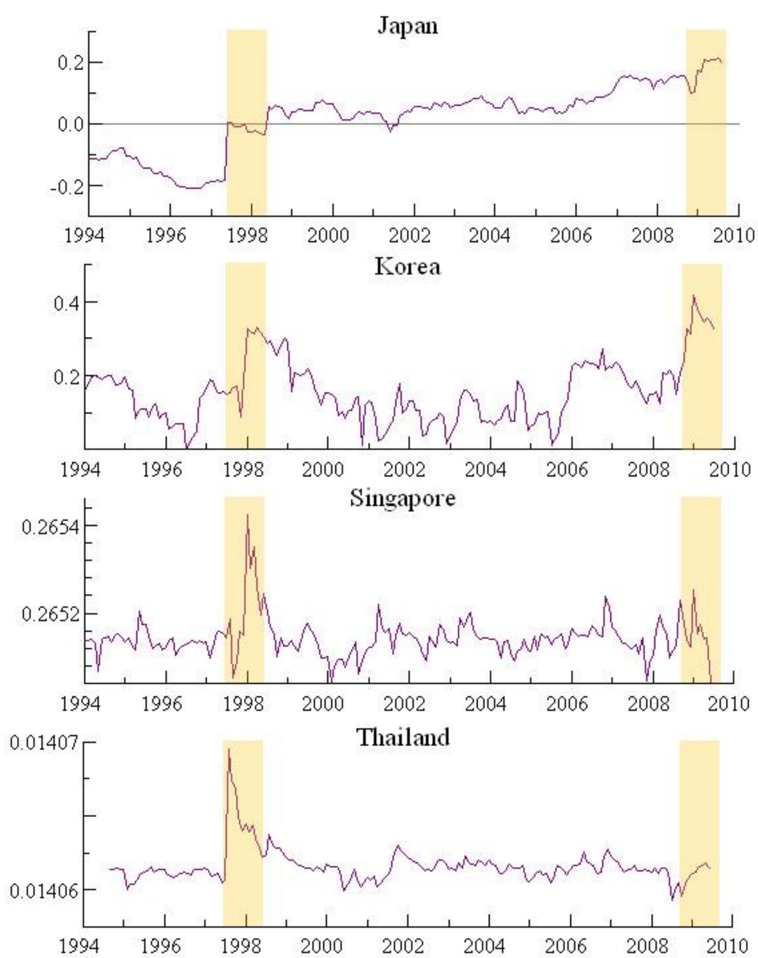


Figure 6 The Dynamic Conditional Correlation Structure between Relative Interest Rate Differentials and Real Exchange Rates: Asia