Dynamic Interactions of Stock Market and Foreign Exchange Market for Six OECD Countries during the US Financial Crisis

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Abstract

We investigate the dynamic relationship between stock returns and exchange rate changes for six OECD countries during and after the US financial crisis period. First, dynamic conditional correlations (DCCs) estimated from the DCC-GARCH model show negative DCCs (substitution effect) for stock returns and exchange rates changes in US and Japan while model provides positive DCCs (wealth effect) for stock returns and exchange rate changes in United Kingdom, Australia, and Canada for the sample period.

Second, DCCs for stock returns and exchange rates changes increase for all six countries (US and Japan: in absolute value) after the Lehman failure and remain high during the post-crisis adjustment period, i.e., dynamic link between two markets become stronger after the US financial crisis.

Third, using Bai-Perron test and Markov-Switching model, we investigate changing patterns of causality for different phases of crisis periods and it is shown that exchange rate changes cause stock return changes during the contagion period of the crisis in Australia, Canada, Japan, Switzerland and US, i.e., when volatility of (stock returns and) exchange rate changes are very high, exchange rate changes lead stock return changes. However, UK does not show any causal relationship at all.

Finally, it is shown that VIX index and TED spread increase conditional correlations between stock returns and exchange rate changes while CDS spread decrease conditional correlations.

Key words: GARCH, dynamic conditional correlation, wealth effect, substitution effect, Market-Switching causality test, VIX index, TED spread, CDS spread

JEL classification code:

I. Introduction

On September 15, 2008, Lehman Brothers Holdings, 4th largest investment bank in the US, declared bankruptcy. After two weeks, the Standard & Poor's 500 index plunged 106.85 points or 8.81%. The Lehman's failure becomes the symbol of the subprime mortgage crisis happened in 2008, which created unexpectedly huge shocks in global economy. Because the shocks caused fundamental changes in both stock market and foreign exchange market during the crisis, it is essential to understand the dynamic relationships between stock market and foreign exchange market during the crisis.

Many studies have reviewed the dynamic interactions between stock market and foreign exchange market in theoretical and/or empirical approaches. According to traditional "Flow approach" (Dornbush and Fisher:1980), on the one hand, the changes in domestic currency value may affect relative competiveness of export goods in international market, thereby increasing stock prices, i.e., change in exchange rates causes change in stock prices. On the other hand, stock price returns may give rise to change in domestic money demand through substitution effect or wealth effect, thereby affecting the value of domestic currency, i.e., change in stock prices leads change in exchange rates [Friedman (1988), Gavin (1989), and Choudhry (1996)]. "Portfolio-balance" or "Stock approach" [Branson (1983), Branson and Henderson (1985), and Frankel (1983)] claims that increase in domestic stock prices causes local currency appreciation since investors rebalance their portfolio. In this model, changes in stock prices cause appreciation of domestic currency.

To investigate the dynamic interactions between stock market and foreign exchange market, this paper focuses on the following research questions. First of all, we find phases of time varying correlations between stock market and foreign exchange market. While the advantages of GARCH-type model allow researchers to measure volatility in financial markets, the method of dynamic conditional correlations (Engle, 2002) enables time varying analysis between stock market and foreign exchange market. In this question, we derive dynamic conditional correlations (DCCs) for 6 OECD countries to find different phases of DCCs during the financial crisis. Whereas a number of previous studies adopt uniform phases for whole countries that are derived arbitrarily by researchers, we identify the phases by estimating unknown structural breaks of Bai and Perron (2003).

In addition, we also investigate changes in causal relationships between two markets. Using structural breaks derived from the Bai-Perron tests, we initiate the Granger causality test if stock market returns cause exchange rate changes for different phases of financial crisis spillover period. From the Granger causality test, we find that lead of exchange market to stock market becomes dominant during the crisis period in all countries, except UK. To figure out why causalities are changing over different phases of financial crisis, we use regime-switching causality test and it is shown that exchange rate changes lead stock returns when volatility of foreign exchange market is high.

Finally, to find transmission channels of two financial markets, we use dynamic conditional correlation with exogenous variables (DCCX) model of Min and Hwang (2011) and we find that exogenous variables, such as the implied volatility of S&P 500 index options (VIX), the implied volatility of foreign exchange rate between US dollar and Euro (FXV), the international interest difference of each country over LIBOR (TED), and CDS spread of each country (CDS), to determine the time varying correlations between stock market and foreign exchange market.

This paper is organized as follows. In Section 2, we review previous literatures about the interactions between stock market and foreign exchange market. Section 3 introduces DCC-MGARCH model and estimates DCCs for 6 OECD countries. Section 4 provides different phases in DCCs using the Bai-Perron tests and investigates changes in Granger-causality by using sub-samples from multiple structural breaks and Markov process. In Section 5, we analysis determinants of DCC in the DCCX model and the final section conclude this paper.

II. Literature Reviews

Studies on dynamic interactions of stock market and foreign exchange market can be classified into three different groups.

First group of studies try to evaluate the exchange rate exposure of multinational firms by testing ICAPM (International CAPM). Jorion (1991) examines the pricing of exchange rate risk in the US stock market, using two factor and multi-factor arbitrage pricing models. The evidence is presented that the relation between stock returns and the value of the dollar differs systematically across industries. Dumas and Solnik (1995) investigates whether exchange rate risks are priced in international asset markets using a conditional approach that allows for time variation in the rewards for exchange rate risk. The results for equities and currencies of the world's four largest equity markets support the existence of foreign exchange risk premium. Choi et al. (1998), using an unconditional and a conditional multi-factor asset pricing model, investigate whether exchange risk is recognized and priced in Japan and find that exchange risk is generally well-priced in Japan. They provide evidence, in the unconditional model, that the exchange risk is priced in both weak and strong yen periods when yen-US dollar exchange rate is used. Muller and Verchoor (2009), motivated by Bartov et al. (1996), investigate the impact of increased exchange rate variability on the stock return volatility of US multinationals by focusing on the turmoil periods around the major financial crises of the last decade: Mexico's float of the peso in December 1994, Argentina's financial crisis and its efforts not to devalue the Argentine peso in March 1995. By using a sample of 673 US-multinational firms with real operations in the crisis-contaminated countries, they find that the stock return volatility of US multinational firms increases significantly in the aftermath of a financial crisis, even relative to the increase in stock return volatility for other US firms belonging to the same industry sector and market capitalization class that are not active in the crisis countries.

Second group of studies focuses on the asymmetric interactions of two market using exponential generalized autoregressive conditional heteroscedasticity (EGARCH) model. Kanas (2000) investigates the relationship between stock returns and exchange rate changes using EGARCH model for the six industrialized countries. He finds (i) the evidence of spillovers from stock returns to exchange rate changes for all countries except Germany, (ii) spillovers from stock market to exchange market are symmetric; the effect of 'bad' news is indifferent with that of 'good' news and (iii) the volatility spillover from exchange rate changes to stock returns are not significant for all countries. Yang and Doong (2004) explore the nature of the mean and volatility transmission mechanism between stock and foreign exchange market for the G-7 countries and they find the asymmetric volatility spillover effect and show that movements in stock prices will affect future changes of exchange rate movements but not vice versa. In a more recent study, Walid et al. (2011) prove the evidence that exchange rate returns have an influence on stock market volatility in four emerging markets (Hong Kong, Singapore, Malaysia, and Mexico) by employing Markov-Switching EGARCH model. They also find the regime dependence between stock and foreign exchange markets and asymmetric reactions of stock price volatility to the innovation of the foreign exchange market.

Third group of studies focuses on causality test and cointegration analysis. Ajayi and Mougoue (1996), using an error correction model (ECM) of the stock price and exchange rate for the Big-eight countries, finds significant short-run and long-run feedback relations between the two financial markets, i.e., an increase in aggregate domestic stock price has a negative short-run effect and positive long-run effect on domestic currency value. However, currency depreciation has negative short-run and long-run effect on the stock market (April 1985-July 1991). Granger et al. (2000) investigate causality and vector autoregressive (VAR) analysis using Asian flu data. They find that exchange rates lead stock prices in Korea, but stock price lead exchange rates in Philippines. Whereas they find feedback relations from Hong Kong, Malaysia, Singapore, Thailand and Taiwan, they cannot find any patterns in Japan.

Nieh and Lee (2001), using the cointegration analysis, find that there is no long-run significant relationship between stock prices and exchange rates in the G-7 countries. However, there is short-run (one-day) significant relationship in several countries. Lean et al. (2005) study the cointegration and the bivariate causality relationship between exchange rates and stock prices on the seven Asian countries badly hit by the Asian Financial Crisis. Their empirical results show that, before the 1997 Asian Financial Crisis, all countries, except the Philippines and Malaysia, experienced no evidence of Granger causality between the exchange rates and the stock prices. However, the causality, but not the cointegration, between the capital and financial markets appeared to become strong during the Asian Financial Crisis period. Surprisingly, after the 911-terrorist-attack, the causality relationship between the two markets returned to normal as in the pre-Asian-crisis period and the cointegration relationship weakened between exchange rates and stock prices. Phylaktis and Ravazzolo (2005) study the long-run and short-run dynamics between stock prices and exchange rates and the channels through which exogenous shocks impact on these markets by using cointegration methodology and multivariate Granger causality tests. They apply the analysis to a group of Pacific Basin countries over the period 1980-1998 and conclude that stock and foreign exchange markets are positively related and the US stock market acts as a conduit for these links. Kanas (2005) uses Markov-Switching VAR model in order to explore the linkage in volatility regimes between the Mexican currency market and six emerging equity markets. The evidence supports that the probability of the Mexican currency market being in the high-volatility regimes causes the probability of equity markets in Mexico, Brazil, Argentina, and Hong Kong being in the high-volatility regime.

III. DCC-MGARCH Model and Estimation

A. Data and Descriptive Statistics

In the empirical study, we use daily data of the stock prices, the exchange rates, the interest rates, CDS spreads, the stock volatility index, and FX volatility index for 6 OECD countries: Australia, Canada, Japan, Switzerland, UK and US. We collect data from Bloomberg and Datastream, which cover from January 2, 2006 to December 31, 2010. Data Appendix presents detailed sources and definitions of each data used in this study. The exchange rates show the purchasing power of local currency in terms of US dollar. For US, the quotation is Euro per unit of US dollar. While Figure 1 plots exchange rates and their returns, Figure 2 depicts stock index and stock price returns for 6 countries.

[Figure 1, 2 about here]

The figures reveal that the volatility of both the stock price return and the exchange rate return increased rapidly during the 2008 US financial crisis period. Also, it is shown that there are huge crashes in national stock index for all markets around middle of 2008. However, the movements of exchange rates during the same period seem to be different among countries.

Table 1 shows the descriptive statistics for exchange rate returns and stock returns. From the Panel A of Table 1, we can see that UK and US have negative sample mean of -0.7 % and -1 % in their exchange rate returns, while Japan has the maximum mean value of 3.6 %. Variance is highest in Australia (standard error of 1.104) but lowest in US (standard error of 0.686). All countries' return data reveal heteroscedasticity and are not normally distributed. Panel B presents summary statistics for the stock market returns. During the sample period, Canada has the highest mean returns (0.014 %) while Japan has the lowest mean return (-0.047 %). On the other hand, volatility is highest in Japan but lowest in Switzerland. Similar to exchange rate returns, all countries show heteroscedasticity in their stock return series.

[Table 1 about here]

B. Unit Root Test and Cointegration Test

Whereas traditional Augmented Dickey–Fuller test (ADF) or Phillips-Perron (PP) tests of unit root do not allow the possibility of abrupt changes in series, the unit root tests with the structural break are able to take account of them. Since our study focuses on the subprime mortgage crisis in 2008, which caused radical changes in financial market, it is rational to include a structural break in testing the existence of unit root. By employing the Lagrangian multiplier (LM) unit root test of Lee and Strazicich (2004), we try to analyze the stationarity of each series in crash model, which allows only change in intercept, and break model, which includes change in trend as well as in intercept, as following:

(1) $$y_t = \alpha_0 + \alpha_1 t + \alpha_2 B_t + \alpha_3 B_t t + \beta y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_t,$$

where t, B_t, and e_t are time trend, the change in intercept, and error term, respectively. Equation (1) describes break model, and without fourth term, which denotes the change in trend, it implies crash model.

Table 2 shows that we cannot reject the null hypothesis of nonstationarity in the level of the exchange rate and the stock price in all countries, but reject in their first differences under 1% significance level. Thus, we conclude that the exchange rate and the stock price in all countries are I(1) process.

[Table 2 about here]

In order to consider the long-term relationship between two financial markets, we analyze the cointegration test using the methodology of Gregory and Hansen (1996). Similar to the unit root test, Gregory-Hansen tests is advantageous to reflect the structural break. Table 3 depicts the result of the cointegration test in the following equation:

(2) $$y_{1t} = \mu_1 + \mu_2\varphi_{t\tau} + \beta t + \alpha_1 y_{2t} + \alpha_2 y_{2t}\varphi_{t\tau} + e_t,$$

where $\mu_1, \mu_2, t,$ and e_t signify the intercept before the break, the change in the intercept at the break, time trend, and error term, respectively, and $\varphi_{t\tau}, \alpha_1, \alpha_2,$ and β denotes the coefficient of level shift, the cointegrating slope before the break, the change in the slope, and time trend respectively.

[Table 3 about here]

Depending on which term is included in the model, we divide the results into model C (constant), C/T (constant and trend), C/S (constant and slope), and C/T/S (constant, trend, and slope). All models include LIBOR to control the international liquidity in the cointegrating system. According to Table 3, it is shown that for Australia, Canada, Japan, and UK, the null hypothesis of no cointegration between the stock price and the exchange rate is rejected with any of four different specifications of the test. On the other hand, we cannot reject the null hypothesis for Switzerland and US.

C. DCC-MGARCH Model

1. Model Specification

Engel (2002) proposes the dynamic conditional correlations model to estimate conditional covariance in the Multivariate GARCH (MGARCH) model. This model is advantageous by reducing the number of parameters in variance equations and allowing time varying correlations in volatilities between variables to be derived. The conditional covariance matrix in the DCC specification can be written as:

(3) $$H_t = D_t R_t D_t,$$

where $D_t = diag(\sqrt{h_{i,t}})$ is $m \times m$ diagonal matrix, where D_t, following the univariate GARCH(p, q) model, is defined as:

(4) $$h_{i,t} = \omega_i + \sum_{p=1}^{P_i} \alpha_{ip} \varepsilon_{i,t-p}^2 + \sum_{q=1}^{Q_i} \beta_{iq} h_{i,t-q},$$

and $R_t = \{\rho_{ij}\}_t$ is the time varying conditional correlation matrix:

(5) $$R_t = Q_t^{*-1} Q_t Q_t^{*-1},$$

where $Q_t = (1 - \sum_{m=1}^{M} \alpha_m - \sum_{n=1}^{N} \beta_n) \bar{Q} + \sum_{m=1}^{M} \alpha_m (\varepsilon_{t-m} \varepsilon'_{t-m}) + \sum_{n=1}^{N} \beta_n Q_{t-n}$, and $\bar{Q}$ is the unconditional covariance of the $\varepsilon_{i,j}$ and $\varepsilon_{i,j}$, and $Q_t^* = diag\{\sqrt{q_{i,i}}\}$ is a diagonal matrix contains the square root of the diagonal elements of Q_t.

The correlation estimator of Q_t is:

(6) $$\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t} q_{jj,t}}}, \text{ for } i, j = 1, 2, \ldots, \text{n and } i \neq j.$$

For maximizing the log-likelihood function:

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

we can get the estimation of the DCC model.

In this study, we develop the DCC-MGARCH(1,1) of stock price returns and exchange rate returns. The mean equations are defined in the following manner:

(8) $$STR_t = \gamma_0 + \sum_{j=1}^{K} \gamma_{1,j} STR_{t-j} + \sum_{j=1}^{K} \gamma_{2,j} FXR_{t-j} + \varepsilon_{1,t},$$

(9) $$FXR_t = \lambda_0 + \sum_{j=1}^{K} \lambda_{1,j} STR_{t-j} + \lambda_2 FXR_{t-1} + \varepsilon_{2,t}, .$$

where STR_t and FXR_t are stock price returns and exchange rate returns, and $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are heteroscedastic error terms of each equation. In the conditional variance equations, we allow the model to include asymmetric effects based on a GJR threshold type formulation (Glosten et. al. (1993)) and EGARCH (Nelson (1991)). It is assumed that the volatility raises proportionally more following negative shocks than positive shocks. Thus, the conditional variance equations can be written as:

(10) $$h_{STR,t} = c_1 + \alpha_1 \varepsilon_{1,t-1}^2 + \beta_1 h_{STR,t-1} + d_1 \varepsilon_{1,t-1} I_{\varepsilon_{t-1}<0} + \upsilon_{1,t},$$

(11) $$h_{FXR,t} = c_2 + \alpha_2 \varepsilon_{2,t-1}^2 + \beta_2 h_{FXR,t-1} + d_2 \varepsilon_{1,t-1} I_{\varepsilon_{t-1}<0} + \upsilon_{2,t},$$

where $h_{STR,t}$ and $h_{FXR,t}$ are volatility terms of stock price returns and exchange rate returns, $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are from Equation (8) and (9), and $\upsilon_{1,t}$ and $\upsilon_{2,t}$ u, follows white noise processes. The fourth term of Equation (10) and (11) implies asymmetric effects; I takes unity, when the innovative shock on ε_{t-1} is negative, and zero otherwise.

2. Estimation of DCC-MGARCH Model

Estimation results from the DCC-MGARCH model presented in Table 4. We observe that lagged exchange rate returns in the stock return mean equation are negative and significant for Japan and Switzerland, while positive and significant for Australia and Canada. However, it is shown that lagged exchange rate returns in the stock return mean equation are insignificant for UK and US. On the other hand, the lagged stock returns in the exchange rate return mean equation is negative and significant for US, positive and significant for Canada, but insignificant for others.

[Table 4 about here]

Looking at the variance equations, we find that all of the coefficients for the squared error and the lagged variance are positively significant in both stock return and exchange return equation for 6 countries. This validates the appropriateness of the DCC-GARCH specification. Positively significant coefficients of A(1) and A(2) support the idea that the shocks from each market may boost volatility in that market. Large value of estimated coefficient in the lagged own variance term indicate that shocks have persistent impact. Moreover, asymmetric terms in the conditional variance of stock market returns show all positive and significant association to their volatility, implying that negative shocks in stock market may cause larger volatility than positive ones. On the other hand, asymmetric effects in foreign exchange markets are significant only in Australia, Canada, and UK. Those are negatively significant in Japan, while not significant in Switzerland and US.

3. DCCs of 6 OECD Countries

Table 5 presents the summary statistics for DCCs between stock market returns and foreign exchange returns in 6 countries. We can see that Australia (0.212), Canada (0.444) and UK (0.245) has a positive mean value of DCCs, while that for Japan (-0.305), Switzerland (-0.035) and US (-0.256) are negative on average. However, all DCCs show heteroscedasticity and deviation from normality.

[Table 5 about here]

Figure 3 shows estimated DCCs of 6 OECD countries. Consistent with Table 5, DCCs are mostly negative for US and Japan. However DCCs of Switzerland negative before the crisis but become positive after the US financial crisis. Other three countries (Australia, Canada and United Kingdom) have positive DCCs throughout the period.

[Figure 3 about here]

From Figure 3, we can see that DCCs increase abruptly near the Lehman failure (contagion phase of the crisis defined in the next section) for all countries. Since DCCs are negative in US and Japan, their absolute values of DCCs increase during the contagion period. This implies that substitution effects (Friedman (1988), and Choudhry (1996)) are stronger than wealth effect in US and Japan for the most of the periods. However, if we focus on the contagion and post-crisis adjustment phases of Switzerland, DCCs become positive and this implies that huge decrease in stock returns cause decrease in exchange rate returns (dominance of wealth effect). On the other hand, United Kingdom, Canada, and Australia have positive DCCs for the most of the periods and this implies that wealth effect dominates substitution effect in those countries.

IV. Changing Patterns of Dynamic Interactions

In this section, first of all, we estimate different phase of financial crisis for 6 OECD countries by employing Bai-Perron test of unknown structural breaks for each country's DCCs. Using structural breaks found by Bai-Perron test, we investigate changing patterns of Granger causality between stock market and foreign exchange. To find robustness of structural breaks, we analyze GARCH with dummy variables model. Finally, we use Markov regime-switching causality test to find out why exchange rate changes lead stock returns during the contagion phase of the financial crisis.

A. Structural Breaks in DCCs: Bai-Perron Test

To investigate changing phases of interactions between two financial markets during the US financial crisis, we estimate unknown structural breaks of DCCs using Bai-Perron test (Bai and Perron, 1998). For this test, we use the equation (12):

$$y_t = c_j + \beta_j y_{t-1} + \varepsilon_t \tag{12}$$

where $t = T_{j-1}+1, \ldots, T_j$, $j = 1, \ldots, m+1$, $T_1, \ldots, T_m$ are the break points, and m is the number of breaks. In this model, we assume all the coefficients are subject to change over time. This method sequentially proceeds the test by increasing the number of breaks. In other words, if the test finds one structural break in the whole sample period, then it repeats the same process in two subsamples, before and after the break. This recursive process continues until any subsamples do not have significant structural break.

[Table 6 about here]

We set the number of maximum structural break as 6 and the shortest distance between two breaks are 60. Table 6 shows the estimation results of the Bai-Perron test for DCCs. From Table 6, Canada and Japan has 4 structural breaks while other countries have 3 structural breaks. From Table 6, we can see that all countries have a structural break around September and October of 2008, which may be caused by the Lehman failure in the mid-September. Using those structural breaks in DCCs, we divide the sample into three distinctive sub-periods, i.e., before-crisis period, contagion period and post-crisis adjustment period. For Japan, we find a break at January 5, 2007 when the NIKKEI plunged 10.72% in December 29, 2006. For US, we find a break at August 9, 2007 where DJIA fell 400 points in that day. On the other hand, the break at January 29, 2009 in US and that at January 7, 2009 in Australia matches the US government and Australian Senate approval of a stimulus package.

B. Sub-Sample Granger Causality Test

Table 7-B reports Granger causality test of the stock returns and exchange rate changes for each sub-periods.

[Table 7 about here]

From Table 7, during the pre-crisis period, US shows the lead of stock returns and Japan shows the lead of exchange rate changes while Australia and Switzerland have bi-directional causality. However, during the contagion period, Australia, Canada, Japan, and Switzerland show the lead of exchange rate changes but US and UK do not show any causality at all. Finally, during the post-crisis adjustment period, Australia shows the lead of exchange rate changes and US returns to their pre-crisis period patterns of lead of stock returns and Japan shows bi-directional causality. However, Canada, Switzerland and UK do not show any causal relations at all. From this analysis, we can say that the lead of exchange rate changes is prominent during the contagion period of the crisis. In other words, we can say that the lead of foreign exchange market increases significantly after the US financial crisis implying that across-the-border capital flows (flight for quality) increase significantly after the US financial crisis and this increase the volatility of exchange rates and those changes in exchange rates are priced in domestic stock market.

From Table 7-A, during the pre-crisis period, advanced economies as a whole, stock returns lead foreign exchange returns 4 out of 12 sub-periods while foreign exchange returns lead stock returns 2 out of 12 sub-periods. However, after the October 2008, stock returns lead foreign exchange returns 1 out of 14 sub-periods while foreign exchange returns lead stock returns in 6 out of 14 sub-periods.

C. Markov-Switching Granger Causality Test

While Granger causality test does explain causal directions between two variables it cannot explain why causal directions are changing in different phases of financial crisis. By applying the regime switching approach (Hamilton (1989)), it is possible to find under what situation (regime) exchange changes lead stock returns or vice versa.

1. Model Specification

In this section, we investigate the Markov-Switching Granger causality test with the Markov chain Monte Carlo (MCMC) method (Krolzig (1997)):

(13) $$STR_t = \gamma_0^{(s_t)} + \sum_{j=1}^{K} \gamma_{1,j}^{(s_t)} STR_{t-j} + \sum_{j=1}^{K} \gamma_{2,j}^{(s_t)} FXR_{t-j} + \varepsilon_{1,t},$$

(14) $$FXR_t = \lambda_0^{(s_t)} + \sum_{j=1}^{K} \lambda_{1,j}^{(s_t)} STR_{t-j} + \lambda_2^{(s_t)} FXR_{t-1} + \varepsilon_{2,t},$$

(15)
$$\begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} \sim i.i.N(0, \Sigma^{(s_t)}),$$

where s_t is an indicator variable for each regime of the system at time t and takes either value in the set {1, 2}, and covariance matrices, $\Sigma^{(s_t)}$, depend on the regimes $s_t = 1, 2$. Moreover, the probability transition from one state to another is governed by the probability transition matrix defined as:

(16)
$$P = \begin{bmatrix} p_{11} \; p_{12} \\ p_{21} \; p_{22} \end{bmatrix}.$$

When $s_{t-1} = j$, the time-invariant transition probability of moving to $s_t = i$ can be written p_{ij}.

There are two advantages of using the MCMC method. First of all, the hidden states of the MCMC method could be interpreted as high variance regime or low variance regime. In this way, we can analyze how the causality between the stock returns and the exchange rate changes is changing in the crisis period (the high variance regime) and the non-crisis period (the low variance regime). Second, Gibbs sampling[1] (Casella at al., 1992: Kim et al., 1999) allows us to be able to estimate traditional ML estimation with exponentially increased number of parameter. In the estimation procedure, we first use the Forward Filter-Backward Sampling (FFBS) algorithm (Chib (1996)) to draw the likelihoods across regimes. Given the

[1] This sampling approach is clearly advantageous, since it enables us to estimate several low-dimensional estimations, instead of one high-dimensional function. To make sure that the results from the Gibbs sampling indeed close enough to a random sample from the joint distribution, we run 5,000 simulations and drop out first 2,000 results as burn-ins.

regimes, Gibbs sampling[2] produces the simulations of following parameters in the function:

(17) $$f_i\left(\theta_i \middle| \theta_{j\neq i}, X, M\right),$$

where θ_i is the model parameter to be estimated, *X* is the data, and *M* is the model. Equation 17 is defined as the conditional distribution of the parameter θ_i. In order to derive the conditional posterior distributions, we assume the prior distribution for the model to be the Wishart distribution, which is a multi-dimensional version of the chi-square distribution. By using the Bayesian inference in the following equation, we derive the conditional posterior distributions:

(18) $$f\left(\theta \middle| X\right) = \frac{f\left(X \middle| \theta\right) P(\theta)}{f\left(X\right)},$$

where $P(\theta)$ is the prior of the Wishart distributions. The posterior distribution is a multivariate normal distribution which belongs to the same family of the prior distribution, indicating that the Wishart distribution is the conjugate prior distribution.

From the earlier procedures, it is possible to obtain the point estimation of means and corresponding variances for the parameters, thereby enabling us to test the significance by using *t*-statistics.

2. Estimation of Markov-Switching Granger Causality Test

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[2] This sampling approach is clearly advantageous, since it enables us to estimate several low-dimensional estimations, instead of one high-dimensional function. To make sure that the results from the Gibbs sampling indeed close enough to a random sample from the joint distribution, we run 5,000 simulations and drop out first 2,000 results as burn-ins.

The estimation results of Markov-Switching VAR models for 6 advanced markets are reported in Table 8. First of all, we check if estimated regimes are in line with the presupposed division of the whole sample period into the high variance period and the low variance period. In Table 8, except Switzerland, all the elements of the estimated covariance matrix between the stock market returns and the exchange rate changes, i.e., COV(i, j) in the third panel of table 9, show significant results for all countries. Among all variances and covariances that are significant, the coefficients in the high variance regime are always greater than those in the low variance regime, implying that the regimes are well divided into the high variance regime and low variance regime during the US crisis around 2008.

[Table 8 about here]

In Figure 4, we show the estimated smoothed probabilities[3] of the high variance regime (solid line) to compare those probabilities with the market volatilities[4] derived from the DCC-MGARCH model in the section 3 (two dotted lines).

[Figure 4 about here]

While volatilities of stock market and foreign exchange market move together, the smoothed probabilities of high variance regime can successfully identify (local or global) peak points of

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[3] The smoothed probability at *t*, given data through the end of sample T , is defined as follows:

$$p_{t|T}^{(s_t=j)} = p_{t|t}^{(s_t=j)} \sum_{i=1}^{M} p_{ij} \frac{p_{t+1|T}^{(s_{t+1}=i)}}{p_{t+1|t}^{(s_{t+1}=i)}},$$

where M is the number of possibility for each S_t , $p_{t|t}$ is the filtered probability at *t* give data through *t*, $p_{t+1|t}$ is predicted probability at *t+1* given data through *t*.

[4] The values of volatilities are converted into a logarithm.

the GARCH volatilities. To check if smoothed probabilities of MCMC moves together with the market volatilities estimated by GARCH model, we run and report a simple regression of market volatilities on smoothed probabilities in table 9.

[Table 9 about here]

From table 9, we can see that the log of the volatilities of stock returns and the exchange rate changes are highly significant in explain the movement of smoothed probabilities for all 6 countries. In other words, we can define high variance regime is a state when market volatilities (estimated by GARCH) are high and low variance regime is the state when market volatilities are low.

To test Granger causality with regime switching model, we utilize the Bonferroni and Scheffe statistics (Savin (1980), and Psaradakis et al. (2005)). For the Bonferroni procedure, *B* is defined as $t_{\delta/2}$, where $\delta = \alpha/(2\times q)$, α is the significance level, and *q* is the number of parameters in the block. For the Scheffe procedure, S is defined as $\left(q\times F\left(q,T-k\right)\right)^{1/2}$, where $T-k$ is the number of free variables.

Table 10 reports the Bonferroni statistic and the Scheffe statistic for testing the null hypotheses of the Markov-Switching Granger causality. It is shown that the Markov-Switching Granger causality results of the high variance period are consistent with the results of subsample VAR during the contagion period (the darkened area in Table 7), except for the US exchange market. It is shown that two (Australia and Japan) out of six countries show the Granger causality from the exchange market to the stock market in the low variance period, 5 out of 6 countries show the Granger causality from the exchange market to the stock market in the high variance period. In addition to that, the lead of the stock market observed in Switzerland during the low variance period disappears in the high variance period and consequently no country reports the lead of stock market over the exchange market in the high variance period. Summarizing, we can confirm that the dominance of the foreign exchange market over the stock market during the contagion phase of the crisis period. In other words, when market is relatively volatile, the exchange rates changes lead stock return changes but not vice versa.

[Table 10 about here]

D. GARCH with Dummy Variables Model

To check the validity of changing phases of correlations and volatilities analyzed in section IV.A – section IV.C., we use GARCH with dummy variables model.

1. Model Specification

To validate the changing phases of DCCs in previous sections, we employ GARCH(1,1) model with time dummy variables, which is determined by different structural breaks in Table 6. Since we focus on the US financial crisis, we drop the structural breaks that happened before the US financial crisis. The model can be written as the following mean equation (19) and the conditional variance equation (20):

$$\rho_t = \gamma_0 + \gamma_1 \rho_{t-1} + \sum_{k=1}^{n} \tau_{1,k} DM_k + \varepsilon_{\rho,t}, \tag{19}$$

$$h_{\rho,t} = c + \alpha\varepsilon_{\rho,t-1}^{2} + \beta h_{\rho,t-1} + \sum_{k=1}^{n}\tau_{2,k} DM_k + \upsilon_{\rho,t}, \tag{20}$$

where, $n = 4$ for Canada and Japan, 3 otherwise. DM_k is a time dummy variable for regime k.

2. Estimation of GARCH with Dummy Variables Model

Table 11 reports estimation results for GARCH with dummy variables model. From Table 11, we can see that estimated coefficients for dummy variables are highly significant for most of the cases implying that interactions between stock returns and exchange rate changes are changing over time.

[Table 11 about here]

From the estimates of DM_1-DM_4, we can classify 6 OECD countries into three distinct groups of countries. First of all, DCCs of Australia, Canada and United Kingdom are positive for the whole sample period and this implies that wealth effects are greater than substitution effect in those countries. At the same time, DCCs of Switzerland are positive during and after the contagion period. For this group of countries, DCCs increase with the US financial crisis and the sign of estimated coefficients of dummy variable (DM_2) for the contagion period are positive and significant except Australia. However, Japan and US show that DCCs between stock returns and exchange rate changes decrease (increase in absolute value) throughout the crisis period and the rate of decrease is accelerating as they move from pre-crisis period to contagion period (DM_2) and from contagion period to post-crisis period (DM_3). Since those countries' DCCs are negative for the most of the period, their conditional correlations between stock returns and exchange returns strengthens during the contagion and post-crisis period and this implies that substitution effects are stronger than wealth effect. However, if we focus on early stage of contagion period in US, conditional correlations are positive and this implies that huge decrease in stock returns caused dominance of wealth effect at the beginning of the crisis. Finally, Switzerland has significant and positive DM_2 and DCCs are positive in contagion phase of the US financial crisis and remain positive during the post-crisis adjustment period implying that wealth effect dominates substitution effect in the post-crisis adjustment period. From the estimated variance equations in the lower panel, we can also confirm that volatilities are changing from one period to the other and this validates our analysis of "changing phases of correlations" between the stock returns and exchange rate changes during the US financial crisis period.

V. Determinants of DCC between Stock Market and Foreign Exchange Market

A. DCCX Model and Explanatory Variables

DCCs derived from DCC-MGARCH model between stock price returns and exchange rate returns in Equation (6) represent the size of the conditional correlation. In this setting, it is important to identify which factors may determine the conditional correlation between stock market and exchange market. Similar to DCCX model of Min and Hwang (2010), we estimate the determinants of DCC in such function:

$$|\rho_{i,t}| = \frac{\exp(\beta' X_{i,t})}{1+\exp(\beta' X_{i,t})}, \tag{21}$$

where $\rho_{i,t}$ and $X_{i,t}$ are DCC and explanatory variables to DCC of each country. We take absolute values of DCC because we investigate the effect of exogenous variables on the strength of its comovement regardless of the direction. This logistic function is to circumvent the restriction on DCC, being $0 \le \left|\rho_{i,t}\right| \le 1$. Also, $(K \times 1)$ vector X_t includes VIX, FX VIX, TED spread and CDS spread[5]. Therefore, the random effect model is defined as:

$$l\left(\left|\rho_{i,t}\right|\right) = \beta_0 + \beta_1 VIXUS_t + \beta_2 FXVUS_t + \beta_3 TED_{i,t} + \beta_4 CDS_{i,t} + u_i + e_{i,t} \quad (22)$$

where $l\left(\left|\rho_{i,t}\right|\right)$ is the transformed DCC and u_i and $e_{i,t}$ are country-specific effect and error term that follows white noise process.

Since Kanas (2000) argue that the strength of volatility spillovers seems to increase in the crisis period, the VIX and FXV are included in the model. CDS spread implies global macroeconomic factors as well as country specific risk factors (Longstaff et al. (2011)) and plays a key role in credit contagion (Jorion and Zhang (2007)). Therefore, the model includes CDS spread to take into account risk premium in each country to determine the conditional correlation. TED spread, defined by the interest rate of each country less LIBOR, is included to consider the effect of liquidity risk on the conditional correlations. Higher TED spread implies tighter liquidity in economy (Lashgari (2000), and Cheung et al. (2010)).

B. Estimation of DCCX Model

Table 12 shows the test results of unit root and cointegration. In panel A of Table 12, we cannot reject the null hypotheses of nonstationarity for all variables. However, we find the cointegrated relations among variables in panel B of Table 12.

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5 Data Appendix provides the detailed description of variables and their sources.

[Table 12 about here]

Table 13 reports the estimation results of DCCX model for 6 countries. First of all, it is shown that the VIX index increase DCCs of stock returns and exchange rate changes. This means that stock market volatility can spillover into the foreign exchange market as shown by Kanas (2000). Second, Foreign exchange market volatility measured by FXV is insignificant. Third, TED spread, which is a measure of liquidity, increases DCCs of stock returns and exchange rate changes. This is consistent with the notion that increased TED spread, or worsened liquidity would lower the stock market returns which then depreciate domestic currency. In other words, the TED spread can strengthen the DCCs between stock price returns and foreign exchange returns. Finally, CDS spread has negative and significant association with DCCs and this is consistent with Bystrom (2005) that increased CDS spread associated with increased volatility in stock market may strengthen the conditional correlation.

[Table 13 about here]

VI. Conclusions

In this paper, we investigate the changing patterns of dynamic correlations between stock market returns and exchange rate changes for the six OECD countries for the period of January 2006-December 2010. First of all, using DCC-MGARCH model, we estimate conditional correlations of stock market returns and exchange rate changes. Estimated DCCs show that the substitution effect dominates wealth effect in US and Japan while the wealth effect is stronger in United Kingdom, Canada, and Australia. Second, using Bai-Perron test and Markov-Switching model, we estimate different phases of regime switching corresponding to each sovereign country's financial markets during the crisis. Also, from Granger causality tests, we find that exchange rate changes Granger cause the stock returns during the contagion phase of the US financial crisis for Australia, Canada, Japan, Switzerland, and US. Third, using GARCH with dummy variables model, we confirm the changing phases of dynamic correlations between the stock returns and exchange rate changes. It is shown that while DCCs between stock returns and exchange rate changes are increasing in US and Japan after the Lehman failure, those for Canada, United Kingdom and Australia decrease during the contagion period but increase during the herding or post-crisis adjustment period. Finally, using DCCX model, we report that VIX index and TED spread increase conditional correlations of two markets, but CDS spread decreases the dynamic correlations between stock returns and exchange rate changes.

Contrary to previous studies which fail to reflect the difference in macroeconomic factors of each sovereign market, our empirical study identifies the framework for different phases of dynamic linkages on FX markets and equity markets for 6 OECD countries during the financial crisis in 2008. For investors and portfolio managers, our results provide better chance to guard against their portfolios from the market turmoil in the future and consequently improve financial strategies. Furthermore, this study can provide policy makers with insights into the transmission channels that affect the strength of time varying correlations between stock market and foreign exchange market and then allow them to accommodate the policy to stabilize the financial market throughout the preemptive and active responses against shocks in the market.

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TABLE 1

Descriptive Statistics

Table 1 reports the descriptive statistics of data. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Panel A. FX Market Returns

	Australia	Canada	Japan	Switzerland	UK	US
Observations	1304	1304	1304	1304	1304	1304
Sample Mean	0.025	0.012	0.036	0.026	-0.007	-0.010
Standard Error	1.104	0.756	1.037	0.702	0.698	0.686
t-Statistic (Mean=0)	0.831	0.564	1.248	1.349	-0.386	-0.500
Skewness	-0.729***	-0.214***	0.691***	0.235***	-0.512***	-0.152**
Kurtosis (excess)	12.021***	2.400***	6.873***	2.562***	2.796***	2.256***
Jarque-Bera Statistics	7967.0***	323.0***	2670.6***	368.5***	481.6***	281.4***
Autocorrelation Test						
Ljung-Box Q Test	22.036***	11.529**	19.764***	3.116	4.333	1.289
Heteroscedasticity Test						
ARCH(15) LM Test	39.23***	25.691***	22.896***	8.879***	22.432***	17.564***

Panel B. Stock Market Returns

	Australia	Canada	Japan	Switzerland	UK	US
Observations	1304	1304	1304	1304	1304	1304
Sample Mean	0.000	0.014	-0.047	-0.013	0.004	0.001
Standard Error	1.334	1.457	1.605	1.317	1.447	1.546
t-Statistic (Mean=0)	0.002	0.335	-1.048	-0.345	0.093	0.013
Skewness	-0.446***	-0.675***	-0.205***	0.116*	-0.093	-0.236***
Kurtosis (excess)	4.170***	8.237***	7.068***	7.866***	7.324***	9.013***
Jarque-Bera Statistics	987.7***	3785.3***	2723.7***	3364.6***	2916.6***	4426.3***
Autocorrelation Test						
Ljung-Box Q Test	8.584	37.604***	11.482**	37.842***	44.642***	37.016***
Heteroscedasticity Test						
ARCH(15) LM Test	26.292***	46.934***	55.431***	41.031***	30.749***	44.907***

TABLE 2

Result of Unit Root Test

Table 2 reports the LM unit root test with a structural break. The optimal number of lags in each series is determined by Akaike information criterion (AIC). '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Country	Variable	Crash Model			Break Model		
		Break Point	# of lags	*t*-statistics	Break date	# of lags	*t*-statistics
Panel A. Level							
Australia	Exchange Rate	2008:10:23	7	-1.878	2008:09:12	7	-2.57032
	Stock Index	2008:10:09	0	-1.500	2008:07:02	0	-2.20266
Canada	Exchange Rate	2008:10:21	9	-2.002	2008:10:03	9	-2.52661
	Stock Index	2008:10:24	10	-1.583	2008:09:26	5	-2.82188
Japan	Exchange Rate	2008:10:03	7	-1.717	2008:10:21	7	-2.56477
	Stock Index	2008:09:15	2	-1.746	2008:11:05	0	-2.84418
Swiss	Exchange Rate	2008:09:29	10	-2.910	2008:09:22	10	-3.84986
	Stock Index	2008:10:21	5	-1.321	2008:10:16	2	-2.04937
UK	Exchange Rate	2008:11:28	10	-1.149	2008:09:03	10	-2.06085
	Stock Index	2008:10:23	4	-1.610	2008:09:26	4	-2.98737
US	Exchange Rate	2008:12:18	8	-2.103	2008:08:25	8	-3.2199
	Stock Index	2008:11:28	7	-1.273	2008:09:16	2	-2.25891
Panel B. Log Return							
Australia	Exchange Rate	2009:03:03	10	-10.380***	2010:05:24	6	-13.779***
	Stock Index	2009:02:23	8	-10.675***	2007:01:03	0	-37.513***
Canada	Exchange Rate	2008:11:03	8	-13.123***	2007:10:29	8	-13.357***
	Stock Index	2009:03:16	9	-8.716***	2009:07:09	9	-11.820***
Japan	Exchange Rate	2009:03:05	4	-15.227***	2008:01:04	4	-15.260***
	Stock Index	2009:03:02	10	-10.680***	2007:12:26	10	-10.937***
Swiss	Exchange Rate	2008:12:16	10	-4.238***	2008:09:17	9	-10.501***
	Stock Index	2009:02:18	9	-12.024***	2007:05:18	6	-15.997***
UK	Exchange Rate	2008:07:25	6	-12.310***	2009:04:10	10	-13.338***
	Stock Index	2010:06:11	1	-27.656***	2010:02:09	1	-27.648***
US	Exchange Rate	2008:09:01	9	-12.749***	2006:08:15	6	-13.489***

Stock Index	2008:12:26	0	-35.574***	2008:08:11	0	-35.667***

TABLE 3

Result of Cointegration Test

Table 3 reports the Gregory-Hansen cointegration root test with a structural break. The optimal number of lags in each series is determined by AIC. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Country		Model C	Model C/T	Model C/S	Model C/T/S
	Break Point	2008:01:22	2008:10:14	2008:01:25	2008:08:18
Australia	# of Lags	2	2	2	2
	t-Statistics	-3.909	-5.429**	-4.773	-6.25**
	Break Point	2007:08:20	2007:08:20	2007:06:12	2007:06:08
Canada	# of Lags	1	1	1	1
	t-Statistics	-4.45	-4.716	-5.302**	-5.544
	Break Point	2009:03:03	2009:02:27	2009:01:21	2009:02:27
Japan	# of Lags	3	1	5	1
	t-Statistics	-3.897	-5.102**	-4.111	-6.708**
	Break Point	2008:01:04	2008:09:19	2008:01:08	2008:07:14
Switzerland	# of Lags	1	1	5	2
	t-Statistics	-3.776	-4.187	-4.311	-4.393
	Break Point	2010:02:11	2010:02:11	2008:10:27	2009:06:04
UK	# of Lags	-4.365	-4.979	-5.086**	-5.597
	t-Statistics	1	1	1	1
	Break Point	2007:10:19	2010:02:08	2008:10:08	2008:10:08
US	# of Lags	0	0	0	1
	t-Statistics	-3.226	-4.124	-4.257	-4.839

TABLE 4

Estimation Results from the DCC-GARCH(1,1) Model

The panel A shows the estimation results of mean equations ($STR_t = \gamma_0 + \sum_{j=1}^{K} \gamma_{1,j} STR_{t-j} + \sum_{j=1}^{K} \gamma_{2,j} FXR_{t-j} + \varepsilon_{1,t}$, $FXR_t = \lambda_0 + \sum_{j=1}^{K} \lambda_{1,j} STR_{t-j} + \lambda_2 FXR_{t-1} + \varepsilon_{2,t}$) and the panel B presents the estimation results of variance equations ($h_{STR,t} = c_1 + \alpha_1 \varepsilon_{1,t-1}^2 + \beta_1 h_{STR,t-1} + d_1 \varepsilon_{1,t-1} I_{\varepsilon_{t-1}<0} + \upsilon_{1,t}$, $h_{FXR,t} = c_2 + \alpha_2 \varepsilon_{2,t-1}^2 + \beta_2 h_{FXR,t-1} + d_2 \varepsilon_{2,t-1} I_{\varepsilon_{t-1}<0} + \upsilon_{2,t}$).
Likelihood-ratio (LR) test examines the cross effects between stock price returns and exchange rate returns in mean equations. *t*-statistics are in parentheses. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Panel A. Mean equations

	Australia	Canada	Japan	Switzerland	UK	US
Constant	0.038*	0.039*	0.020	0.041*	0.062**	0.068***
	(1.698)	(1.776)	(0.695)	(1.754)	(2.544)	(2.939)
STR{1}	-0.141***	-0.064**	-0.096***	0.005	-0.070**	-0.060**
	(-5.292)	(-2.534)	(-3.528)	(0.191)	(-2.53)	(-2.079)
STR{2}		-0.042*				
		(-1.700)				
FXR{1}	0.477***	0.120***	-0.445***	-0.076*	-0.021	0.006
	(16.592)	(3.336)	(-15.249)	(-1.905)	(-0.470)	(0.164)
FXR{2}		0.07**				
		(1.991)				
Constant	0.052***	0.021	-0.023	0.025	0.014	-0.026*
	(3.200)	(1.503)	(-1.51)	(1.629)	(0.937)	(-1.862)
FXR{1}	-0.073***	-0.057**	-0.004	-0.058**	-0.013	-0.038
	(-4.183)	(-2.397)	(-0.156)	(-2.172)	(-0.482)	(-1.403)
STR{1}		0.022*	0.004	0.010	0.016	-0.033***
		(1.841)	(0.243)	(0.705)	(1.388)	(-2.743)

Panel B. Variance equations

	Australia	Canada	Japan	Switzerland	UK	US
C(1)	-0.142***	-0.112***	-0.101***	-0.162***	-0.169***	-0.126***
	(-6.935)	(-47.372)	(-36.642)	(-44.525)	(-43.897)	(-60.722)
C(2)	-0.160***	-0.12***	-0.144***	-0.066***	-0.101***	-0.085***
	(-8.158)	(-51.44)	(-71.145)	(-57.465)	(-49.983)	(-54.042)
A(1)	0.168***	0.141***	0.141***	0.197***	0.224***	0.169***
	(6.233)	(45.541)	(38.246)	(37.708)	(43.918)	(53.796)
A(2)	0.190***	0.129***	0.212***	0.083***	0.106***	0.104***
	(7.483)	(42.651)	(76.384)	(56.632)	(40.540)	(50.691)
B(1)	0.955***	0.975***	0.963***	0.949***	0.965***	0.977***
	(87.574)	(307.01)	(251.572)	(165.711)	(194.107)	(471.88)
B(2)	0.977***	0.981***	1.002***	0.997***	0.984***	0.995***
	(150.763)	(404.758)	(402.22)	(866.424)	(567.511)	(747.698)
D(1)	0.018***	0.008***	0.009***	0.02***	0.009***	0.006***
	(3.209)	(7.081)	(8.558)	(7.037)	(4.770)	(4.951)
D(2)	0.009**	0.018***	-0.027***	0.000	0.016***	-0.003
	(2.536)	(3.035)	(-8.36)	(0.030)	(3.298)	(-0.528)
Log Likelihood	-3528.68	-3126.13	-3754.59	-3182.03	-3226.94	-3112.82
LR Test $H_0: \gamma_2 = \lambda_1 = 0$	275.288***	18.517***	232.646***	4.229	2.149	7.552**

TABLE 5

Descriptive Statistics for DCC of Major Developed Countries

Table 5 presents the descriptive statistics for DCCs of major developed countries which are Australia, Canada, Japan, Switzerland, UK, and US. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

	Australia	Canada	Japan	Switzerland	UK	US
Observations	1303	1303	1303	1303	1303	1303
Sample Mean	0.212	0.444	-0.305	-0.035	0.245	-0.256
Standard Error	0.000	0.165	0.166	0.184	0.000	0.220
t-Statistic (Mean=0)	68383157.924	97.195	-66.386	-6.820	696850.440	-42.091
Skewness	0.361***	-0.552***	0.419***	-0.319***	-0.414***	0.762***
Kurtosis (excess)	-1.468***	-0.521***	0.123	-0.266*	-1.092***	-0.165
Jarque-Bera Statistics	145.3***	80.8***	38.9***	25.9***	101.9***	127.7***
			Autocorrelation Test			
Ljung-Box Q Test	6429.035	6251.252	6227.765	6135.385	6483.81	6436.166
			Heteroscedasticity Test			
ARCH(15) LM Test	50703.08***	19636.73***	10619.68***	6221.398***	9618.383***	33770.33***

TABLE 6

Estimation Results from Structural Breaks

Table 6 presents the result of Bai-Perron test of multiple structural breaks. The number of significant breaks in each DCC is determined by Bayesian information criterion (BIC). '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Country	# of Breaks	Break Point	Lower 95%	Upper 95%
Australia	3	2008:07:22	2008:06:13	2008:07:22
		2008:10:14	2008:10:13	2008:10:16
		2009:01:07	2009:01:07	2009:02:26
Canada	4	2008:05:01	2008:04:28	2008:05:26
		2008:09:04	2008:08:29	2008:09:19
		2010:05:20	2010:04:30	2010:05:24
		2010:08:30	2010:08:27	2010:09:27
Japan	4	2007:01:05	2006:08:24	2007:01:19
		2008:10:06	2008:05:12	2008:10:07
		2008:12:29	2008:12:26	2009:05:01
		2010:05:11	2010:05:10	2011:01:20
Switzerland	3	2008:03:14	2007:08:30	2008:03:26
		2008:10:03	2008:09:29	2008:10:08
		2009:10:07	2009:09:15	2010:08:18
UK	3	2008:07:07	2007:10:04	2008:07:08
		2008:10:22	2008:10:16	2008:10:24
		2009:05:29	2008:06:09	2009:06:12
US	3	2007:08:09	2007:07:30	2007:08:15
		2008:09:04	2008:08:14	2008:09:05
		2009:01:29	2009:01:16	2009:03:17

TABLE 7

Estimation Results from the Granger Causality

Table 7 reports the result of sub-sample Granger causality test between stock price returns and exchange rate returns. The darkened area signifies the contagion phase of the crisis around September and October in 2008. B, S, E, and X in the first column stand for bidirectional relationship, lead of stock market, lead of foreign exchange market, and no causality, respectively. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Panel A. Granger Causality Test for all structural breaks by Bai-Perron Break

Country	Causality	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
Australia (B-E-E)	Period	2006:01:02	2008:07:21	2008:07:22	2008:10:13	2008:10:14	2009:01:06			2009:01:07	2010:12:31
	E-/->S	41.2792***	0.000	6.2525***	0.0036	11.568***	0.0001			58.3547***	0.000
	S-/->E	2.8345*	0.0595	3.9148**	0.0257	1.2113	0.3055			2.0459	0.1065
Canada (X-E-X)	Period	2006:01:02	2008:04:30	2008:05:01	2008:09:03	2008:09:04	2010:05:19	2010:05:20	2010:08:29	2010:08:30	2010:12:31
	E-/->S	0.7798	0.3775	2.3443	0.1294	12.1078***	0.0000	0.0000	0.9945	0.2611	0.6106
	S-/->E	0.8420	0.3592	1.2943	0.2584	1.0449	0.3526	0.5074	0.4786	0.0285	0.8663
Japan (X-E-E)	Period	2006:01:02	2007:01:04	2007:01:05	2008:10:05	2008:10:06	2008:12:28	2008:12:29	2010:05:10	2010:05:11	2010:12:31
	E-/->S	0.1290	0.7198	54.5758***	0.0000	12.7389***	0.0007	67.0967***	0.0000	7.4148***	0.0001
	S-/->E	0.7987	0.3723	0.9959	0.3188	0.7242	0.3983	0.8420	0.3594	2.0767	0.1054
Switzerland (E-B-S-X)	Period	2006:01:02	2008:03:13	2008:03:14	2008:10:02	2008:10:03	2009:10:06			2009:10:07	2010:12:31
	E-/->S	3.4435*	0.0640	9.6401**	0.0023	2.3734**	0.0397			0.0165	0.8979
	S-/->E	0.4554	0.5001	17.2786***	0.0001	1.0466	0.3908			0.0675	0.7952
UK (S-X-X)	Period	2006:01:02	2008:07:06	2008:07:07	2008:10:21	2008:10:22	2009:05:28			2009:05:29	2010:12:31
	E-/->S	0.5560	0.5738	0.1368	0.7125	1.0156	0.3151			0.2920	0.5893
	S-/->E	6.1317**	0.0023	4.1414**	0.0454	0.0987	0.7539			0.1390	0.7095
US	Period	2006:01:02	2007:08:08	2007:08:09	2008:09:03	2008:09:04	2009:01:28			2009:01:29	2010:12:31

(S-X-S)	E-/->S	0.1047	0.7465	1.3223	0.2512	0.8461	0.3598			0.2249	0.6356
	S-/->E	6.6807**	0.0101	8.3319**	0.0042	0.4371	0.5100			6.1565**	0.0134

Panel B. Granger causality Test for 3 periods (Pre-crisis, Contagion, and Post-crisis)

Country	Causality	F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
Australia (B-E-E)	Period	2006:01:02	2008:10:13	2008:10:14	2009:01:06	2009:01:07	2010:12:31
	E-/->S	14.6174***	0.000	11.568***	0.0001	58.3547***	0.000
	S-/->E	7.3549***	0.000	1.2113	0.3055	2.0459	0.1065
Canada (X-E-X)	Period	2006:01:02	2008:09:03	2008:09:04	2010:05:19	2010:05:20	2010:12:31
	E-/->S	0.000	0.9928	12.1078***	0.0000	0.0944	0.7591
	S-/->E	1.3228	0.2505	1.0449	0.3526	0.1037	0.7478
Japan (E-E-E)	Period	2006:01:02	2008:10:06	2008:10:06	2008:12:28	2008:12:29	2010:12:31
	E-/->S	52.6994***	0.000	12.7389***	0.0007	80.8344***	0.000
	S-/->E	1.3878	0.2392	0.7242	0.3983	3.0975*	0.0781
Switzerland (B-E-X)	Period	2006:01:02	2008:10:02	2008:10:03	2009:10:06	2009:10:07	2010:12:31
	E-/->S	13.1593***	0.000	2.3734**	0.0397	0.0165	0.8979
	S-/->E	15.5661***	0.000	1.0466	0.3908	0.0675	0.7952
UK (X-X-X)	Period	2006:01:02	2008:10:21	2008:10:22	2009:05:28	2009:05:29	2010:12:31
	E-/->S	1.2579	0.2851	1.0156	0.3151	0.2920	0.5893
	S-/->E	0.7507	0.5577	0.0987	0.7539	0.1390	0.7095
US (S-X-S)	Period	2006:01:02	2008:09:03	2008:09:04	2009:01:28	2009:01:29	2010:12:31
	E-/->S	0.5845	0.4448	0.8461	0.3598	0.2249	0.6356
	S-/->E	15.9739***	0.000	0.4371	0.5100	6.1565**	0.0134

TABLE 8

Estimation Results of Markov-Switching VAR

Table 8 reports the result of Markov-Switching Granger causality test between stock price returns and exchange rate returns in Australia. COV(*i*,*j*) signifies each element of the covariance; COV(1,1) is the variance of the stock return equation, COV(2,2) is the variance of the exchange return equation, whereas COV(2,1) is the covariance of two equations. P(*i*,*j*) represents the probability of being in regime *i* at *t*, given that in regime *j* at *t-1*. The absolute values of *t*-statistics are in parentheses. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Panel A. Australia

Low Variance Regime			High Variance Regime		
Variable	Coefficient	*t*-Statistics	Variable	Coefficient	*t*-Statistics
		Stock Return Equation			
Constant	0.035	(1.129)	Constant	-0.162	(1.328)
STR{1}	-0.166***	(4.743)	STR{1}	-0.189***	(3.048)
STR{2}	-0.013	(0.406)	STR{2}	-0.052	(0.897)
FXR{1}	0.466***	(9.320)	FXR{1}	0.470***	(7.231)
FXR{2}	0.070	(1.489)	FXR{2}	0.203***	(2.859)
		Exchange Return Equation			
Constant	0.09***	(3.913)	Constant	-0.226*	(1.915)
STR{1}	0.028	(1.077)	STR{1}	-0.048	(0.814)
STR{2}	0.000	(0.000)	STR{2}	-0.030	(0.536)
FXR{1}	-0.082**	(2.216)	FXR{1}	-0.117*	(1.887)
FXR{2}	0.013	(0.361)	FXR{2}	-0.048	(0.696)
		Covariance and transition probabilities			
COV(1,1)	0.786***	(17.087)	COV(1,1)	3.953***	(9.172)
COV(2,1)	0.108***	(4.696)	COV(2,1)	1.178***	(4.566)
COV(2,2)	0.451***	(14.548)	COV(2,2)	3.643***	(8.907)
P(1,1)	0.980***	(163.333)	P(1,2)	0.065***	(0.021)
P(2,1)	0.020***	(3.333)	P(2,2)	0.935***	(0.021)

Panel B. Canada

	Low Variance Regime			High Variance Regime	
Variable	Coefficient	*t*-Statistics	Variable	Coefficient	*t*-Statistics
			Stock Return Equation		
Constant	0.108***	(3.484)	Constant	-0.319*	(1.865)
STR{1}	-0.040	(1.081)	STR{1}	-0.263***	(3.507)
STR{2}	-0.040	(1.111)	STR{2}	-0.126	(1.615)
STR{3}	-0.096***	(2.667)	STR{3}	0.080	(1.000)
STR{4}	-0.060*	(1.714)	STR{4}	0.095	(1.234)
FXR{1}	0.092*	(1.673)	FXR{1}	0.533***	(3.211)
FXR{2}	0.028	(0.538)	FXR{2}	0.089	(0.527)
FXR{3}	0.013	(0.241)	FXR{3}	-0.036	(0.208)
FXR{4}	0.075	(1.389)	FXR{4}	0.049	(0.277)
			Exchange Return Equation		
Constant	0.042**	(2.211)	Constant	-0.078	(0.987)
STR{1}	0.031	(1.292)	STR{1}	-0.032	(0.914)
STR{2}	0.006	(0.261)	STR{2}	-0.024	(0.649)
STR{3}	-0.010	(0.400)	STR{3}	0.057	(1.541)
STR{4}	-0.016	(0.696)	STR{4}	0.003	(0.083)
FXR{1}	-0.087**	(2.289)	FXR{1}	0.035	(0.443)
FXR{2}	-0.015	(0.417)	FXR{2}	0.059	(0.747)
FXR{3}	-0.001	(0.029)	FXR{3}	-0.034	(0.420)
FXR{4}	0.000	(0.000)	FXR{4}	0.117	(1.393)
			Covariance and transition probabilities		
COV(1,1)	0.730***	(15.532)	COV(1,1)	6.771***	(8.759)
COV(2,1)	0.193***	(8.773)	COV(2,1)	1.705***	(7.016)
COV(2,2)	0.327***	(15.571)	COV(2,2)	1.452***	(10.225)
P(1,1)	0.978***	(139.714)	P(1,2)	0.080***	(3.333)
P(2,1)	0.022***	(3.143)	P(2,2)	0.920***	(38.333)

Panel C. Japan

Low Variance Regime			High Variance Regime		
Variable	Coefficient	*t*-Statistics	Variable	Coefficient	*t*-Statistics
		Stock Return Equation			
Constant	0.005	(0.139)	Constant	-0.196	(1.14)
STR{1}	-0.107***	(3.057)	STR{1}	-0.279***	(3.77)
STR{2}	-0.044	(1.333)	STR{2}	-0.168**	(2.182)
STR{3}	0.004	(0.118)	STR{3}	-0.030	(0.385)
STR{4}	-0.045	(1.364)	STR{4}	0.128*	(1.753)
FXR{1}	-0.403***	(6.948)	FXR{1}	-0.719***	(7.049)
FXR{2}	-0.111**	(1.982)	FXR{2}	-0.240**	(2.051)
FXR{3}	-0.026	(0.5)	FXR{3}	0.047	(0.398)
FXR{4}	-0.095*	(1.792)	FXR{4}	0.103	(0.873)
		Exchange Return Equation			
Constant	-0.015	(0.625)	Constant	0.254**	(2.032)
STR{1}	0.035*	(1.667)	STR{1}	0.091*	(1.655)
STR{2}	0.005	(0.238)	STR{2}	0.099*	(1.737)
STR{3}	-0.001	(0.048)	STR{3}	0.018	(0.31)
STR{4}	0.025	(1.25)	STR{4}	0.014	(0.259)
FXR{1}	-0.040	(1.081)	FXR{1}	0.137*	(1.851)
FXR{2}	-0.002	(0.056)	FXR{2}	0.142	(1.632)
FXR{3}	-0.017	(0.515)	FXR{3}	-0.102	(1.159)
FXR{4}	0.010	(0.303)	FXR{4}	-0.010	(0.112)
		Covariance and transition probabilities			
COV(1,1)	1.206***	(16.297)	COV(1,1)	6.253***	(8.709)
COV(2,1)	-0.155***	(5.536)	COV(2,1)	-2.148***	(5.698)
COV(2,2)	0.453***	(14.156)	COV(2,2)	3.427***	(8.278)
P(1,1)	0.971***	(121.375)	P(1,2)	0.110***	(3.929)
P(2,1)	0.029***	(3.625)	P(2,2)	0.890***	(31.786)

Panel D. Switzerland

Low Variance Regime			High Variance Regime		
Variable	Coefficient	*t*-Statistics	Variable	Coefficient	*t*-Statistics
		Stock Return Equation			
Constant	0.084***	(2.897)	Constant	-0.318**	(2.446)
STR{1}	-0.004	(0.118)	STR{1}	-0.033	(0.569)
STR{2}	-0.038	(1.118)	STR{2}	-0.144**	(2.441)
STR{3}	-0.037	(1.057)	STR{3}	-0.064	(1.049)
STR{4}	-0.036	(1.091)	STR{4}	0.106*	(1.797)
FXR{1}	-0.023	(0.46)	FXR{1}	-0.310**	(2.214)
FXR{2}	0.017	(0.362)	FXR{2}	0.091	(0.641)
FXR{3}	-0.056	(1.217)	FXR{3}	0.159	(1.053)
FXR{4}	-0.001	(0.022)	FXR{4}	0.447***	(3.000)
		Exchange Return Equation			
Constant	0.040**	(2.105)	Constant	-0.024	(0.4)
STR{1}	-0.006	(0.25)	STR{1}	0.008	(0.296)
STR{2}	0.070***	(2.917)	STR{2}	-0.033	(1.179)
STR{3}	-0.063***	(2.864)	STR{3}	-0.025	(0.926)
STR{4}	-0.014	(0.583)	STR{4}	-0.011	(0.393)
FXR{1}	-0.071**	(2.152)	FXR{1}	-0.009	(0.145)
FXR{2}	-0.057	(1.541)	FXR{2}	0.059	(0.797)
FXR{3}	-0.017	(0.515)	FXR{3}	-0.037	(0.544)
FXR{4}	0.003	(0.097)	FXR{4}	-0.016	(0.235)
		Covariance and transition probabilities			
COV(1,1)	0.644***	(14.636)	COV(1,1)	4.626***	(10.538)
COV(2,1)	-0.028	(1.556)	COV(2,1)	-0.012	(0.094)
COV(2,2)	0.327***	(19.235)	COV(2,2)	0.981***	(10.9)
P(1,1)	0.973***	(121.625)	P(1,2)	0.081***	(3.375)
P(2,1)	0.027***	(3.375)	P(2,2)	0.919***	(38.292)

Panel E. United Kingdom

Low Variance Regime			High Variance Regime		
Variable	Coefficient	*t*-Statistics	Variable	Coefficient	*t*-Statistics
		Stock Return Equation			
Constant	0.062*	(1.879)	Constant	-0.245	(1.361)
STR{1}	-0.052	(1.625)	STR{1}	-0.120*	(1.714)
STR{2}	0.005	(0.152)	STR{2}	-0.111	(1.563)
STR{3}	-0.021	(0.636)	STR{3}	-0.151**	(2.068)
STR{4}	-0.049	(1.581)	STR{4}	0.228***	(3.123)
FXR{1}	-0.102*	(1.729)	FXR{1}	0.266*	(1.652)
FXR{2}	-0.006	(0.103)	FXR{2}	-0.130	(0.788)
FXR{3}	-0.069	(1.190)	FXR{3}	0.259	(1.551)
FXR{4}	0.070	(1.148)	FXR{4}	-0.174	(1.048)
		Exchange Return Equation			
Constant	0.013	(0.765)	Constant	-0.112	(1.349)
STR{1}	0.008	(0.444)	STR{1}	-0.017	(0.531)
STR{2}	0.031*	(1.722)	STR{2}	-0.034	(1.030)
STR{3}	-0.013	(0.765)	STR{3}	0.022	(0.667)
STR{4}	-0.032*	(1.882)	STR{4}	0.022	(0.667)
FXR{1}	-0.042	(1.273)	FXR{1}	0.132*	(1.784)
FXR{2}	0.023	(0.719)	FXR{2}	-0.056	(0.737)
FXR{3}	0.032	(1.032)	FXR{3}	-0.052	(0.675)
FXR{4}	-0.007	(0.212)	FXR{4}	-0.030	(0.395)
		Covariance and transition probabilities			
COV(1,1)	0.956***	(14.938)	COV(1,1)	6.631***	(8.771)
COV(2,1)	0.062***	(3.444)	COV(2,1)	0.989***	(4.281)
COV(2,2)	0.290***	(19.333)	COV(2,2)	1.368***	(8.883)
P(1,1)	0.984***	(164.000)	P(1,2)	0.067***	(2.913)
P(2,1)	0.016***	(2.667)	P(2,2)	0.933***	(40.565)

Panel F. Unites States

	Low Variance Regime			High Variance Regime	
Variable	Coefficient	*t*-Statistics	Variable	Coefficient	*t*-Statistics
			Stock Return Equation		
Constant	0.089***	(2.871)	Constant	-0.280*	(1.944)
STR{1}	-0.042	(1.200)	STR{1}	-0.202***	(3.424)
STR{2}	-0.058	(1.611)	STR{2}	-0.134**	(2.233)
STR{3}	0.025	(0.694)	STR{3}	-0.030	(0.492)
FXR{1}	-0.064	(1.032)	FXR{1}	-0.161	(1.052)
FXR{2}	-0.101*	(1.772)	FXR{2}	0.109	(0.699)
FXR{3}	0.065	(1.161)	FXR{3}	-0.468***	(2.889)
			Exchange Return Equation		
Constant	-0.025	(1.471)	Constant	0.055	(0.965)
STR{1}	-0.025	(1.136)	STR{1}	0.003	(0.130)
STR{2}	-0.042**	(2.000)	STR{2}	0.041*	(1.708)
STR{3}	0.011	(0.524)	STR{3}	0.021	(0.875)
FXR{1}	-0.056	(1.556)	FXR{1}	0.050	(0.820)
FXR{2}	-0.011	(0.324)	FXR{2}	-0.012	(0.194)
FXR{3}	-0.021	(0.618)	FXR{3}	0.043	(0.672)
			Covariance and transition probabilities		
COV(1,1)	0.635***	(7.299)	COV(1,1)	6.432***	(9.162)
COV(2,1)	-0.098***	(5.158)	COV(2,1)	-0.934***	(5.627)
COV(2,2)	0.255***	(15.938)	COV(2,2)	1.018***	(9.695)
P(1,1)	0.963***	(68.786)	P(1,2)	0.091***	(3.138)
P(2,1)	0.037***	(2.643)	P(2,2)	0.909***	(31.345)

TABLE 9

Estimation Results of Smoothed Probabilities with GARCH Volatilities

Table 9 reports the least square estimation with a heteroscedasticity-robust covariance matrix between smoothed probabilities of high volatility regime and GARCH volatilities. $l(smp_i)$ signifies the logistic transformation of the smoothed probabilities. $h_{S,t}$ and $h_{E,t}$ represent the GARCH volatilities of stock market returns and FX market returns. *t*-statistics are in parentheses. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Variable	Australia	Canada	Japan	Switzerland	UK	US
			$l(smp_i)$			
Constant	-4.065***	-4.331***	-5.443***	-3.206***	-5.116***	-3.321***
	(-49.125)	(-62.361)	(-63.526)	(-48.242)	(-78.088)	(-50.911)
Log($h_{S,t}$)	5.046***	4.115***	4.174***	4.08***	3.907***	3.522***
	(26.587)	(32.274)	(26.99)	(30.505)	(38.552)	(40.597)
Adj. R-sq	0.484	0.579	0.419	0.572	0.553	0.615
			$l(smp_i)$			
Constant	-2.263***	-0.221	-2.501***	0.022	0.122	1.014***
	(-20.456)	(-1.266)	(-27.718)	(0.126)	(0.709)	(5.532)
Log($h_{E,t}$)	4.029***	4.295***	2.79***	3.498***	4.366***	3.672***
	(33.446)	(31.475)	(31.239)	(22.714)	(30.186)	(25.951)
Adj. R-sq	0.461	0.412	0.454	0.268	0.443	0.363

TABLE 10

The Summary of Markov-Switching Granger Causality Results

Table 10 reports the summary results of Markov-Switching Granger causality for 6 advanced countries in Table 9. 'O' implies the existence of Granger causality and 'X' implies no Granger causality, when statistical inferences of Granger causality is based on the Bonferroni and the Scheffe procedures (Savin (1980)). The sub-sample Granger causality tests are the estimation results from the darkened area in Table 7. The critical values for the Bonferroni and the Scheffe procedures are provided for each significance level, according to the optimal lag structure of each countries; Australia shows AR(2) process, U.S. shows AR(3), and other countries show AR(4). The largest *t*-statistics are in parentheses. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively, based on the Bonferroni procedure, which has higher power than the Scheffe procedure.

		MS Granger Causality Tests		Sub-sample Granger Causality Tests
Country	Causality	Low Variance Period	High Variance Period	Mid-Crisis
Australia	E-/->S	O (9.320)***	O (7.231)***	O
	S-/->E	X (1.077)	X (0.814)	X
Canada	E-/->S	X (1.673)	O (3.211)***	O
	S-/->E	X (1.292)	X (1.514)	X
Japan	E-/->S	O (6.948)***	O (7.049)***	O
	S-/->E	X (1.667)	X (1.737)	X
Switzerland	E-/->S	X (1.217)	O (3.000)**	O
	S-/->E	O (2.864)**	X (1.179)	X
UK	E-/->S	X (1.729)	X (1.652)	X
	S-/->E	X (1.882)	X (1.030)	X
US	E-/->S	X (1.772)	O (2.889)**	X
	S-/->E	X (2.000)	X (1.708)	X
Total	E-/->S	2	5	4
	S-/->E	1	0	0

			Critical Value	
	Significance Level	AR(2)	AR(3)	AR(4)
B procedure	10%	1.960	2.128	2.241
	5%	2.241	2.394	2.498
	1%	2.807	2.935	3.023
S procedure	10%	2.148	2.504	2.793
	5%	2.451	2.800	3.086
	1%	3.042	3.377	3.654

TABLE 11

Estimation Results of DCC with Time Dummy Variables

The panel A shows the estimation results of mean equations ($\rho_t = \gamma_0 + \gamma_1 \rho_{t-1} + \sum_{k=1}^{n} \tau_{1,k} TDM_t + \varepsilon_{\rho,t}$), and the panel B presents the estimation results of variance equations ($h_{\rho,t} = c + \alpha \varepsilon^2_{\rho,t-1} + \beta h_{\rho,t-1} + \sum_{k=1}^{n} \tau_{2,k} TDM_t + \upsilon_{\rho,t}$). LR test examines the joint significance of time dummy variables in mean equations, variance equation, and both equations. *t*-statistics are in parentheses. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

<u>*Panel A. Mean equations*</u>

	Australia	Canada	Japan	Switzerland	UK	US
Constant	0.001***	0.011***	-0.001	-0.206***	2814***	-0.001
	(4.074)	(4.623)	(-0.424)	(-190.393)	(5.07E+05)	(-1.403)
RHO{1}	0.993***	0.967***	0.969***	0.726***	0.989***	0.988***
	(609.586)	(154.275)	(164.941)	(176.908)	(3.21E+08)	(239.011)
DM_1	-2.5E-05	-0.009***	-0.01***	-0.133***	--	0.003**
	(-0.184)	(-3.55)	(-4.241)	(-38.971)		(2.311)
DM_2	4.82E-05	0.008***	-0.017***	0.057***	0.276***	-0.009***
	(0.358)	(4.674)	(-4.387)	(25.628)	(3.637)	(-2.979)
DM_3	1.9E-04***	0.013***	-0.009***	0.133***	0.267***	-0.005***
	(5.225)	(4.831)	(-3.839)	(41.137)	(16.520)	(-2.922)
DM_4	--	0.004**	-0.011***	--	--	--
		(2.178)	(-3.956)			

Panel B. Variance equations

	Australia	Canada	Japan	Switzerland	UK	US
C	6.45E-09***	6.97E-05***	2.44E-04***	0.001***	0.003***	1.70E-04***
	(6.246)	(4.938)	(7.547)	(37.692)	(11.692)	(7.073)
A	0.413***	0.105***	0.226***	0.609***	0.283***	0.143***
	(9.282)	(5.534)	(6.516)	(12.030)	(45.127)	(3.923)
B	0.626***	0.779***	0.222***	0.265***	0.760***	0.044
	(25.459)	(22.585)	(3.251)	(14.242)	(237)	(0.380)
DM_1	2.43E-07**	2.06E-05	5.03E-05*	7.73E-05	0.094***	1.19E-04***
	(2.544)	(0.937)	(1.672)	(0.467)	(6.421)	(3.576)
DM_2	9.34E-08	-5.3E-05***	-9.4E-05**	-2.76E-04***	0.008***	0.001***
	(1.352)	(-4.607)	(-2.132)	(-8.241)	(9.543)	(4.517)
DM_3	-2E-10	-5.1E-05***	-1E-05	2.14E-04**		-9.6E-05***
	(-0.180)	(-4.232)	(-0.366)	(2.075)		(-5.925)
DM_4		-5.6E-05***	-8.7E-05***			
		(-4.551)	(-3.408)			
Log Likelihood	8804.93	3433.032	3269.552	1813.813	-683.501	3743.646

Panel C. LR Test

	Australia	Canada	Japan	Switzerland	UK	US
$H_0: \sum_{k=1}^{n} \tau_{1,k} = 0$	27.92***	42.77***	20.40***	3927***	143.08***	19.97***
$H_0: \sum_{k=1}^{n} \tau_{2,k} = 0$	7.36*	24.35***	68.00***	69.25***	66.16***	49.98***
$H_0: \sum_{k=1}^{n} \tau_{1,k} = \sum_{k=1}^{n} \tau_{2,k} = 0$	35.53***	65.12***	89.46***	3986***	104.62***	67.68***

TABLE 12

Unit Root and Cointegration Tests for DCCX

The panel A reports $Z_{t\text{-}bar}$ statistics of Im et al. (2003) for TED, CDS, and $l(|\rho_{i,t}|)$, and ADF-statistics for VIXUS and FXVUS. The panel B presents the result of Pedroni test of panel cointegration (Pedroni, 2004). '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

Panel A. Unit Root Test

Variable	Test Statistics
VIXUS	-1.324
FXVUS	-1.226
TED	0.347
CDS	0.396
$l(\|\rho_{i,t}\|)$	2.820

Panel B. Panel Cointegration

	Test Statistics
Group Rho-statistics	2.527**
Group PP-statistics	4.701***
Group ADF-statistics	4.701***

TABLE 13

Estimation Results from the DCCX Model

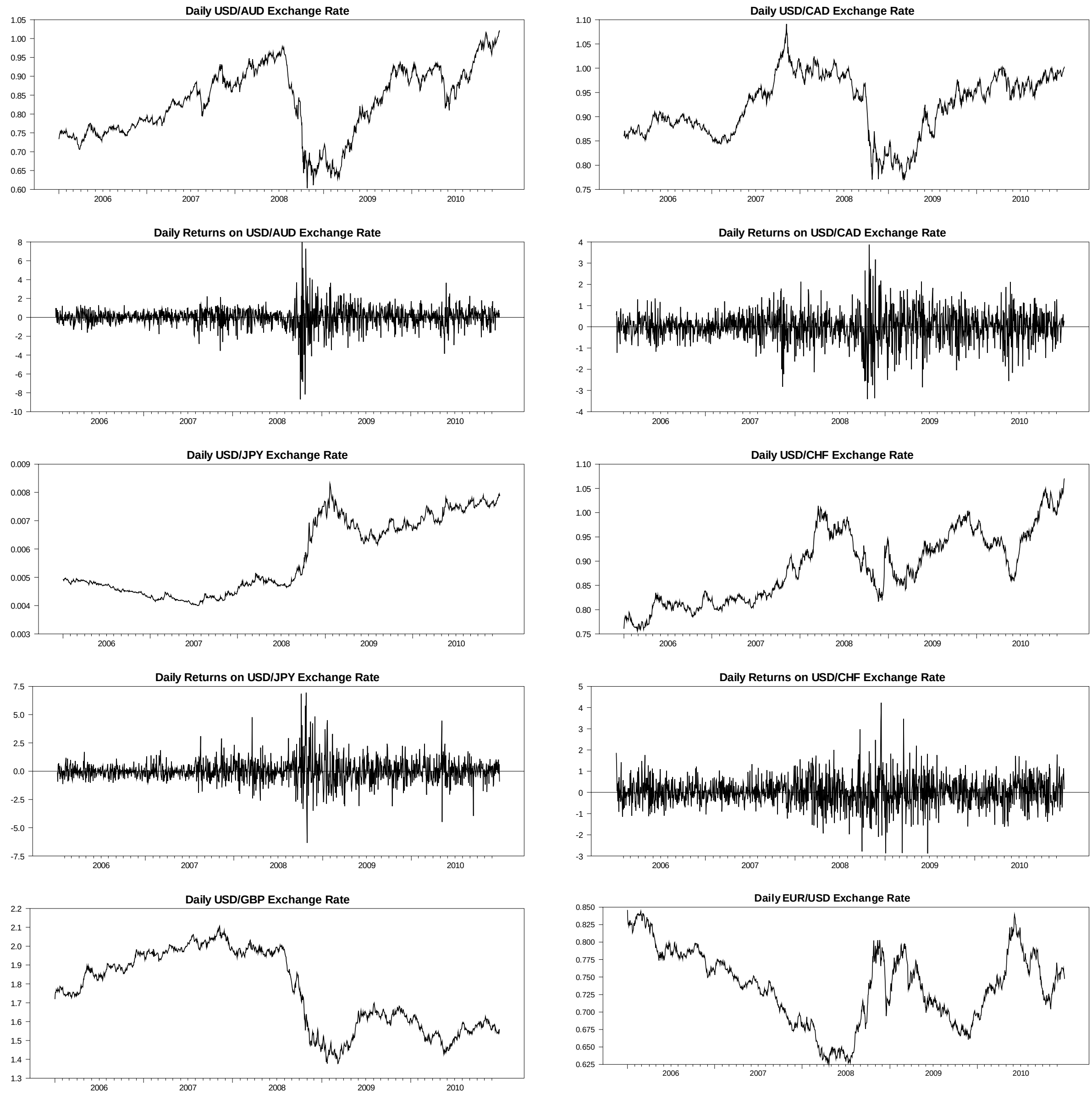
The table presents the result of the DCCX model with random effect. VIX is the volatility index for S&P 500 index options. $l\left(\left|\rho_{i,t}\right|\right)$ signifies the logistic transformation of the DCCs in the absolute value. FXV is the 3 month implied FX volatility index for USD/EUR, TED is the interest rate of each country less LIBOR in 3 month, and CDS is the CDS spread of each country. '***', '**', and '*' represent the significance level of 1%, 5%, and 10%, respectively.

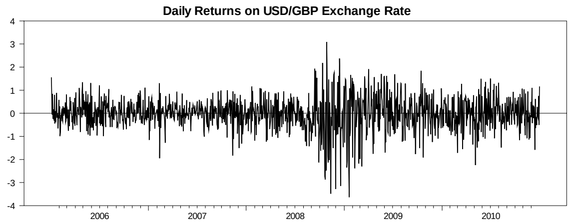
Dependent Variable	$l\left(\left|\rho_{i,t}\right|\right)$	
	Coefficient	*t*-Statistics
Constant	-1.550***	(-5.141)
VIX{1}	0.029***	(12.141)
FXV{1}	-0.004	(-0.508)
TED{1}	0.120***	(10.616)
CDS{1}	-0.004***	(-5.105)
Number of Observations	2776	

FIGURE 1

Daily Dollar Exchange Rate and Returns of Major Developed Countries

Figure 1 shows exchange rates and their changes for 6 OECD countries.




Daily Returns on USD/GBP Exchange Rate
4
3
2
1
0
-1
-2
-3
-4
2006
2007
2008
2009
2010

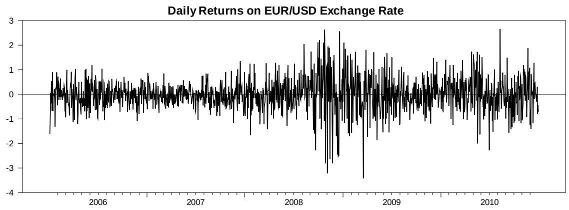

Daily Returns on EUR/USD Exchange Rate
3
2
1
0
-1
-2
-3
-4
2006
2007
2008
2009
2010

FIGURE 2

Daily Stock Index and Returns of Major Developed Countries

Figure 2 shows stock market indices and their returns for six OECD countries.

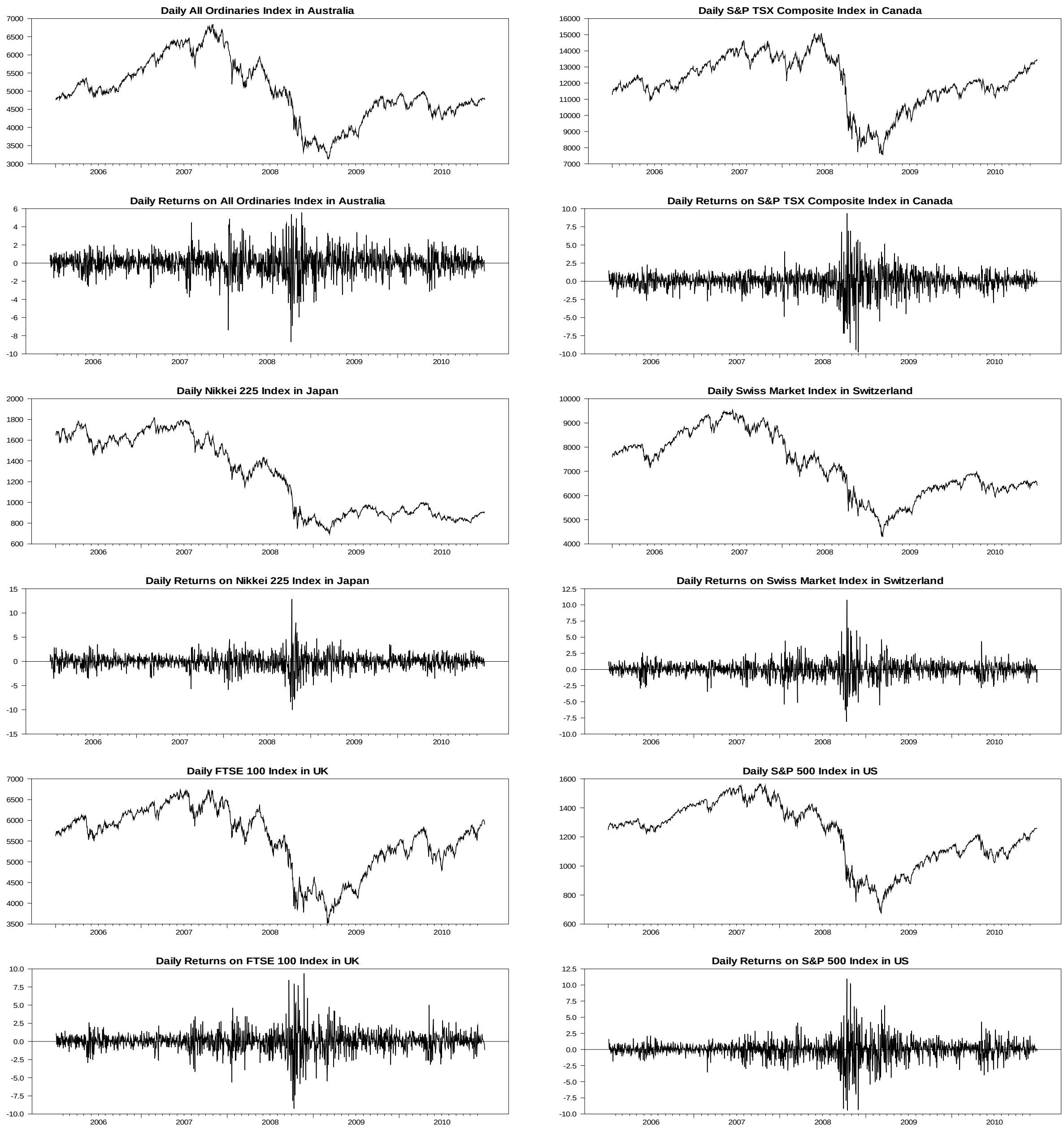
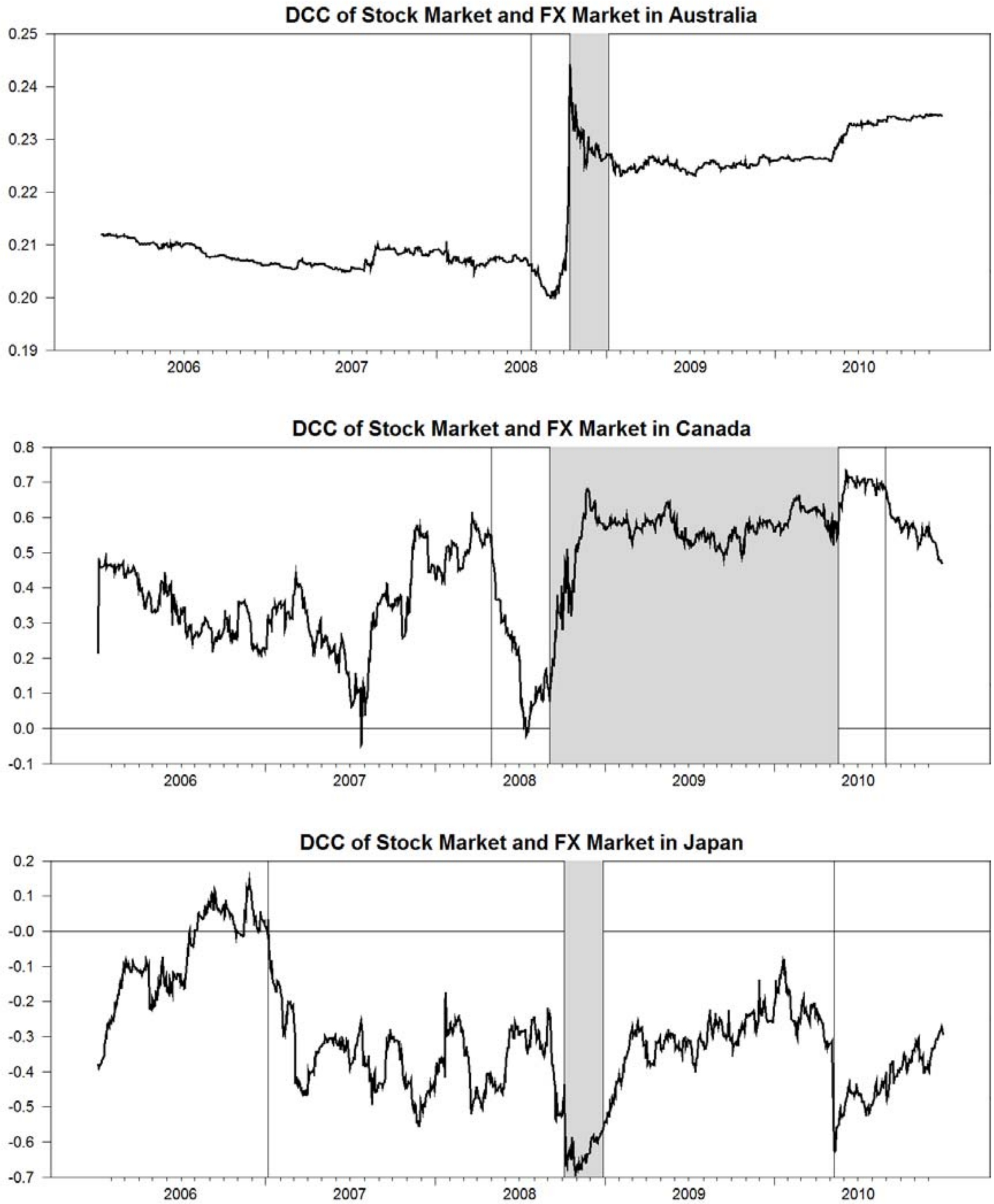


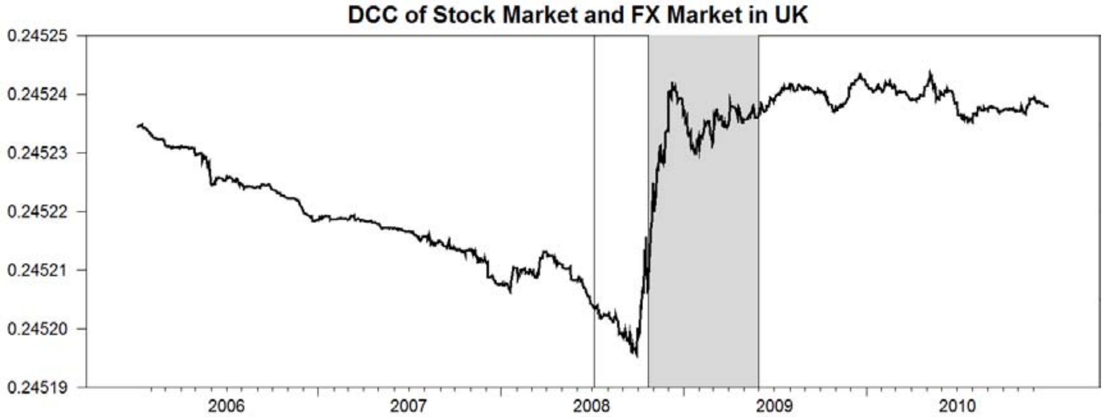
FIGURE 3

DCC of Stock Market and FX Market in Major Developed Countries

Figure 3 shows DCCs between exchange rate changes and stock returns estimated by DCC-MGARCH model for 6 OECD countries and structural breaks are shown as vertical lines. Shaded area is contagion period caused by US financial crisis.




DCC of Stock Market and FX Market in Switzerland
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
2006
2007
2008
2009
2010


DCC of Stock Market and FX Market in UK
0.24525
0.24524
0.24523
0.24522
0.24521
0.24520
0.24519
2006
2007
2008
2009
2010

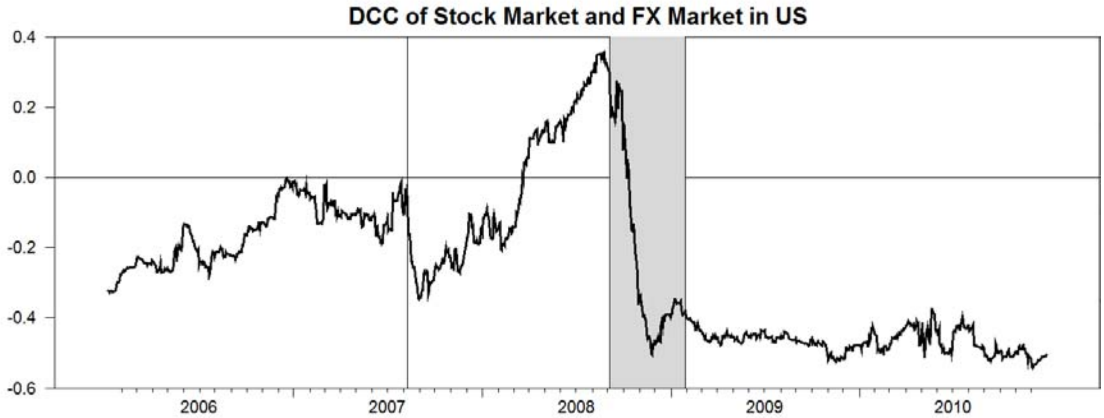
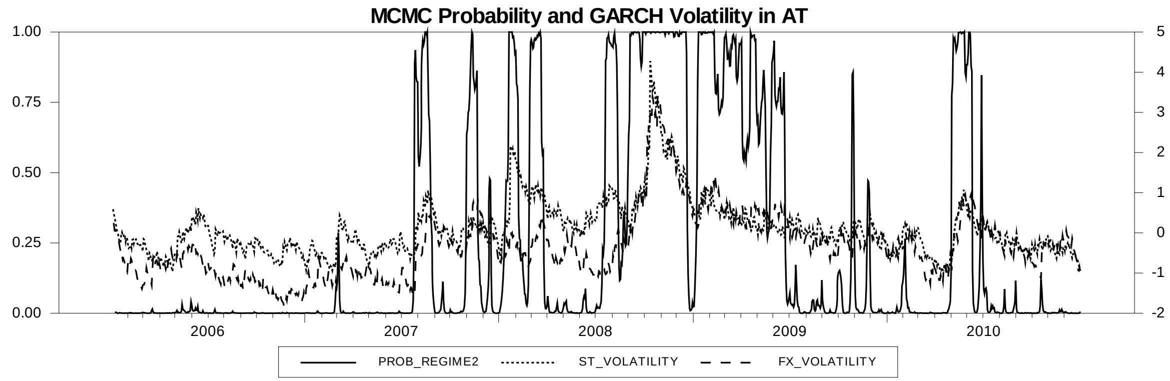

DCC of Stock Market and FX Market in US
0.4
0.2
0.0
-0.2
-0.4
-0.6
2006
2007
2008
2009
2010

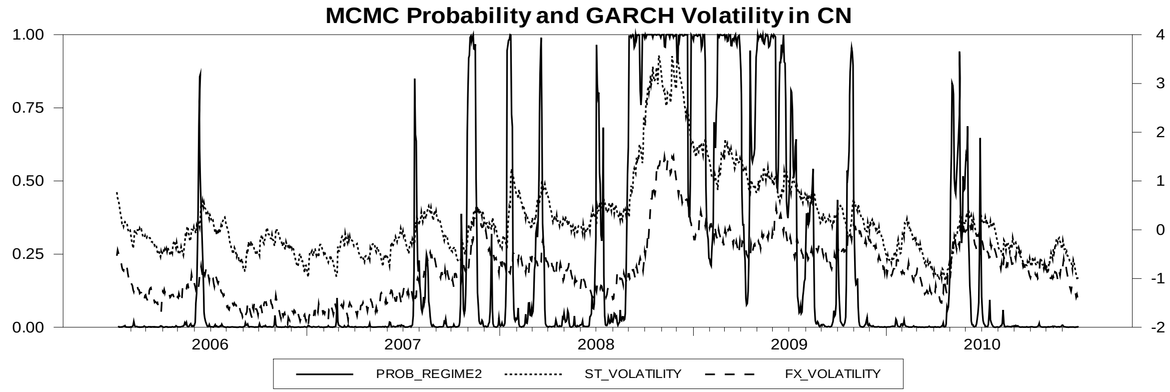
FIGURE 4

Smoothed Probability of High Variance and GARCH Volatilities

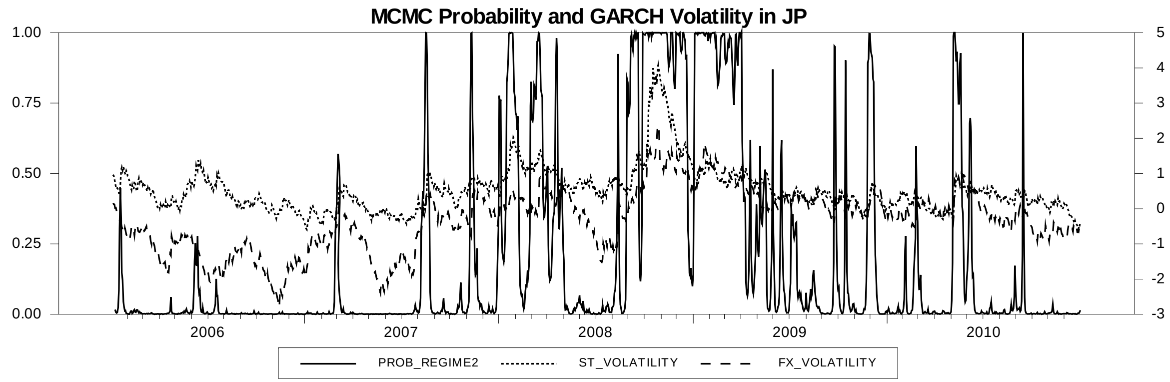
Figure 4 shows smoothed probabilities of the high-variance regime and two broken lines are volatilities of stock returns and exchange rate changes estimated by MGARCH variance equations in table 4.

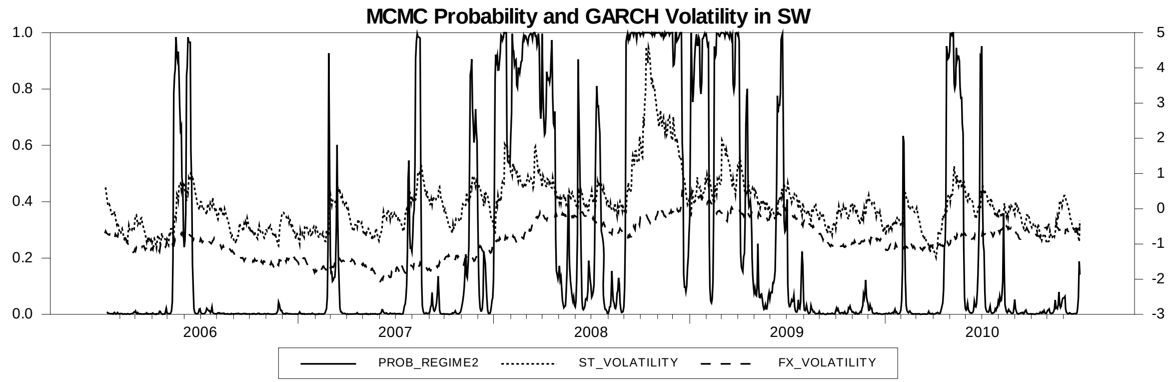
Graph A. Australia and Canada



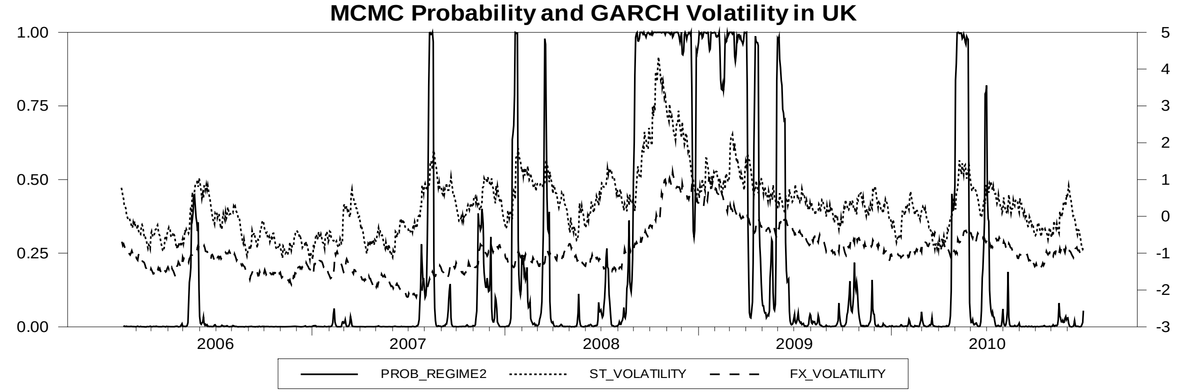


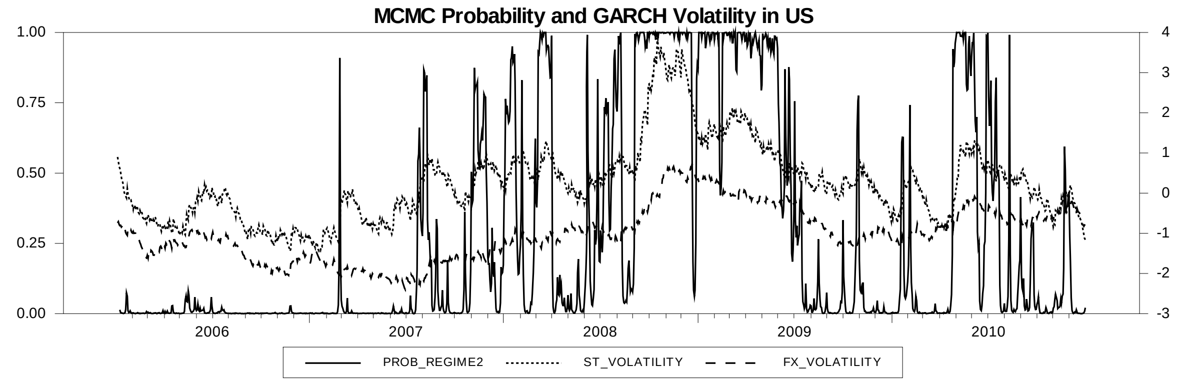
Graph B. Japan and Switzerland




MCMC Probability and GARCH Volatility in SW
1.0
0.8
0.6
0.4
0.2
0.0
5
4
3
2
1
0
-1
-2
-3
2006
2007
2008
2009
2010
PROB_REGIME2
ST_VOLATILITY
FX_VOLATILITY

Graph C. United Kingdom and United States





Data Appendix

Country	Item	Description	Source
Australia	Stock Index	All Ordinaries Index	Datastream
	Exchange Rate	USD/AUD Exchange Rate	Datastream
	Interest Rate	Australian Deposit 3-Month	Bloomberg
	CDS Spread	Australia CDS USD 5-Year	Bloomberg
Canada	Stock Index	S&P TSX Composite Index	Datastream
	Exchange Rate	USD/CAD Exchange Rate	Datastream
	Interest Rate	Canada T-Bill 3Month	Datastream
	CDS Spread	Not available	Bloomberg
Japan	Stock Index	Nikkei 225 Index	Datastream
	Exchange Rate	USD/JPY Exchange Rate	Datastream
	Interest Rate	Japan T-Bill 3-Month	Bloomberg
	CDS Spread	Japan CDS USD 5-Year	Bloomberg
Switzerland	Stock Index	Swiss Market Index	Datastream
	Exchange Rate	USD/CHF Exchange Rate	Datastream
	Interest Rate	Swiss Interbank 3-Month	Datastream
	CDS Spread	Swiss CDS USD 5-Year	Bloomberg
UK	Stock Index	FTSE 100 Index	Datastream
	Exchange Rate	USD/GBP Exchange Rate	Datastream
	Interest Rate	UK T-Bill 3 Month	Bloomberg
	LIBOR	GBP LIBOR 3-Month	Bloomberg
	CDS Spread	UK CDS USD 5-Year	Bloomberg
US	Stock Index	S&P 500 Index	Datastream
	Exchange Rate	EUR/USD Exchange Rate	Datastream
	Interest Rate	T-Bill 3-Month	Bloomberg
	CDS Spread	US CDS EUR 5-Year	Bloomberg
	Stock Volatility Index	CBOE VIX Index	Bloomberg
	FX Volatility Index	USD/EUR 3-Month VIX	Datastream