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Abstract

This study examines the nature of the linkages between stock market prices and exchange rates in six advanced economies, namely the US, the UK, Canada, Japan, the euro area, and Switzerland, using data on the banking crisis between 2007 and 2010. Bivariate GARCH-BEKK models are estimated producing evidence of unidirectional spillovers from stock returns to exchange rate changes in the US and the UK, in the opposite direction in Canada, and of bidirectional spillovers in the euro area and Switzerland. Furthermore, causality-in-variance from stock returns to exchange rates changes is found in Japan and in the opposite direction in the euro area and Switzerland, whilst there is evidence of bidirectional feedback in the US and Canada. These findings imply limited opportunities for investors to diversify their assets during this period.

Keywords: Stock prices; Exchange rates; Causality-in-variance; Cointegration

JEL Classification: F31; G15; C32

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1. Introduction

The collapse on September 15th 2008 of Lehman Brothers (LB, until that point the fourth largest investment bank in the US) sent a wave of global panic across financial markets. Following global bank failures and the resulting collapse in liquidity and inter-bank lending, stock market indices in most developed economies experienced significant declines.[1] Higher uncertainty also generated turbulence in the foreign exchange markets, with the major currencies being hit by a reduction in international transactions and a flight to value.[2] An interesting issue is whether financial markets have become more dependent as a result of the uncertainty created by the crisis. Aloui et al. (2011), Kenourgios et al. (2011), Samarakoon (2011), and Dufrénot et al. (2011) among others find indeed an increase in dependence between international stock markets, and similar findings are reported by Coudert et al. (2011) and Bubak et al. (2011) for foreign exchange markets.

Surprisingly, very few studies have investigated the linkages between stock market prices and exchange rates during the recent crisis. At times of financial turmoil, the high volatility of stock markets generates speculative actions by investors and capital flight to value and this may lead to considerable instability in other markets such as foreign exchange markets. This has been shown in the case of the Asian financial crisis when stock markets led the foreign exchange markets (see Granger et al., 2000; Caporale et al., 2002). However, in turbulent times, decoupling may also occur: when stock markets experience severe downturns, investors may only focus on markets where their assets can be seen as

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[1] From early October 2007 until the second week of March 2009, the S&P 500 (US), FTSE 350 (UK), and Stoxx 50 Euro (euro area) indices declined by approximately 56%, 48%, and 59%, respectively. Similar stock market falls occurred in Switzerland and Japan, where the lowest points were reached in the second week of March 2009 following peaks on June 1st and July 10th, 2007, respectively. The Swiss market index declined by approximately 54%, whereas the Japanese Nikkei 225 index dropped by roughly 61% during this period.

[2] Pound Sterling and the Canadian dollar depreciated against the currencies of their trading partners by approximately 30% (from September 3, 2007 to January 22, 2009) and 28% (from November 7, 2007 to March 9, 2009), respectively. By contrast, the Japanese yen and Swiss franc appreciated steadily by approximately 38% and 61% until late 2011.

safe havens irrespective of foreign exchange movements; consequently, there might not be interactions between different markets (see, for example, Hatemi-J and Roca, 2005).

To the best of our knowledge, the study by Wong and Li (2010) is the only one to date to have examined the interactions between stock prices and exchange rates during the recent crisis; however, it has some limitations. The first is the use of monthly data which cannot capture the timing of events such as the bailouts of AIG in the US and RBS and HBOS in the UK. The second is the fact that their analysis ends in 2008, thereby ignoring the turbulent period following the collapse of LB. The third is their econometric methodology, namely the dynamic conditional correlation (DCC) model of Engle (2002) that does not allow the authors to consider the issue of causality between the two variables.

The present study aims to address the interactions between stock and exchange rate returns as well as their volatilities in a comprehensive manner by analysing weekly data for six advanced economies, namely the US, the UK, Canada, Japan, the euro area and Switzerland. Specifically, two sub-periods are examined: the pre-crisis (August 6, 2003-August 8, 2007) and the crisis period (August 15, 2007-December 28, 2011). These are selected to enable us to analyse linkages in both normal and turbulent times, which can provide important insights to investors in terms of portfolio management strategies by focusing their attention on the right segments of the market during such times with the aim of minimising risk and maximising returns in highly integrated financial markets.

The chosen econometric framework is a bivariate VAR-GARCH model in the BEKK representation of Engle and Kroner (1995). Unlike the DCC model which estimates the time-varying conditional correlations directly, the BEKK specification allows for interactions in the variances and covariances in a lead-lag framework. The 'curse of dimensionality' highlighted by Caporin and McAleer (2012) associated with it is not a serious issue in our application with only two variables. Furthermore, to circumvent potential missing variable errors in the conditional mean, the model is extended to incorporate the underlying short-run deviations between stock prices and exchange rates in the conditional mean in case both variables are cointegrated; the Gregory and Hansen (1996) cointegration test is employed. Therefore, a thorough econometric analysis is conducted of the dependence between stock prices and exchange rates during the period under examination.

The paper is organised as follows. Section 2 provides a brief review of the theoretical and empirical literature on the relationship between stock prices and exchange rates. Section 3 describes the data. Section 4 outlines the econometric methodology. Section 5 discusses the empirical results and Section 6 concludes.

2. A review of the literature

There are two main types of theoretical models analysing the linkages between exchange rates and stock prices. ‘Flow-oriented’ models (Dornbusch and Fischer, 1980) posit that causality runs from the former to the latter, whereas portfolio-based approaches (Branson, 1983; Frankel, 1983) suggest the opposite. In the first case a more competitive exchange rate, assuming that the Marshall-Lerner conditions hold, will improve the trade position of an economy and stimulate the real economy through firm profitability and stock market prices. This approach has been given some empirical support in the literature on asset pricing models based on consumption- and income- (Gregoriou et al., 2009) as well as output (Sousa, 2010). In the second case, the exchange rate is thought to respond to increases in the demand for financial assets such as bonds and stocks. Hence, a bullish domestic stock market will signal favourable domestic economic prospects, thereby inducing capital inflows and an appreciation of the exchange rate (Kollias et al., 2012). Another channel for this type of causality stems from the demand for money (Gavin, 1989).

The empirical literature also provides mixed results. For example, Aggarwal (1981) found a significant positive correlation between US stock prices and the strength of the US dollar using monthly data between 1974 and 1978, although Soenen and Hennigar (1988) reported that the sign depends on the sample used. Subsequent studies used the two-step cointegration procedure of Engle and Granger (1987) and the maximum likelihood technique of Johansen (1995) to examine the time series properties of both stock prices and exchange rates in the long run. Using monthly data on the US economy for the period 1973-1988, Bahmani-Oskooee and Sohrabian (1992) found that these two variables are not cointegrated, yet there is bidirectional feedback in the short run. Similar findings were reported by Nieh and Lee (2001), who investigated stock prices and exchange rates for the G7 countries and found one-day significant linkages in some countries.

Cointegration may not be detected as a result of model misspecification, and in particular the omission of variables. Phylaktis and Ravazzolo (2005) found that US stock prices were a key channel linking the exchange rates of five Pacific basin countries to their stock indices. On the other hand, Ülkü and Demirci (2012) showed that global developed and emerging stock market returns explain a large portion of the permanent comovement between stock and foreign exchange markets for eight European emerging economies.

The seminal article of Engle (1982) showed that the ARCH family of models can capture volatility clustering and ARCH effects in financial returns. Kanas (2000) found positive volatility spillover effects from stock returns to exchange rate changes for all the G-7 except Germany. Ning (2010), instead, used copulas to show that there is significant symmetric upper and lower tail dependence between stock and foreign exchange markets for the G5 countries (US, UK, Germany, France and Japan). Katechos (2011) found that the sign of the link between global stock market returns and exchange rates depends on whether the currency in question is a high yielding (positive) or a low yielding one (negative). Furthermore, a very recent study by Chkili et al. (2012), who estimates a bivariate CCC-FIAPARCH specification to capture asymmetry and long memory in daily data from January 1999 to December 2010 for three major European countries (namely France, Germany, and the UK), reports strong correlation between the two variables and more accurate in-sample estimates as well as better out-of-sample performance than in the case of GARCH specifications.

3. Data description

We employ weekly data (Wednesday to Wednesday) to analyse the linkages between stock market prices and exchange rates, because daily or intra-daily data are affected by noise and anomalies such as day-of-the-week effects, while monthly data may be inadequate to trace the short-run evolution of capital across international financial markets. We consider six advanced economies: Canada, the euro area, Japan, Switzerland, the UK, and the US from August 6, 2003 to December 28, 2011, a sample of 441 observations. The exchange rates used are trade-weighted (as calculated by the Bank of England), thus providing a better measure of the competitiveness of these economies (Kanas, 2000), while the stock prices are the main local stock exchange indices. The currencies of these economies are the most actively traded in the foreign exchange markets, while their stock markets are the largest among the developed economies in terms of market capitalisation. The data have been obtained from Thomson DataStream.

We consider two sub-periods: a tranquil or pre-crisis period from August 6, 2003 to August 8, 2007, and a crisis period from August 15, 2007 to December 28, 2011. It is well known that the former corresponds to the so-called "Great Moderation" (see Stock and Watson, 2002), which was characterised by stable and low inflation and a decline in the volatility of other macroeconomic fundamentals. The subsequent global financial crisis (and the associated "Great Recession") clearly represents a new regime.

The start date of the pre-crisis sample is chosen to avoid the impact of major global events such as the 9/11 terrorist attacks and their anniversary in 2002 (see Gregoriou et al., 2009), and the ensuing conflicts in Afghanistan and Iraq as well as the dotcom bubble that burst in late 2002. On the other hand, the crisis period is defined as starting with the first signs of the subprime mortgage crisis in the US in the summer of 2007, ahead of the failure of Fannie Mae and Freddie Mac and the collapse of LB and AIG. This is also consistent with the study of Melvin and Taylor (2009), who consider August 16th 2007 as the beginning of the crisis in the foreign exchange markets.

The variables in levels are denoted by s_t and e_t, respectively the log stock prices and log exchange rates, while their first differences ($R_{S,t}$ and $R_{E,t}$) are continuously compounded returns; the data are in percentages and are multiplied by 100. A wide range of descriptive statistics are displayed in Table A1 (see Appendix A). Fig.1a and Fig. 1b show the weekly evolution of the trade-weighted exchange rates and stock prices with their corresponding changes for the period under investigation. Stock returns and exchange rate changes exhibit volatility clustering, especially in the crisis period, which indicates an ARCH model might be appropriate. The Figures also suggest that the log of exchange rates and stock prices might be non-stationary and follow a stochastic trend, while their first difference is co-variance stationary or has a finite variance.[3]

[Insert Fig. 1a-Fig. 1b about here]

4. The VAR-GARCH model

We employ the BEKK representation of Engle and Kroner (1995) for our bivariate VAR-GARCH (1, 1) model to examine the joint processes governing weekly changes in stock market prices and exchange rates for the two sub-periods. This enables us to examine the dependence between both the first and the second moments of stock prices and exchange rates in a dynamic framework. In particular, the conditional mean equation is specified as follows:

$$R_t = \mu + \sum_{i=1}^{p} \psi_i R_{t-i} + \lambda R_{wt} + \gamma R_{rft} + \delta \Delta p_{oilt} + \varepsilon_t$$

$$\mu = \begin{bmatrix} \mu_S \\ \mu_E \end{bmatrix}, \ \psi_i = \begin{bmatrix} \psi^i_{SS} & \psi^i_{SE} \\ \psi^i_{ES} & \psi^i_{EE} \end{bmatrix}, \ \varepsilon_t = \begin{bmatrix} \varepsilon_{St} \\ \varepsilon_{Et} \end{bmatrix} \tag{1}$$

[3] This is confirmed by a battery of unit root tests, including the augmented Dickey–Fuller (1981) test, the Phillips and Perron (1988) test and the minimum LM test of Lee and Strazicich (2004) with one structural break in the intercept and a trend.

where R_t = $[R_{S,t}, R_{E,t}]$, the innovation vector $\varepsilon_t|\Omega_{t-1} \sim N(0, H_t)$ is normally distributed with $|H_t|$ being the corresponding variance-covariance matrix, and Ω_{t-1} is the information set available at time t-1. $\psi_{SS}^{(i)}$, $\psi_{EE}^{(i)}$ indicate respectively the response of stock market returns and exchange rate changes to their own lags, whereas $\psi_{ES}^{(i)}, \psi_{SE}^{(i)}$ measure respectively mean spillovers from stock market returns to exchange rate changes, and vice versa. The model is augmented with some exogenous variables, namely R_{wt} (returns on the world stock index), R_{rft} (the three-month domestic interest rate), and p_{oilt} (the logarithm of the world oil price).[4] Returns on the world stock market capture shocks from other financial markets around the globe. Interest rates reflect domestic monetary policy and the availability of credit, given that monetary authorities are using interest rate rules responding to inflation and output. The oil price can be seen as representing supply shocks; for example Amano and van Norden (1998) showed that world oil price movements can capture the underlying shocks to the terms of trade. In most cases a lag length *p=1* is sufficient to capture the dynamics associated with financial returns. If necessary, further lags are added to eliminate any serial correlation on the basis of the multivariate *Q*-statistics of Hosking (1981) on the standardised residuals $z_{it} = \varepsilon_{it}/\sqrt{h_{it}}$ for *i = S, E*.

Note that in the event of detecting cointegration between stock market prices and exchange rates, (1) is also augmented by a lagged error correction term (ect_{t-1}), as shown below, in line with Li et al., (2001). The exclusion of an error correction term in the differenced VAR gives rise to a vector moving average term that is generally non-invertible (see Burke and Hunter, 2005). Cointegration is tested using the Gregory and Hansen (1996) method that allows for a single unknown endogenous structural break:

$$R_t = \mu + \sum_{i=1}^{p} \psi_i R_{t-i} + \lambda R_{w,t} + \gamma R_{rf,t} + \delta \Delta P_{oil,t} + \eta\, ect_{t-1} + \varepsilon_t \qquad (2)$$

[4] Returns on the world stock index for all countries in the sample except the US are represented by returns on the S&P 500 index. In the case of the US, the world stock index is represented by the MSCI world (excluding the US) index. The world oil price is represented by the West Texas Intermediate Cushing crude oil spot index, US dollars per barrel. The data have been obtained from DataStream.

Having specified the conditional mean equation, a differenced VAR (Sims, 1980) is estimated in the case of no cointegration between the two financial assets, whereas a vector error correction form is adopted (Johansen, 1995) when the variables are cointegrated. The model is then estimated conditional on the multivariate GARCH model in the BEKK form. This ensures that the estimated conditional covariance matrices are positive definite by constraining them to be symmetric. The conditional variance can be expressed as follows:

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B, \quad (3)$$

More explicitly:

$$\begin{bmatrix} H_{SS,t} & H_{SE,t} \\ H_{ES,t} & H_{EE,t} \end{bmatrix} = C'C + A'\begin{bmatrix} u_{S,t-1}^2 & u_{S,t-1}u_{E,t-1} \\ u_{E,t-1}u_{S,t-1} & u_{E,t-1}^2 \end{bmatrix} A + B'\begin{bmatrix} H_{SS,t-1} & H_{SE,t-1} \\ H_{ES,t-1} & H_{EE,t-1} \end{bmatrix} B. \quad (4)$$

Where C is a lower triangular matrix, and A and B are ARCH and GARCH parameter matrices:

$$C = \begin{bmatrix} c_{SS} & 0 \\ c_{ES} & c_{EE} \end{bmatrix}, A = \begin{bmatrix} a_{SS} & a_{SE} \\ a_{ES} & a_{EE} \end{bmatrix}, B = \begin{bmatrix} b_{SS} & b_{SE} \\ b_{ES} & a_{EE} \end{bmatrix}.$$

It follows from (4) that in the BEKK form each conditional variance and covariance in H_t is modelled as a linear function of lagged conditional variances and covariances, and lagged squared innovations and the cross-product of the innovations. Note that the variance-covariance matrix is not extended to take into account asymmetric responses as sign and size bias tests (as in Engle and Ng, 1993) produced no evidence of asymmetry for the two variables.[5]

[5] These results are not reported to save space; however, they are available upon request.

Volatility is transmitted between stock returns and exchange rate changes through two channels represented by the off-diagonal parameters in the ARCH and GARCH matrices: a symmetric shock $u_{i,t-1}$ and the conditional variance $H_{ii,t-1}$. Specifically, volatility transmission from stock returns to exchange rate changes is tested by setting $a_{SE} = b_{SE} = 0$, and in the reverse direction $a_{ES} = b_{ES} = 0$. Using Monte Carlo Simulation, Hafner and Hewartz (2008) showed that these causality-in-variance tests in the context of multivariate GARCH-BEKK models have superior power to the cross-correlation function (CCF) two-step approach proposed by Cheung and Ng (1996). Causality-in-variance is tested using a likelihood ratio test statistic:

$$LR=-2(L_r - L_{ur}) \sim \chi^2_{df} \tag{5}$$

where L_r and L_{ur} indicate the restricted and unrestricted log-likelihood function values; LR follows the chi-squared distribution with the degrees of freedom equal to the number of restricted parameters.

When the innovations are assumed to be normally distributed, the log-likelihood function is given by:

$$L(\theta) = \frac{-Tn}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{t}(\ln|H_t| + \varepsilon'_t H^{-1}{}_t \varepsilon_t) \tag{6}$$

where $n = 2$, T is 209 and 228 respectively for the pre-crisis and crisis periods, and θ is a vector of unknown parameters. Specifically, the quasi-maximum likelihood estimator of Bollerslev and Wooldridge (1992) is applied as the corresponding computed standard errors are robust even when the error process is non-normal.[6] We also employ the multivariate Q-statistics (Hosking, 1981) for the

[6] The procedure was implemented with a convergence criterion of 0.00001, using the quasi-Newton method of Broyden, Fletcher, Goldfarb, and Shanno, which does not require exact estimates of the matrix of second derivatives in contrast to the approach of Berndt, Hall, Hall, and Hausman (see Sargan, 1988).

squared standardised residuals to determine the adequacy of the estimated model of the conditional variance-covariance matrix to capture the multivariate ARCH and GARCH dynamics.

5. Empirical results

5.1. Cointegration test results

The first step is to examine the time series properties of the stock price and exchange rate series. Then, cointegration is tested using the Gregory and Hansen (1996) procedure which allows for a single unknown structural break. This test is likely to be more informative, especially in the crisis period, than time-invariant cointegration tests such as the Johansen (1995) trace test and the pairwise Engle and Granger (1987) test (see Campos et al.,1996; Gregory and Hansen, 1996). The test results are displayed in Table 1.

[Insert Table 1 about here]

The null hypothesis of no cointegration between stock prices and exchange rates is rejected in three cases, in particular, for the euro area and Japan in the pre-crisis period, and for the UK in the crisis period. This suggests that the comovement between stock prices and exchange rates in the euro area and Japan had broken down by the onset of the financial crisis. A possible explanation in the case of Japan is the overvaluation of the yen since 2008. Specifically, the yen hit a record high against the US dollar in late 2011 with the crisis leading to a decoupling of the Japanese stock and foreign exchange markets in the long run. In the euro area, the depreciation of the euro and the uncertainty surrounding the single currency ever since the onset of the crisis might be the reason for the breakdown of the long-run. By contrast, it seems that the long-run relation between financial markets in the UK was strengthened by the financial crisis, which led to both series being influenced by similar underlying factors and as a result sharing a single common stochastic trend.

Note that the lack of cointegrating relations may also be the result of misspecification as other fundamental economic variables may work as channels through which the two types of financial markets (stock and foreign exchange markets) are linked in the long run. However, our findings of limited cointegration between stock prices and exchange rates are in line with much of the existing empirical literature (Bahmani-Oskooee and Sohrabian, 1992; Granger et al., 2000; Nieh and Lee, 2001; Alagidede et al., 2011).

5.2. Multivariate VAR-GARCH (1, 1) BEKK results

The quasi-maximum likelihood estimates of the bivariate GARCH-BEKK parameters as well as the associated multivariate *Q*-statistics (Hosking, 1981) are displayed in Tables 2–7 for Japan, the US, the euro area, Canada, Switzerland, and the UK in turn. Panels A and B concern the pre-crisis and crisis periods, respectively. On the basis of the cointegration tests of Section 5.1, the lagged error correction terms are included in the conditional mean equations for the cases for which cointegration was detected. The Hosking multivariate *Q*-statistics for the standardised residuals indicate no serial correlation at the 5% level. In all cases, a lag length of 1 captures the dynamics, except for the UK in the pre-crisis sample where p = 3 and the US and Switzerland in the crisis sample where p = 3 and p = 5 are required, respectively (note that the insignificant parameters in the mean equations are excluded). Overall, the estimated models appear to be well specified.

[Insert Tables 2–7 about here]

The dynamic interactions between the first moments of stock returns and exchange rate changes, captured by $\psi_{ES}^{(i)}$ and $\psi_{SE}^{(i)}$, suggest that there are limited dynamic linkages between the two variables in the pre-crisis compared with the crisis period. The results for the pre-crisis period imply the existence of return spillovers from stock returns to exchange rate changes in the case of Japan, while there are spillovers in the opposite direction in the UK. However, since lagged error correction terms are included in the cases of cointegration, there will be a further channel for causality between the two variables through the error correction term if this is negative and significant as, for example, in Japan in the equations for both stock returns and exchange rates changes. This implies that both variables adjust to the steady-state equilibrium in Japan, and there is bidirectional feedback. By contrast, the lagged error correction term in the euro area is negative and significant only in the equation for exchange rate changes, suggesting that the adjustment towards equilibrium takes place through this variable.

In the crisis period, instead, the results indicate the existence of spillovers from stock returns to exchange rates changes in the US and the UK, in the opposite direction in Canada, and bidirectional spillovers in the euro area and Switzerland. With regard to the UK, the lagged error correction term in the equation for exchange rate changes is found to be negative and significant, implying an adjustment mechanism through the exchange rate and reinforcing the evidence of causality from stock returns to exchange rate changes.

Granger et al. (2000) concluded that capital flows played a major role in the interactions between stock prices and exchange rates during the Asian flu period. Fig. 2 shows the evolution of portfolio investment liabilities and current accounts as a percentage of GDP for all countries over the sample period considered here. The causality from stock returns to exchange rate changes in the US and UK is seemingly consistent with the portfolio approach. Given that the US was the centre of the crisis, the decline in the stock market at the onset of the crisis in late 2007, along with the collapse of LB and the downgrade of its debt status, induced capital outflows (see Fig. 2) and a depreciation of its currency. This also applies to the UK as the collapse of LB in the US and the shutdown of their offices in London sent a wave of panic right through the UK stock market followed by severe downturns and a sharp depreciation of the British pound.

[Insert Fig. 2 about here]

The finding of causality from exchange rate changes to stock returns in Canada, on the other hand, is consistent with the monetary approach. The depreciation of the Canadian dollar resulted in a decline of the Canadian stock market, even though Canada did not seem to experience major capital outflows compared to other countries. The lack of any interactions between stock returns and exchange rate changes in Japan, by contrast, can be attributed to country-specific factors. The fact that Japan is a well-regulated economy and owns huge foreign exchange reserves played a significant role in strengthening its currency and making it immune to the crisis (Wong and Li, 2010).

As far as the exogenous variables in the conditional mean equations are concerned, the return on the world stock index exerts strong influence on stock returns and exchange rates changes in most cases, especially in the crisis period, suggesting its dominance in the transmission of shocks and information to other markets around the globe. The impact of the domestic interest rate, by contrast, appears to be limited. This reinforces the notion that the quantitative easing policies adopted by the monetary authorities throughout the crisis period were ineffective. One possible explanation is that the economic cycle did not respond because of the breakdown of both the financial system and the monetary transmission mechanism via the banks.

With regard to the influence of world oil price changes, this increased in the crisis period compared with the pre-crisis one in most countries, except Switzerland. The effects on stock returns in the case of Switzerland, in the pre-crisis period, and Canada and the UK, in the crisis period, are consistent with the findings of Filis et al. (2011), who argued that stock markets react positively to demand-side oil price shocks. The two periods in this study are characterised by such shocks. The pre-crisis period was accompanied by an increase in oil prices because of an increase in demand, primarily in China, whereas in the crisis period there was a decline in oil prices as a consequence of the global recession induced by the financial crisis. The increased impact of oil price changes on exchange rate changes in the crisis period compared with the pre-crisis one, on the other hand, is in line with the findings of Roboredo (2011). During the crisis, the impact on the US dollar and Japanese yen is negative, whereas for the British pound, the Canadian dollar, and euro is positive, consistently with the findings of Lizardo and Mollick (2010).

Next, the estimates of the conditional variance equations suggest that the stock price–exchange rate process in the two sub-periods displays strong conditional heteroscedasticity: the diagonal elements of the ARCH matrices are positive and significant in 79% of the cases in the pre-crisis period and 87.5%

during the crisis period. The conditional variances, on the other hand, exhibit persistence in all cases with only two exceptions, i.e., US stock returns and UK exchange rate changes in the pre-crisis period. More specifically, the estimated conditional variances of stock returns range from 0.62 (the lowest) for the UK to 0.85 (the highest) for Japan in the pre-crisis period, whilst they range from 0.66 (the lowest) for Switzerland to 0.95 (the highest) for the UK in the crisis period. The corresponding estimates for exchange rate changes range from 0.60 (the US) to 0.95 (Canada and euro area) in the pre-crisis period and from 0.43 (euro area) to 0.98 (US) in the crisis period.

Furthermore, the off-diagonal elements of the ARCH and GARCH matrices indicate that shocks to exchange rate changes (stock returns) affect the conditional variance of stock returns (exchange rate changes) in Japan and Switzerland across the two sub-periods, the UK in the pre-crisis period, and Canada and the US in the crisis period; the 5% critical value of the chi-squared distribution with 4 degrees of freedom is 9.49.

More specifically, the results of the likelihood ratio tests suggest the existence of causality-in-variance that operates as an information flow, from exchange rate changes to stock returns in the UK, Japan, and Canada in the pre-crisis period. In the crisis period, there is evidence of causality-in-variance from stock returns to exchange rate changes in Japan, in the opposite direction in the euro area and Switzerland, and of bidirectional feedback in the US and Canada. Therefore these two types of financial markets appear to have become integrated in all countries, except the UK, during the recent financial crisis.

The Hosking multivariate *Q*-statistics of order (4) and (8) for the squared standardised residuals suggests at the 5% significance level that the multivariate GARCH (1,1) structure adequately captures volatility, and hence no further variance dynamics are required.

6. Conclusions

In this study, we have analysed the nature of the linkages between stock market returns and exchange rate changes in six advanced economies, namely the US, the UK, Canada, Japan, the euro area, and Switzerland. Specifically, we have examined the extent to which they have been affected by the banking crisis of 2007–2010 employing weekly data from August 2003 to December 2011. The estimation of bivariate GARCH-BEKK models provides evidence of unidirectional spillovers from stock returns to exchange rate changes in the US and the UK, in the opposite direction in Canada, and of bidirectional feedback in the euro area and Switzerland during the recent financial crisis. Our findings are consistent with those of Granger et al. (2000) and Caporale et al. (2002), who examined the 1997 Asian financial crisis.

Furthermore, causality-in-variance tests for the crisis period lend support to the existence of causality-in-variance from stock returns to exchange rate changes in Japan, in the opposite direction in the euro area and Switzerland, and of bidirectional feedback in the US and Canada. These results reflect cross-country differences in terms of policies, cycle phases, expectations, the degree of liberalisation, and capital controls (Nieh and Lee, 2001). Furthermore, given the fact that the currencies under investigation are the most actively traded and the corresponding economies are top trading partners, their heterogeneous strength throughout the financial crisis may have played an important role in generating capital flows into and out of these countries. This might be one of the reasons for the different results when analysing the interactions between stock returns and exchange rate changes in these economies.

Finally, our findings also imply the existence of limited diversification opportunities on a domestic basis during financial crises. Since stock prices and exchange rates have been shown to be interlinked strongly within national economies, it follows that investors cannot use them as effective instruments for portfolio hedging and diversification strategies. This applies to all countries examined except the UK.

Appendix A

Appendix Table A: Summary of descriptive statistics for weekly data of stock returns and traded-weighted exchange rate changes.

Statistics	Variable	Canada	UK	Euro area	Japan	Switzerland	US
Panel A: Pre-crisis Period (6/8/2003 – 8/8/2007)							
Mean	R_E	0.128	0.045	0.034	-0.044	-0.022	-0.078
	R_S	0.313	0.216	0.278	0.288	0.279	0.209
St. Dev	R_E	0.987	0.692	0.573	0.976	0.468	0.887
	R_S	1.567	1.456	1.805	2.307	1.638	1.327
Skewness	R_E	-0.152	-0.060	0.040	0.300	0.418	0.256
	R_S	-0.584	-0.861	-0.747	-0.441	-0.714	-0.412
Ex. kurtosis	R_E	2.875	2.977	4.335	3.370	3.513	3.009
	R_S	3.497	5.227	4.056	3.445	4.012	3.137
JB	R_E	0.942	0.133	15.595[a]	4.341	8.398[a]	2.284
	R_S	14.048[a]	69.064[a]	29.19[a]	8.527[b]	26.700[a]	6.098[b]
*LB(*10)	R_E	8.299	15.379	14.91	17.039[c]	14.047	3.454
	R_S	12.684	12.435	9.081	10.439	7.159	16.687[c]
LB^2(10)	R_E	14.113	6.917	29.125[a]	23.688[a]	23.874[a]	11.081
	R_S	24.280[a]	7.402	4.876	16.027[c]	8.148	5.054
Panel B: Crisis Period (15/8/2007 – 28/12/ 2011)							
Statistics	Variable	Canada	UK	Euro area	Japan	Switzerland	US
Mean	R_E	0.0153	-0.110	-0.024	0.186	0.122	-0.047
	R_S	-0.046	-0.045	-0.271	-0.294	-0.168	-0.051
St. Dev	R_E	1.754	1.2755	0.995	1.655	1.344	1.160
	R_S	2.952	3.061	4.526	3.755	2.926	3.159
Skewness	R_E	-0.217	0.250	0.432	0.595	-1.634	-0.554
	R_S	-0.817	-0.753	-0.677	-0.834	-0.485	-0.936
Ex. kurtosis	R_E	4.184	6.072	6.587	4.808	19.833	6.274
	R_S	6.046	4.502	4.939	8.018	6.1306	6.997
JB	R_E	15.122[a]	92.049[a]	129.36[a]	44.534[a]	2793.4[a]	113.58[a]
	R_S	113.55[a]	43.014[a]	53.18[a]	265.74[a]	102.06[a]	185.1[a]
LB(10)	R_E	15.365	20.988[b]	17.594[c]	12.489	21.872[b]	16.777[c]
	R_S	34.121[a]	17.910[c]	27.242[a]	13.784	14.475	16.506[c]
LB^2(10)	R_E	115.31[a]	106.16[a]	38.498[a]	51.492[a]	36.632[a]	21.726[b]
	R_S	54.807[a]	35.511[a]	27.242[a]	31.010[a]	46.755[a]	32.214[a]

R_S and R_E indicate stock market returns and exchange rate changes, respectively. *LB*(p) and $LB^2(p)$ are Ljung-Box tests for p^{th}-order serial correlation on the returns $R_{i.t}$ and squared returns $R_{i,t}^2$, respectively where *i* = *S*, *E*. JB is the Jarque-Bera test for normality.

[a] significant at 1 %.

[b] significant at 5%.

[c] significant at 10%.

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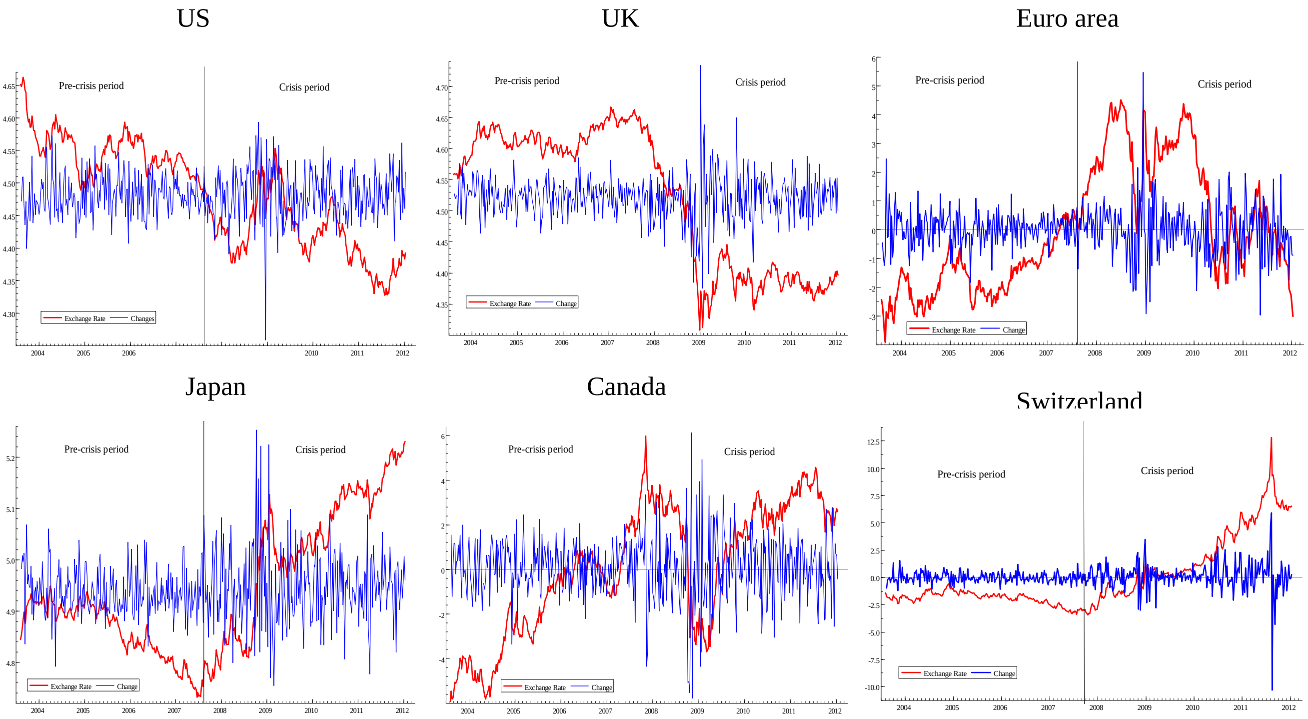

Fig. 1a. Weekly trade-weighted exchange rates with their corresponding changes over the period August 6, 2003-December 28, 2011.

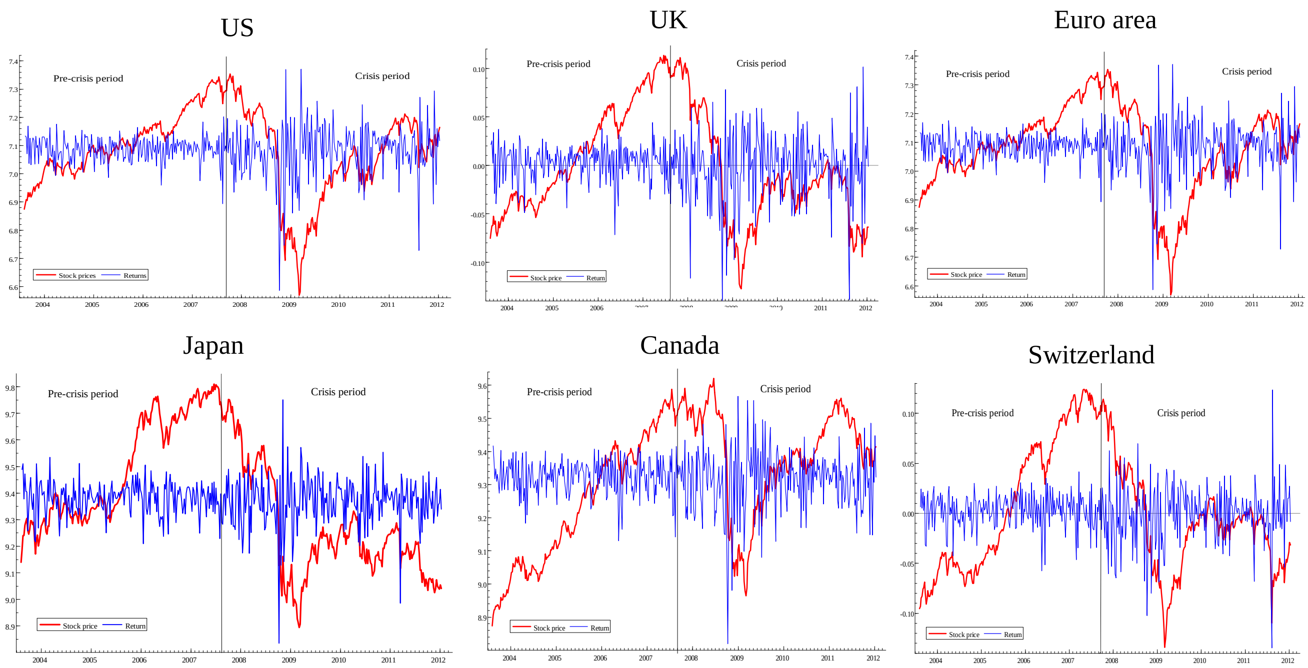

Fig. 1b. Weekly stock market prices with their corresponding returns over the period August 6, 2003-December 28, 2011.

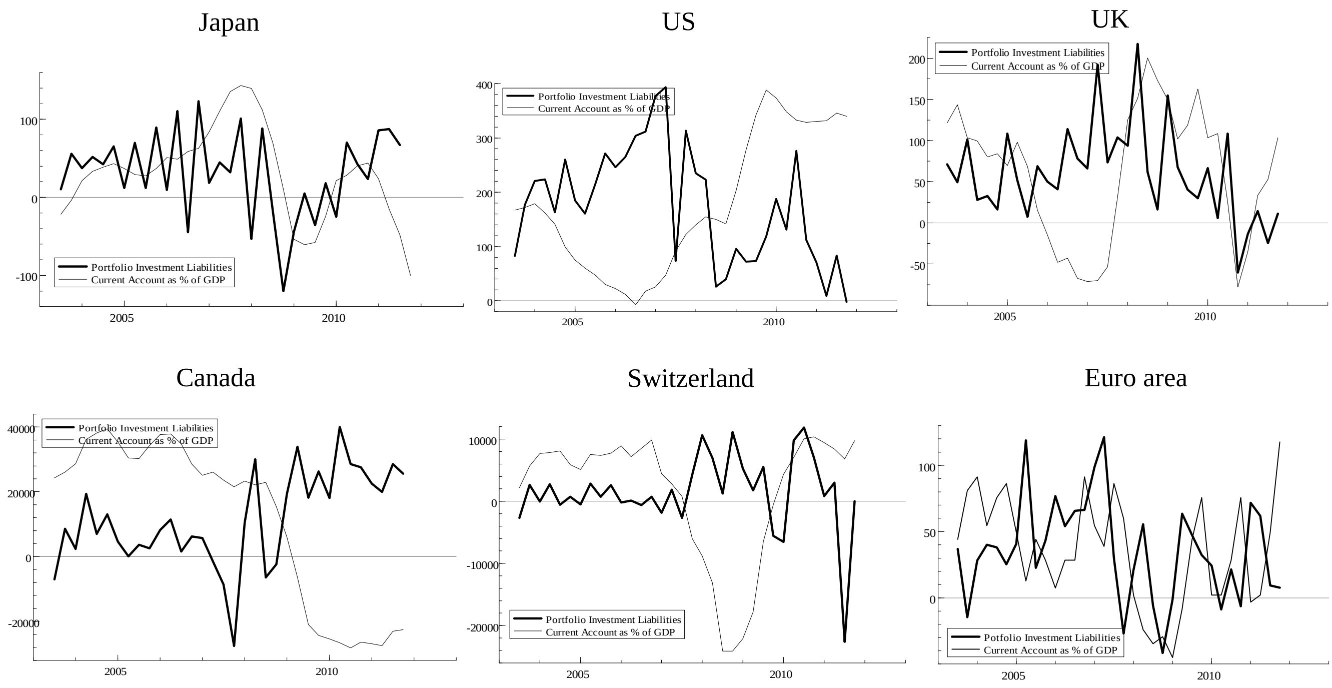

Fig. 2. The evolution of portfolio investment liabilities and current account as a percentage of GDP over the sample period (August 6, 2003-December 28, 2011) (Source: Bloomberg).

Table 1
Results of Gregory and Hansen (1996)' cointegration tests allowing for a shift at unknown date.

Regression	Model	US	UK	Euro area	Canada	Japan	Switzerland
Panel A: Pre-crisis Period (6/8/2003 – 8/8/2007)							
s_t on e_t	C	-3.19196(0)	-3.08175(4)	-3.82809(5)	-3.67072(7)	-4.70262(6)[b]	-4.02025(7)
		[2005:10:12]	[2004:03:17]	[2005:07:13]	[2006:09:20]	[2005:10:05]	[2004:04:21]
	C/T	-4.53539(8)	-4.63858(8)	-4.90082(8)	-4.05644(3)	-4.82672(0)	-3.90222(1)
		[2007:01:10]	[2004:05:26]	[2004:05:26]	[2004:06:09]	[2005:10:19]	[2005:10:12]
	C/S	-4.53539(0)	-3.17808(4)	-3.87397(3)	-3.86972(0)	-4.55561(6)	-4.16180(1)
		[-4.53539]	[2005:05:18]	[2005:04:20]	[2006:12:20]	[2005:10:05]	[2005:07:20]
e_t on s_t	C	-3.53476(0)	-3.75928(4)	-3.45693(5)	-3.46975(7)	-4.06898(6)	-4.01916(0)
		[2005:06:08]	[2006:09:13]	[2005:07:13]	[2006:09:20]	[2006:09:06]	[2004:04:21]
	C/T	-3.76708(0)	-3.60004(5)	-5.04845(0)[b]	-3.53679(7)	-4.45423(6)	-4.67705(0)
		[2005:06:08]	[2006:09:06]	[2005:05:25]	[2006:09:20]	[2004:11:10]	[2004:05:26]
	C/S	-4.53794(0)	-3.83692(4)	-3.49849(5)	-3.87491(0)	-4.33849(6)	-4.06924(0)
		[2005:06:08]	[2006:06:14]	[2005:07:13]	[2006:12:20]	[2006:07:12]	[2004:05:26]
Panel B: Crisis Period (15/8/ 2007- 28/12/ 2011)							
s_t on e_t	C	-3.84091 (0)	-4.40818(0)	-2.82358(7)	-3.11350(0)	-3.56361(0)	-2.96637(5)
		[2008:10:01]	[2009:09:02]	[2008:08:06]	[2008:11:26]	[2009:12:16]	[2008:08:27]
	C/T	-4.24787 (0)	-4.43335(0)	-3.10692(8)	-3.13766(8)	-4.04147(0)	-3.13346(0)
		[2008:10:01]	[2009:09:02]	[2008:07:30]	[2008:11:26]	[2008:06:04]	[2008:09:24]
	C/S	-4.28696(0)	-4.84225(0)	-2.65910(7)	-3.09940(8)	-4.33630(0)	-3.74662(5)
		[2008:09:10]	[2009:05:13]	[2008:08:06]	[2008:11:12]	[2009:07:15]	[2009:09:30]
e_t on s_t	C	-3.53036(5)	-4.56105(0)	-3.70638(7)	-3.22176(8)	-3.59815(0)	-2.89831(6)
		[2008:08:27]	[2009:09:02]	[2010:03:17]	[2009:08:05]	[2009:12:16]	[2010:06:30]
	C/T	-4.23494(6)	-4.45426(0)	-3.95378(7)	-3.19527(8)	-4.06951(0)	-3.79277(5)
		[2010:02:03]	[2008:11:19]	[2010:03:17]	[2009:07:29]	[2008:06:04]	[2010:10:20]
	C/S	-3.44785(5)	-5.12481(0)[b]	-3.96372(7)	-3.28833(8)	-3.91908(0)	-3.20739(6)
		[2008:04:23]	[2009:09:02]	[2010:04:14]	[2009:12:16]	[2009:12:16]	[2010:04:14]

The test due to Gregory and Hansen (1996) is conducted by regressing s_t on e_t and the reverse regression. Model C allows for a shift in the intercept, Model C/T allows for a shift in the intercept and trend, and Model C/S allows for a shift in both intercept and slope vector. The corresponding critical values for each model are from Table 1 in Gregory and Hansen (1996). The lag order is chosen on the basis of *t*-tests in parenthesis (.) subject to a maximum of 8 lags. Breakpoints are in square brackets [.].

[a] significant at 1 %.

[b] significant at 5%.

Table 2

The estimated bivariate GARCH-BEKK model for Japan.

Panel A: Pre-crisis Period (6/8/ 2003-8/8/2007)	R_S (*i*=*S*)	R_E (*i*=*E*)	Panel B: Crisis period (15/8/2007-28/12/2011)	R_S (*i*=*S*)	R_E (*i*=*E*)
Conditional Mean Equation					
μ_i	0.065 (0.134)	-0.097 (0.064)	μ_i	-0.283^b (0.136)	0.202^a (0.072)
$\psi_{Si,t-1}$	0.136^b (0.057)		$\psi_{Ei,t-1}$		-0.151^a (0.049)
$\psi_{Ei,t-1}$	0.052^b (0.024)		λ_i	0.966^a (0.053)	-0.271^a (0.030)
η_i	-3.293^b (1.446)	-3.395^a (0.931)	δ_i		-0.044^a (0.015)
λ_i	0.859^a (0.089)				
Conditional Variance Equation					
c_{Si}	0.702^a (0.151)	0	c_{Si}	1.513^a (0.291)	0
c_{Ei}	-0.554^a (0.046)	0.000002 (0.353)	c_{Ei}	-0.591^a (0.080)	-0.00001 (0.044)
α_{Si}	0.159^a (0.057)	0.062 (0.065)	α_{Si}	0.053 (0.145)	0.115 (0.091)
α_{Ei}	-0.646^a (0.052)	0.391^a (0.121)	α_{Ei}	-0.466^a (0.136)	0.312^a (0.088)
b_{Si}	0.855^a (0.041)	0.124^a (0.027)	b_{Si}	0.719^a (0.037)	0.125^a (0.025)
b_{Ei}	0.147^c (0.091)	0.712^a (0.028)	b_{Ei}	0.053 (0.074)	0.931^a (0.044)
Loglik	-694.856		*Loglik*	-862.384	
$Q(6)$	9.426[0.894]	$Q^2(6)$ 15.119[0.653]	$Q(6)$	20.755[0.188]	$Q^2(6)$ 20.392[0.118]
$Q(12)$	23.78[0.851]	$Q^2(12)$ 43.472[0.249]	$Q(12)$	32.592[0.437]	$Q^2(12)$ 26.587[0.644]
Tests of No Volatility Transmission:			Tests of No Volatility Transmission:		
(i) Between R_S and R_E			(i) Between R_S and R_E		
$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$		*LR*=14.103	$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$		*LR*=10.674
(ii) From R_S to R_E			(ii) From R_S to R_E		
$H_0: \alpha_{SE}=b_{SE}=0$		*LR*=5.637	$H_0: \alpha_{SE}=b_{SE}=0$		*LR*=8.177
(iii) From R_E to R_S			(iii) From R_E to R_S		
$H_0: \alpha_{ES}=b_{ES}=0$		*LR*=12.343	$H_0: \alpha_{ES}=b_{ES}=0$		*LR*=5.637

R_S and R_E indicate stock market returns and exchange rate changes, respectively; while *LR* indicates likelihood ratio test statistics. Heteroscedasticity-consistent standard errors are in parentheses (.), whereas *p*-values are reported in [.]. *Q* (*p*) and Q^2 (*p*) are multivariate Hosking (1981) tests for p^{th} order serial correlation on the standardized residuals z_{it} and their squares z_{it}^2, respectively where *i* = 1 (for stock market returns (*S*)), 2 (for exchange rates changes (*E*)).

[a] significant at 1 %.

[b] significant at 5%.

[c] significant at 10%.

Table 3

The estimated bivariate GARCH-BEKK model for the US.

Panel A: Pre-crisis Period (6/8/ 2003-8/8/2007)			Panel B: Crisis Period (15/8/2007-28/12/2011)		
	R_S (*i*=*S*)	R_E (*i*=*E*)		R_S (*i*=*S*)	R_E (*i*=*E*)
Conditional Mean Equation					
μ_i	0.025 (0.053)	0.016 (0.046)	μ_i	0.165^a (0.082)	−0.016 (0.058)
$\psi_{Si,t-1}$	-0.217^a (0.043)		$\psi_{Si,t-1}$	-0.068^b (0.030)	
λ_i	0.522^a (0.033)	-0.244^a (0.026)	$\psi_{Ei,t-1}$	0.026^c (0.015)	
δ_i	-0.028^a (0.006)		$\psi_{Ei,t-2}$	0.035^b (0.016)	0.128^a (0.043)
			$\psi_{Si,t-3}$	0.055^c (0.028)	
			λ_i	0.735^a (0.034)	-0.172^a (0.028)
			δ_i		-0.029^b (0.012)
Conditional Variance Equation					
c_{Si}	0.211 (0.260)	0	c_{Si}	0.093 (0.148)	0
c_{Ei}	0.260 (0.095)	0.0001 (0.147)	c_{Ei}	0.286^a (0.084)	−0.000006 (0.147)
α_{Si}	0.032 (0.092)	−0.028 (0.099)	α_{Si}	0.474^a (0.078)	0.120^a (0.054)
α_{Ei}	-0.207^b (0.082)	0.299^a (0.090)	α_{Ei}	−0.009 (0.115)	-0.213^a (0.055)
b_{Si}	0.150 (0.097)	-0.573^a (0.100)	b_{Si}	0.718^a (0.054)	-0.188^a (0.044)
b_{Ei}	0.610^a (0.126)	0.604^a (0.094)	b_{Ei}	0.543^a (0.083)	0.988^a (0.048)
Loglik	-504.510		*Loglik*	-670.683	
$Q(6)$	9.492[0.891]	$Q^2(6)$ 5.497[0.977]	$Q(6)$	25.932[0.054]	$Q^2(6)$ 21.370[0.092]
$Q(12)$	19.83[0.954]	$Q^2(12)$ 26.13[0.668]	$Q(12)$	43.881[0.078]	$Q^2(12)$ 41.429[0.080]
Tests of No Volatility Transmission:			Tests of No Volatility Transmission:		
(i) Between R_S and R_E			(i) Between R_S and R_E		
$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$		*LR*=5.258	$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$		*LR*=28.155
(ii) From R_S to R_E			(ii) From R_S to R_E		
$H_0: \alpha_{SE}=b_{SE}=0$		*LR*=2.894	$H_0: \alpha_{SE}=b_{SE}=0$		*LR*=24.591
(iii) From R_E to R_S			(iii) From R_E to R_S		
$H_0: \alpha_{ES}=b_{ES}=0$		*LR*=0.638	$H_0: \alpha_{ES}=b_{ES}=0$		*LR*=21.034

The notes of this Table are the same as in Table 2.

Table 4

The estimated bivariate GARCH-BEKK model for the euro area.

Panel A: Pre-crisis Period (6/8/ 2003-8/8/2007)			Panel B: Crisis Period (15/8/2007-28/12/2011)		
	R_S (*i*=*S*)	R_E (*i*=*E*)		R_S (*i*=*S*)	R_E (*i*=*E*)
Conditional Mean Equation					
μ_i	0.118 (0.084)	-0.235^c (0.142)	μ_i	-0.176 (0.166)	-0.201^a (0.076)
η_i		-7.076^a (2.336)	$\psi_{Si,t-1}$	-0.175^a (0.043)	0.278^c (0.154)
λ_i	0.857^a (0.054)		$\psi_{Ei,t-1}$	-0.032^b (0.014)	
γ_i		0.096^b (0.045)	λ_i	1.000^a (0.051)	0.045^c (0.024)
			γ_i		0.050^b (0.023)
			δ_i		0.060^a (0.012)
Conditional Variance Equation					
c_{Si}	0.734^b (0.146)	0	c_{Si}	0.098 (0.221)	0
c_{Ei}	0.116 (0.074)	-0.003 (0.158)	c_{Ei}	-0.589^a (0.082)	-0.00001 (0.402)
α_{Si}	0.362^a (0.100)	0.038 (0.029)	α_{Si}	0.310^a (0.107)	-0.030 (0.036)
α_{Ei}	-0.033 (0.341)	0.163^c (0.102)	α_{Ei}	-0.461^c (0.249)	0.666^a (0.172)
b_{Si}	0.733^a (0.094)	-0.036 (0.042)	b_{Si}	0.870^a (0.040)	0.021 (0.031)
b_{Ei}	-0.223 (0.207)	0.951^a (0.056)	b_{Ei}	0.781^a (0.192)	0.435^b (0.205)
Loglik	-512.1292		*Loglik*	-794.673	
$Q(6)$ 25.098[0.068]	$Q^2(6)$ 19.052[0.162]		$Q(6)$ 16.313[0.431]	$Q^2(6)$ 10.362[0.664]	
$Q(12)$ 34.407[0.353]	$Q^2(12)$ 38.467[0.138]		$Q(12)$ 35.831[0.293]	$Q^2(12)$ 25.235[0.665]	
Tests of no volatility transmission:			Tests of no volatility transmission:		
(i) Between R_S and R_E			(i) Between R_S and R_E		
$H_0: \alpha_{SE} = \alpha_{ES} = b_{SE} = b_{ES} = 0$		*LR*=3.740	$H_0: \alpha_{SE} = \alpha_{ES} = b_{SE} = b_{ES} = 0$		*LR*=7.254
(ii) From R_S to R_E			(ii) From R_S to R_E		
$H_0: \alpha_{SE} = b_{SE} = 0$		*LR*=1.567	$H_0: \alpha_{SE} = b_{SE} = 0$		*LR*=0.926
(iii) From R_E to R_S			(iii) From R_E to R_S		
$H_0: \alpha_{ES} = b_{ES} = 0$		*LR*=2.491	$H_0: \alpha_{ES} = b_{ES} = 0$		*LR*=9.466

The notes of this Table are the same as in Table 2.

Table 5
The estimated bivariate GARCH-BEKK model for Canada.

Panel A: Pre-crisis Period (6/8/ 2003-8/8/2007)			Panel B: Crisis Period (15/8/2007-28/12/2011)		
	R_S (i=S)	R_E (i=E)		R_S (i=S)	R_E (i=E)
Conditional Mean Equation					
μ_i	0.170^b (0.073)	0.105^c (0.061)	μ_i	-0.109 (0.091)	0.037 (0.071)
λ_i	0.750^a (0.056)	0.152^a 0.052	$\psi_{Si,t-1}$		-0.136^b (0.057)
			$\psi_{Ei,t-1}$		-0.107^b (0.051)
			λ_i	0.641^a (0.037)	0.279^a (0.025)
			δ_i	0.143^a (0.016)	0.061^a (0.014)
Conditional Variance Equation					
c_{Si}	0.371^a (0.133)	0	c_{Si}	0.256^c (0.153)	0
c_{Ei}	-0.210^c (0.126)	-0.000001 (0.075)	c_{Ei}	0.426^a (0.119)	0.000002 (0.091)
α_{Si}	0.258^a (0.068)	0.127 (0.083)	α_{Si}	-0.247^c (0.142)	0.254^a (0.090)
α_{Ei}	0.356^a (0.080)	-0.086 (0.112)	α_{Ei}	0.152^a (0.052)	0.454^a (0.118)
b_{Si}	0.846^a (0.042)	-0.097^c (0.052)	b_{Si}	0.915^a (0.069)	-0.128^c (0.077)
b_{Ei}	0.200^a (0.066)	0.952^a (0.024)	b_{Ei}	0.150^c (0.078)	0.784^a (0.106)

Panel A				Panel B			
Loglik	-604.2614			*Loglik*	-749.813		
$Q(6)$	20.303[0.206]	$Q^2(6)$	19.401[0.150]	$Q(6)$	20.990[0.178]	$Q^2(6)$	10.310[0.739]
$Q(12)$	37.567[0.229]	$Q^2(12)$	31.000[0.415]	$Q(12)$	31.581[0.487]	$Q^2(12)$	29.445[0.494]

Panel A: Tests of No Volatility Transmission:		Panel B: Tests of No Volatility Transmission:	
(i) Between R_S and R_E		(i) Between R_S and R_E	
$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$	*LR*=8.246	$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$	*LR*=26.314
(ii) From R_S to R_E		(ii) From R_S to R_E	
$H_0: \alpha_{SE}=b_{SE}=0$	*LR*=3.171	$H_0: \alpha_{SE}=b_{SE}=0$	*LR*=20.633
(iii) From R_E to R_S		(iii) From R_E to R_S	
$H_0: \alpha_{ES}=b_{ES}=0$	*LR*=8.016	$H_0: \alpha_{ES}=b_{ES}=0$	*LR*=19.299

The notes of this Table are the same as in Table 2.

Table 6

The estimated bivariate GARCH-BEKK model for Switzerland.

Panel A: Pre-crisis Period (6/8/ 2003-8/8/2007)	R_S (*i*=*S*)	R_E (*i*=*E*)	Panel B: Crisis Period (15/8/2007-28/12/2011)	R_S (*i*=*S*)	R_E (*i*=*E*)
Conditional Mean Equation					
μ_i	0.192^{b} (0.092)	-0.016 (0.031)	μ_i	-0.136 (0.117)	0.172^{a} (0.048)
$\psi_{Si,t-1}$	-0.095^{b} (0.047)		$\psi_{Si,t-1}$	-0.107^{b} (0.048)	
λ_i	0.803^{a} (0.051)	-0.043^{b} (0.022)	$\psi_{Ei,t-1}$	0.048^{a} (0.017)	
δ_i	0.020^{c} (0.010)		$\psi_{Si,t-2}$		-0.166^{c} (0.092)
			$\psi_{Ei,t-4}$		-0.195^{a} (0.061)
			$\psi_{Ei,t-5}$		-0.185^{a} (0.054)
			λ_i	0.643^{a} (0.040)	-0.096^{a} (0.017)
Conditional Variance Equation					
c_{Si}	0.513^{a} (0.174)	0	c_{Si}	1.268^{a} (0.251)	0
c_{Ei}	-0.019 (0.060)	0.104^{c} (0.058)	c_{Ei}	-0.306^{a} (0.063)	-0.000001 (0.052)
α_{Si}	-0.047 (0.139)	0.120^{a} (0.030)	α_{Si}	0.203^{b} (0.081)	0.047^{b} (0.022)
α_{Ei}	0.819^{b} (0.412)	0.146 (0.188)	α_{Ei}	-0.553^{a} (0.174)	0.687^{a} (0.109)
b_{Si}	0.848^{a} (0.052)	-0.018 (0.049)	b_{Si}	0.665^{a} (0.130)	0.112^{a} (0.030)
b_{Ei}	-0.005 (0.217)	0.908^{a} (0.045)	b_{Ei}	0.282^{b} (0.117)	0.754^{a} (0.07)
Loglik	-452.951		*Loglik*	-746.106	
$Q(6)$	20.090[0.216]	$Q^2(6)$ 14.296[0.427]	$Q(6)$	30.444[0.062]	$Q^2(6)$ 8.630[0.853]
$Q(12)$	32.829[0.426]	$Q^2(12)$ 29.145[0.509]	$Q(12)$	39.509[0.169]	$Q^2(12)$ 20.28[0.908]
Tests of No Volatility Transmission:			Tests of No Volatility Transmission:		
(i) Between R_S and R_E			(i) Between R_S and R_E		
$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$		*LR*=9.734	$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$		*LR*=18.952
(ii) From R_S to R_E			(ii) From R_S to R_E		
$H_0: \alpha_{SE}=b_{SE}=0$		*LR*=4.945	$H_0: \alpha_{SE}=b_{SE}=0$		*LR*=5.262
(iii) From R_E to R_S			(iii) From R_E to R_S		
$H_0: \alpha_{ES}=b_{ES}=0$		*LR*=1.316	$H_0: \alpha_{ES}=b_{ES}=0$		*LR*=13.659

The notes of this Table are the same as in Table 2.

Table 7

The estimated bivariate GARCH-BEKK model for the UK.

Panel A: Pre-crisis Period (6/8/ 2003-8/8/2007)			Panel B: Crisis Period (15/8/2007-28/12/2011)		
	R_S (*i*=*S*)	R_E (*i*=*E*)		R_S (*i*=*S*)	R_E (*i*=*E*)
Conditional Mean Equation					
μ_i	0.117^c (0.071)	0.055 (0.044)	μ_i	−0.108 (0.136)	−0.042 (0.065)
$\psi_{Si,t-1}$	-0.102^b (0.046)		$\psi_{Si,t-1}$	-0.145^a (0.049)	
$\psi_{Si,t-3}$		0.235^b (0.097)	$\psi_{Ei,t-1}$	-0.062^a (0.020)	
$\psi_{Ei,t-3}$		-0.137^b (0.062)	η_i		-2.645^a (0.724)
λ_i	0.664^a (0.045)		λ_i	0.745^a (0.050)	
			δ_i	0.084^a (0.024)	0.045^a (0.015)
Conditional Variance Equation					
c_{Si}	0.092 (0.090)	0	c_{Si}	0.352^b (0.152)	0
c_{Ei}	-0.633^a (0.039)	−0.00001 (0.435)	c_{Ei}	−0.137 (0.472)	0.382^a (0.110)
α_{Si}	0.120 (0.096)	−0.063 (0.128)	α_{Si}	0.228^a (0.073)	−0.047 (0.043)
α_{Ei}	-0.301^b (0.144)	0.406^a (0.099)	α_{Ei}	−0.025 (0.102)	0.474^a (0.156)
b_{Si}	0.629^a (0.028)	−0.078 (0.139)	b_{Si}	0.959^a 0.025	0.002 (0.058)
b_{Ei}	-0.821^a (0.046)	0.058 (0.280)	b_{Ei}	0.041 (0.047)	0.801^a (0.113)
Loglik	-508.877		*Loglik*	-800.1193	
$Q(6)$	17.948[0.265]	$Q^2(6)$ 14.714[0.397]	$Q(6)$	18.119[0.316]	$Q^2(6)$ 7.921[0.893]
$Q(12)$	42.182[0.107]	$Q^2(12)$ 23.148[0.809]	$Q(12)$	29.472[0.595]	$Q^2(12)$ 15.29[0.987]

Panel A: Tests of No Volatility Transmission:		Panel B: Tests of No Volatility Transmission:	
(i) Between R_S and R_E		(i) Between R_S and R_E	
$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$	*LR*=12.821	$H_0: \alpha_{SE}=\alpha_{ES}=b_{SE}=b_{ES}=0$	*LR*=2.313
(ii) From R_S to R_E		(ii) From R_S to R_E	
$H_0: \alpha_{SE}=b_{SE}=0$	*LR*=0.362	$H_0: \alpha_{SE}=b_{SE}=0$	*LR*=1.317
(iii) From R_E to R_S		(iii) From R_E to R_S	
$H_0: \alpha_{ES}=b_{ES}=0$	*LR*=11.817	$H_0: \alpha_{ES}=b_{ES}=0$	*LR*=0.867

The notes of this Table are the same as in Table 2.