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Volatility spillovers between foreign-exchange and stock markets

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Abstract

This paper empirically analyses the evidence of intra-spillovers and inter-spillovers between foreign exchange and stock markets in the seven economies which concentrate the majority of foreign exchange transactions (i.e. United Kingdom, Euro area, Australia, Swiss, Canada, United Kingdom and Japan), using daily data, during the period 1990 to 2015 and during the pre-global and post-global financial crisis periods. To that end, we employ two econometric methodologies: the C-GARCH methodology by Engle and Lee (1999) and the SVAR framework (Sohel Azad *et al.*, 2015). Results suggest that: (i) permanent and transitory components of the conditional variance exhibit several well-known peaks in volatilities; (ii) the long-run volatility relationships are stronger than the short-run linkages volatility with a reinforcement during the post-global financial crisis period; (iii) the presence of intra-spillovers and inter-spillovers increases substantially during the post-global financial crisis period and (iv) in all samples, the stock markets play a dominant role in the transmission of long-run and short-run volatility, except for in the period after the Global Financial Crisis, where the foreign-exchange markets are the main long-run volatility triggers.

Keywords: Stock markets, Exchange rates, Market spillovers, Component-GARCH model, Long-term volatility, Short-term volatility.

JEL Classification Codes: C32, F31, G15

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Index

1. Introduction 7

2. Econometric methodology 8

2.1 C-GARCH model 9

2.2. SVAR framework 10

2.2.1. Intra-spillovers models 10

2.2.1.1. Long-run intra-spillovers models 10

2.1.2. Short-run intra-spillovers model 10

2.2.2. Inter-spillovers models 10

2.2.2.1. Long-run inter-spillovers models 10

2.2.2.2. Short-run inter-spillovers models 11

2.3 Granger causality 11

3. Data and empirical results 11

3.1 Data 11

3.2. Empirical Results 12

3.2.1. Permanent and transitory components 12

3.2.2. Correlations between permanent components 14

3.2.3. Correlations between transitory components 18

3.2.4. Intra-spilovers 22

3.2.4.1. Full Sample (1 January 1990 to 31 December 2015) 22

3.2.4.2. Sub-samples: Pre-GFC and post-GFC 23

3.2.5. Inter-spillovers 24

3.2.5.1. Full Sample (1 January 1990 to 31 December 2015) 24

3.2.5.2. Sub-samples: Pre-GFC and post-GFC 28

3.2.6. Granger-causality analysis 33

4. Concluding remarks 7

1. Introduction

Economic and financial globalization generates intense co-movement across countries. Mutual relations between foreign exchange markets and stock markets have attracted much attention of researchers and academics since the beginning of 1990s, especially because this influence can help to explain some excess variability in foreign exchange markets, since equity markets have a tendency to develop significant pricing errors [see, e. g., Shiller (1981) and Campbell and Shiller (1987)].

Two theoretical approaches have been proposed in the literature to explain the interdependence between stock prices and exchange rates (the flow-oriented models and the stock-oriented models), providing conflicting results on both the existence of relationship between stock prices and exchange rates and the direction of the relationship. The flow-oriented approach suggest that exchange rates will affect stock prices because they affect the trade balance and the competitiveness of domestic products, thus influencing output and real income; as stock prices reflect the present value of estimated future income, fluctuations in the exchange rate drive fluctuations in the stock price. Therefore, flow-oriented models claim a positive linkage between the exchange rate and stock prices with direction of causation running from exchange rates to stock prices (see, e.g. Dornbusch and Fischer, 1980). Alternatively, the stock-oriented approach emphasizes the role of the financial account in the exchange rates determination. Broadly speaking, two types of stock-oriented models can be identified: the portfolio balance and monetary models. Portfolio balance models postulate a negative relationship between stock prices and exchange rates and come to the conclusion that stock prices have an impact on exchange rates (see, e. g. Frankel, 1983, or Branson and Henderson, 1985). Such models suggest that innovations in the stock market would have an impact on wealth and liquidity, thus influencing money demand and exchange rates. According to the monetary approach, the exchange rate is assimilated into financial asset prices and therefore the actual exchange rate has to be determined by the expected future exchange rate (Macdonald and Taylor, 1993). Since both exchange rates and stock prices may be influenced by a number of common factors, these "stock-oriented" exchange rate models suggest that there is no linkage between exchange rates and stock prices (Gavin, 1989).

The interdependence of stock price returns and exchange rate changes has been extensively examined in the empirical literature with mixed findings on the directional causality[1]. Likewise, empirical evidence on the dynamic linkage between stock and currency market volatilities also provides conflicting findings. Early studies, such as Jorion (1990), suggested that exchange rate fluctuations do not affect stock return volatility, while others (see, for example, Engle, Ito and Lin (1990), Dumas and Solnik, 1995; Roll, 1992) identified the existence of a strong linkage. More recently, Kanas (2000) has analysed volatility transmission between stock and currency markets in the USA, the UK, Japan, Germany, France and Canada finding evidence of spillovers between stock returns and exchange rate changes for five of the six countries analysed (with Germany being the exception). Yang and Doong (2004) investigated volatility spillovers between stock prices and exchange rates for the G-7 countries finding that stock markets play a relatively more important role than foreign exchange markets in the second moment interactions and spillovers. Wang et al. (2013) use a dependence-switching copula model to describe the dependence structure between the stock and foreign exchange markets s for six major industrial countries (Canada, France, Germany, Italy, Japan and the United Kingdom) over the 1990–2010 period concluding that the dependence and tail dependence among the above four market statuses are asymmetric

[1] See Adler and Dumas, 1984; Booth and Rotenberg, 1990; Jorion, 1990; Jorion, 1991; Sercu and Vanhulle, 1992; Smith 1992; Bahmani-Oskooee and Sohrabian, 1992; Bodnar and Gentry, 1993; Bartov and Bodnar, 1994; Choi and Prasad,, 1995; Ajayi and Mougoue, 1996; Chow et al., 1997; Abdalla and Murinde, 1997; He and Ng, 1998; Nieh and Lee, 2001; Granger et al., 2000; Smyth and Nandha, ,2003; Hatemi-J and Irandoust, 2005; Pan et al., 2007; and Inci and Lee, 2014; among others.

for most countries in the negative correlation regime, but symmetric in the positive correlation. Caporale *et al.* (2014) examine the linkages between stock-market prices and exchange rates in six advanced economies, finding evidence of unidirectional Granger causality from stock returns to exchange rate changes in the US and the UK, in the opposite direction in Canada, and bidirectional causality in the Euro area and Switzerland. Andreas *el al.* (2014) explore the structure of the volatility transmission mechanism between stock and currency markets for Euro area economies with systemic fiscal problems, presenting evidence of the presence of bidirectional, asymmetric volatility spillovers between currency and stock markets. Finally, Tian and Hamori (2016) study the cross-market financial shocks transmission mechanism on the foreign exchange, equity, bond, and commodity markets in the United States using a time-varying structural vector autoregression model with stochastic volatility, finding that the dynamics of volatility spillovers vary tremendously over time.

In this study we will focus on the volatility spillovers between foreign-exchange and stock markets[2], since volatility is an important metric of financial performance, indicating uncertainty or risk and volatility spillovers can provide a measure of the transmission of financial stress across the markets. Therefore, our analysis is motivated by the need to better capture the understanding phenomena behind the elusive dynamics of volatility spillovers (namely crashes, distress and contagion), since it seems that the growing interdependence between economies, markets, and asset classes has resulted in increased transmission of negative shocks across markets (see, e. g., Wu, 2001). Furthermore, explaining, predicting and understanding the behaviour of volatility is relevant in valuation, portfolio selection, and risk management as well as designing optimal hedging strategies for options and futures (French et al., 1987; Chou, 1988).

[2] Masson (1999) employs the term "spillovers" for effects that arise from macroeconomic interdependence among developing countries, but following Gelos and Sahay (2001), this paper uses the term in a broader sense where a "spillover" is any type of impact on other financial markets

Given previous research suggesting that returns volatility may contain both short-run and long-run components due to the existence of heterogeneous information flows or heterogeneous agents (see, e. g., Andersen and Bollerslev 1997a, 1997b; and Müller *et al.*, 1997), this paper investigates the existence of such volatility decomposition to assess the strength and direction of the volatility transmission process between the exchange-rate and stock markets. Strength is measured through the correlation between the long- and short-term components, while direction is measured through the causality of these components. Our volatility decomposition is also in line with the classification of the channels of transmission of volatility shocks proposed by Dornbusch *et al.* (2000): fundamental-based and investor behaviour-based links. While the fundamental-based transmission mechanism works through real and financial linkages across countries the behaviour-based mechanism is more sentiment-driven. In this study, we relate the first transmission channel with the long-run component of volatility and the second one with the short-run component of volatility. Indeed, Engle *et al.* (2008) suggest that the short-term component captures the dynamics of conditional volatility associated with the transitory effects of volatility innovations, while the long-term component characterizes the slower variations in the volatility process associated with persistent effects.

The rest of the paper is organized as follows. Section 2 explains the econometric methodology. The data and empirical results are reported in Section 3. Finally, Section 5 summarizes the findings and offers some concluding remarks.

2. Econometric methodology

This section describes the econometric methodology adopted in this study. We follow three steps in the analysis: First, we decompose time-varying volatility into permanent and transitory components and then we analyze whether there are correlations between permanent and transitory components of volatil-

ity between foreign exchange and stock markets. Second, under the SVAR framework, we analyse whether volatility spillsover between the markets reciprocally. Third, we use Granger causality approach to assess whether there is evidence in favour of bidirectional or unidirectional causality.

2.1 C-GARCH model

Engle and Lee (1999) proposed a "component-GARCH" (C-GARCH) model to decompose time-varying volatility into a permanent (long-run) and a transitory (short-run) component. The C-GARCH is a superior volatility model for exchange rates stock markets, being widely used in finance, as it can describe volatility dynamics better than other GARCH models (see Christoffersen *et al*., 2006).

Consider the original GARCH model:

$$\sigma_t^2 = \omega + \alpha(\varepsilon_{t-1} - \omega) + \beta(\sigma_{t-1}^2 - \omega) \quad (1)$$

As can be seen, the conditional variance of the returns here has mean reversion to some time-invariable value, ω. The influence of a past shock eventually decays to zero as the volatility converges to this value according to the powers of (α+β). The standard GARCH model therefore makes no distinction between the long-run and short-run decay behaviour of volatility persistence.

For the permanent specification, the C-GARCH model replaces the time- invariable mean reversion value, ω, of the original GARCH formulation in equation (6) with a time variable component q_t:

$$q_t = \hat{\omega} + \rho(q_{t-1} - \hat{\omega}) + \varphi(\varepsilon_{t-1}^2 - \sigma_{t-1}^2) \quad (2)$$

Here, q_t is the long-run time-variable volatility level, which converges to the long-run time-invariable volatility level $\hat{\omega}$ according to the magnitude of ρ. This permanent component thus describes the long-run persistence behaviour of the variance. The long-run time-invariable volatility level $\hat{\omega}$ can be viewed as the long-run level of returns variance for the relevant sector when past errors no longer influence future variance in any way. Stated differently, the value $\hat{\omega}$ can be seen as a measure of the 'underlying' level of variance for the respective series. The closer the estimated value of the ρ in equation (2) is to one the slower q_t approaches $\hat{\omega}$, and the closer it is to zero the faster it approaches $\hat{\omega}$. The value ρ therefore provides a measure of the long-run persistence.

The second part of C-GARCH model is the specification for the short-run dynamics, the behaviour of the volatility persistence around this long-run time-variable mean, q_t:

$$\sigma_t^2 - q_t = \gamma(\varepsilon_{t-1}^2 - q_{t-1}) + \lambda(\sigma_{t-1}^2 - q_{t-1}) \quad (3)$$

According to this transitory specification, the deviation of the current condition variance from the long-run variance mean at time t $(\sigma_t^2 - q_t)$ is affected by the deviation of the previous error from the long-term mean $(\varepsilon_{t-1}^2 - q_{t-1})$ and the previous deviation of the condition variance from the long-term mean $(\sigma_{t-1}^2 - q_{t-1})$. Therefore, in keeping with its GARCH theoretical background, the C-GARCH specification continues to take account of the persistence of volatility clustering by having the conditional variance as a function of past errors. As the transitory component describes the relationship between the short-run and long-run influence decline rates of past shocks values of (γ+λ) closer to one imply slower convergence of the short-run and long-run influence decline rates, and values closer to zero the opposite. The value (γ+λ) is therefore a measure of how long this non-long-run (i.e. short-run) influence decline rate is.

Together, these two components of the C-GARCH model describe, just like the original GARCH formulation, how the influence of a past shock on future volatility declines over time. With the C-GARCH model however, this persistence is separated into a short-run and long-run component, along with the estimation of the underlying variance level once the effect of both components has been removed from a series. The long-run (permanent) component provides a measure of volatility generated by fundamental factors [see, for example, Blake and McMillan (2004) and Byrne and

Davis (2005)], while the short-run (transitory) component represents transitory volatility conditioned by financial market considerations, such as the arrival of new information, speculation and hedging positions.

2.2. SVAR framework

We consider the variance causality among the estimated volatility components in a structural Vector Auto-Regression (SVAR) framework (Azad *et al.*, 2015)[3]. Following Bollerslev (1990) under this multivariate regression framework, the models can be thought of as an extension of Seemingly Unrelated Regression (SUR) and, thus, the models are estimated in a SUR framework.

We distinguish between intra-spillovers and inter-spillovers models. In the first kind of models, we analyse de evidence of spillovers between exchange foreign and stock markets inside a country. In the second kind of models, we study the evidence of spillovers between exchange foreign and stock markets but across countries.

2.2.1. Intra-spillovers models

2.2.1.1. Long-run intra-spillovers models

Under this framework we estimate two equations for each of the countries under study. In the case of United States the equations are as follows:

$$V_{LR}^{StockUSA} = \rho_0 + \rho_1 V_{LR,t-1}^{StockUSA} + \rho_2 V_{LR,t-1}^{FEUSA} + \epsilon_{1,t} \quad (4a)$$

$$V_{LR}^{FEUSA} = \gamma_0 + \gamma_1 V_{LR,t-1}^{FEUSA} + \gamma_2 V_{LR,t-1}^{StockUSA} + \epsilon_{2,t} \quad (4b)$$

where $V_{LR}^{StockUSA}$ is the long-run component of volatility in the stock market and V_{LR}^{FEUSA} is the long-run component of volatility in the foreign exchange market. To test for long-run volatility spillovers we check whether the coefficients ρ_2 and γ_2, of equations (4a) and (4b) respectively, are statistically significant or not.

[3] We choose these two stage approach with the GARCH modelling followed by the VAR, rather than a VAR-MGARCH model for computational convenience, given the large number of parameters to estimate.

2.1.2. Short-run intra-spillovers models

In the short-run framework and, for example, for United States, the two equations to estimate are:

$$V_{SR}^{StockUSA} = \mu_0 + \mu_1 V_{SR,t-1}^{StockUSA} + \mu_2 V_{SR,t-1}^{FEUSA} + \omega_{1,t} \quad (5a)$$

$$V_{SR}^{FEUSA} = \varphi_0 + \varphi_1 V_{SR,t-1}^{FEUSA} + \varphi_2 V_{SR,t-1}^{StockUSA} + \omega_{2,} \quad (5b)$$

where $V_{SR}^{StockUSA}$ is the short-run component of volatility in the stock market and V_{SR}^{FEUSA} is the short-run component of volatility in the foreign exchange market. To test for short-run volatility spillovers we check whether the coefficients μ_2 and φ_2, of equations (5a) and (5b) respectively, are statistically significant or not.

2.2.2. Inter-spillovers models

2.2.2.1. Long-run inter-spillovers models

Similarly to the case of intra-spillovers, we analyse the volatility spillovers across countries using the following models (for example for Unites States):

$$V_{LR}^{StockUSA} = \alpha_0 + \alpha_1 V_{LR,t-1}^{StockUSA} + \alpha_2 V_{LR,t-1}^{FEUSA} + \alpha_3 V_{LR,t-1}^{FEAUS} + \alpha_4 V_{LR,t-1}^{FECAN} + \alpha_5 V_{LR,t-1}^{FEEUR} + \alpha_6 V_{LR,t-1}^{FEJAP} + \alpha_7 V_{LR,t-1}^{FESWI} + \alpha_8 V_{LR,t-1}^{FEUK} + \varepsilon_{1,t} \quad (6a)$$

$$V_{LR}^{FEUSA} = \beta_0 + \beta_1 V_{LR,t-1}^{FEUSA} + \beta_2 V_{LR,t-1}^{StockUSA} + \beta_3 V_{LR,t-1}^{StockAUS} + \beta_4 V_{LR,t-1}^{StockCAN} + \beta_5 V_{LR,t-1}^{StockEUR} + \beta_6 V_{LR,t-1}^{StockJAP} + \beta_7 V_{LR,t-1}^{StockSWI} + \beta_8 V_{LR,t-1}^{StockUK} + \varepsilon_{2,t} \quad (6b)$$

where $V_{LR,t-1}^{FEUSA}, V_{LR,t-1}^{FEAUS}, V_{LR,t-1}^{FECAN}, V_{LR,t-1}^{FEEUR}, V_{LR,t-1}^{FEJAP}, V_{LR,t-1}^{FESWI}$ and $V_{LR,t-1}^{FEUK}$ are the long-run components of volatility in the foreign exchange markets of the seven countries under study and $V_{LR,t-1}^{FEUSA}$, $V_{LR,t-1}^{StockUSA}, V_{LR,t-1}^{StockAUS}, V_{LR,t-1}^{StockCAN}, V_{LR,t-1}^{StockEUR}$, $V_{LR,t-1}^{StockJAP}, V_{LR,t-1}^{StockSWI}$ and $V_{LR,t-1}^{StockUK}$ are the long-run components of volatility in the stock markets of the seven countries under study. For example, to test for the long-run volatility spillovers between United States and Australia we check whether the coefficients α_3 and β_3, of equations (6a) and (6b) respectively, are statistically significant or not.

2.2.2.2. Short-run inter-spillovers models

For the case of short-run inter-spillover, the models to estimate for the case of United States

$$V_{SR}^{StockUSA} = \delta_0 + \delta_1 V_{SR,t-1}^{FEUSA} + \delta_2 V_{SR,t-1}^{FEEUR} + \delta_3 V_{SR,t-1}^{FEAUS} + \delta_4 V_{SR,t-1}^{FESWI} + \delta_5 V_{SR,t-1}^{FECAN} + + \delta_6 V_{SR,t-1}^{FEUK} + \delta_7 V_{SR,t-1}^{FEJAP} + \vartheta_{1,t} \quad (7a)$$

$$V_{LR}^{FEUSA} = \theta_0 + \theta_1 V_{SR,t-1}^{StockUSA} + \theta_2 V_{SR,t-1}^{StockEUR} + \theta_3 V_{SR,t-1}^{StockAUS} + \theta_4 V_{SR,t-1}^{StockSWI} + + \theta_5 V_{SR,t-1}^{StockCAN} + \theta_6 V_{SR,t-1}^{StockUK} + \theta_7 V_{SR,t-1}^{StockJAP} + \vartheta_{2,t} \quad (7b)$$

where $V_{SR,t-1}^{FEUSA}, V_{SR,t-1}^{FEEUR}, V_{SR,t-1}^{FEAUS}, V_{SR,t-1}^{FESWI}, V_{SR,t-1}^{FECAN}, V_{SR,t-1}^{FEUK}$ and $V_{SR,t-1}^{FEJAP}$ are the short-run components of volatility in the foreign exchange markets of the seven countries under study and $V_{SR,t-1}^{StockUSA}, V_{SR,t-1}^{StockEUR}, V_{SR,t-1}^{StockAUS}, V_{SR,t-1}^{StockSWI}, V_{SR,t-1}^{StockCAN}, V_{SR,t-1}^{StockUK}$ and $V_{SR,t-1}^{StockJAP}$ are the short-run components of volatility in the stock markets of the seven countries under study. Again, for example, to test for the short-run volatility spillovers between United States and Australia we check whether the coefficients δ_3 and θ_3, of equations (7a) and (7b) respectively, are statistically significant or not.

2.3. Granger causality

Finally, we complete the previous analysis with the Granger's causality approach. The concept of Granger-causality was introduced by Granger (1969) and Sims (1972) and is widely used to ascertain the importance of the interaction between two series. This is based on the time series notion of predictability (Hoover, 2001): given two variables, variable *X* causes variable *Y* if the present value of *Y* can be predicted more accurately by using the past values of *X* and *Y* than by using only past values of *X*.

To test for Granger causality between two series *Y* and *X,* we run bivariate regressions of the form:

$$Y_t = \alpha_0 + \sum_{i=1}^{m} \delta_i Y_{t-i} + + \sum_{i=1}^{m} \delta_i X_{t-i} + \varepsilon_t \quad (8a)$$

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + + \sum_{i=1}^{m} \delta_i Y_{t-i} + \varepsilon_t \quad (8b)$$

for all possible pairs of series (*Y*, *X*) and report the Wald statistics for the joint hypothesis: $\delta_1 = \delta_2 = \ldots = \delta_m = 0$. The null hypothesis is that does not Granger-cause in the first regression (8a) and that does not Granger-cause in the second regression (8b).

3. Data and empirical results

3.1 Data

The data consist of daily closing stock prices denominated in local currency for the US (Standard & Poor's 500 composite index, S&P500), the Euro area (Eurostoxx 50 Index), Japan (Nikkei 225 index), the UK (Financial Times Stock Exchange 100 Index, FTSE100), Australia (All Ordinaries Index, AOI), Switzerland (Swiss Market Index, SMI) and Canada (Toronto Stock Exchange Composite Index, TSX). The exchange rate series for each country is a trade-weighted exchange rate, to account for each country's diverse investment positions in foreign equities. In particular, we examine the following effective exchange rates: US Dollar (USD), Euro (EUR), Australian dollar (AUD), Swiss franc (CHF), Canadian dollar (CAD), British pound (GBP) and Japanese yen (JPY). The stock price data has been extracted from Datastream. The exchange rate series are the Bank of England trade-weighted exchange rates. Note that focusing on these seven major world economies, we cover 174.9% of global foreign exchange market turnover[4].

Our data covers the period 1 January 1990 to 31 December 2015. In order to assess the possible effect of the Global Financial Crisis (GFC), in addition to the full sample period, we consider in our estimations two sub-periods: pre-GFC (1 January 1990-8 August 2007) and post-GFC (9 August 2007-31 December 2015). The breakpoint date has been fixed at 9 August 2007 when BNP Paribas, France's largest bank, halted redemptions on three investment funds, triggering the active phase of the crisis.

[4] Average of currency distribution of global foreign exchange market turnover over 2001, 2004, 2007, 2010, 2013 and 2016 Bank for International Settlements (2016). Because two currencies are involved in each transaction, the sum of the percentage shares of individual currencies totals 200% instead of 100%.

3.2. Empirical Results[5]

3.2.1. Permanent and transitory components

In order to have a visual representation of the role played by the two volatility components of the conditional variance, Figure 1 to 3 plot the time evolution of the total volatility and the estimated transitory and permanent components of volatility for the full sample, the pre-GFC and the post-GFC, respectively[6]. In general, the plots indicate that the permanent component has smooth movements and approaches a moving average of the GARCH volatility, while the transitory component responds largely to market fluctuations, tracking much of the variation in conditional volatility. Consistent with the findings of Engle and Lee (1999), Alizadeh *et al.* (2002) and Brandt and Jones (2006), we show that the long-run component is characterised by a time varying but highly persistent trend, while the short run component is strongly mean-reverting to this trend. For all countries and periods, the temporary component of volatility is much smaller than the permanent component, suggesting that transitory shifts in market sentiment tend to be less important determinants of volatility than shocks to the underlying fundamentals. Yet, relative to its lower mean level, the transitory component is in all cases much more volatile than the long-run trend level of volatility, as one would expect.

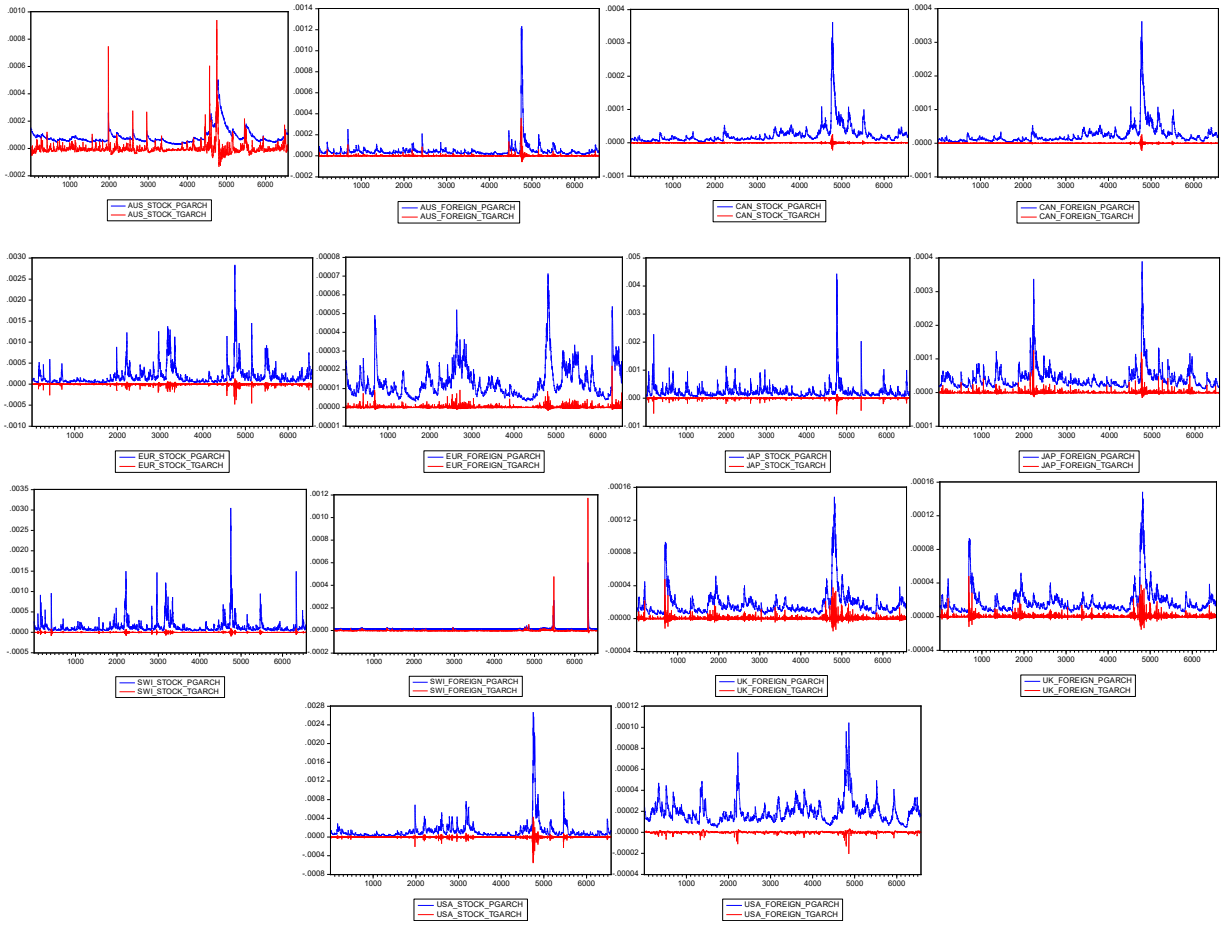


Figure 1. Permanent and Transitory volatility components, Full sample (1 January 1990 to 31 December 2015)

[5] We summarize the results by pointing out the main regularities. The reader is asked to browse through Tables 1 to 15 and Figures 1 to 3 to find evidence for particular country, market or group of countries or markets of her/his special interest.

[6] To save space, the estimation results for the C-GARCH models are not shown here, but available from the authors upon requests.

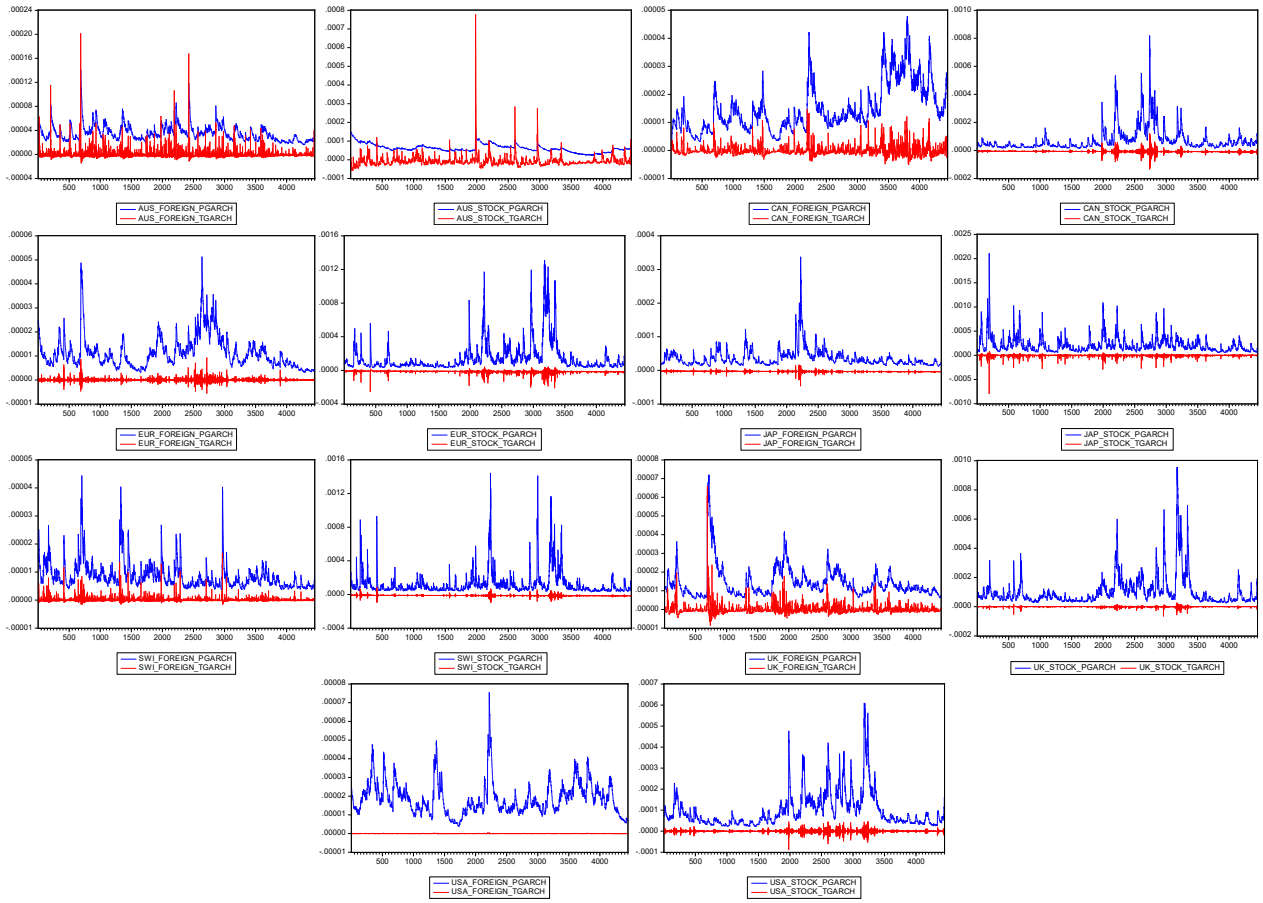


Figure 2. Permanent and Transitory volatility components, Pre-GFC period (1 January 1990-8 August 2007)

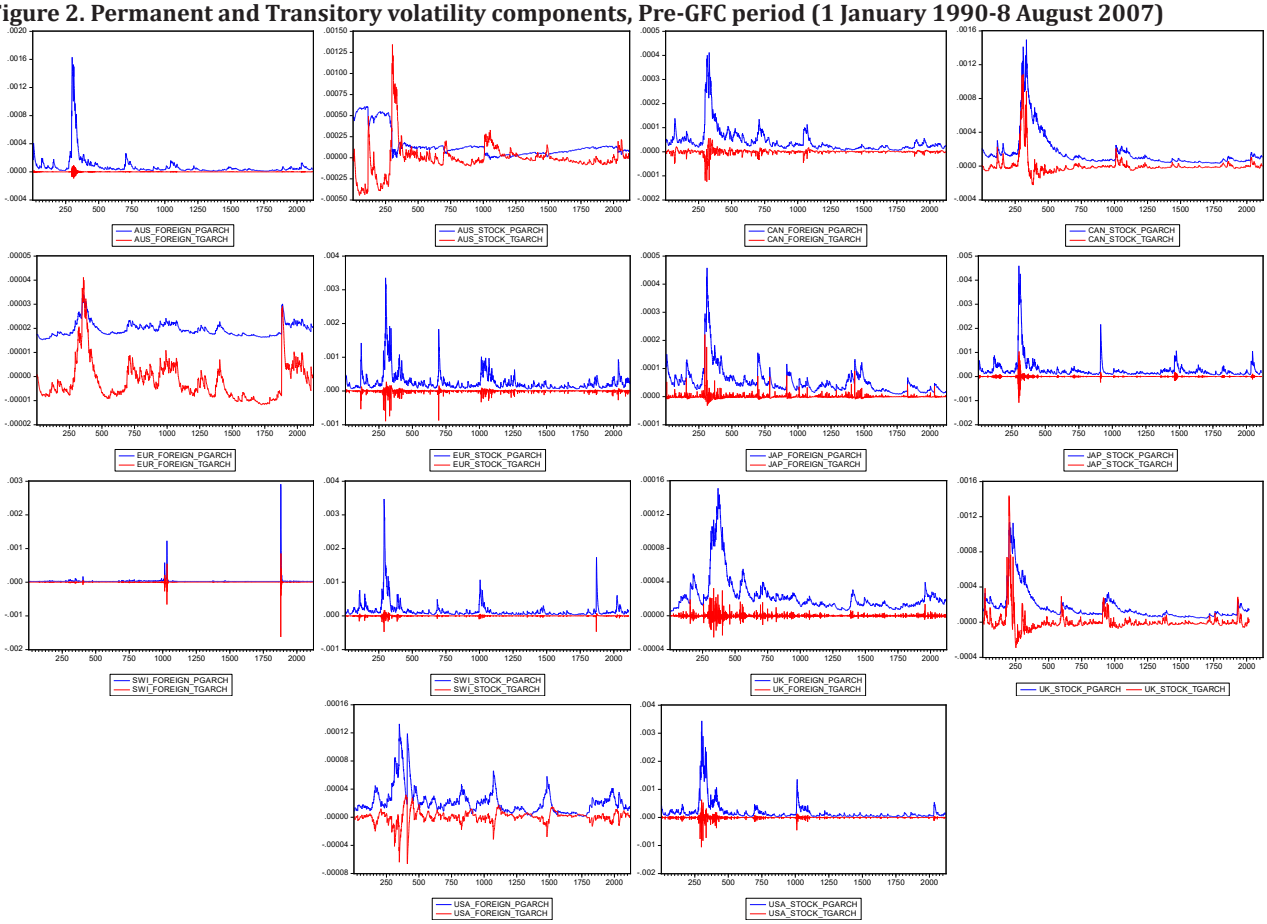


Figure 3. Permanent and Transitory volatility components, Post-GFC period (9 August 2007-31 December 2015)

In these graphs, we observe several well-known peaks in volatilities which coincide with i) the tensions in the European Exchange Rate Mechanism (ERM) in September 1992; ii) the global stock market crash in October 1997 caused by an economic crisis in Asia; iii) the Russian financial crisis in August 1998; iv) the Lehman Bros. demise in September 2008; and v) the European Debt crisis in May 2010.

3.2.2. Correlations between permanent components

Table 1 reports the estimated correlations between the permanent components results for the full sample (1 January 1990 to 31 December 2015). If we first focus on the results for the relationships between stock markets, we observe positive correlations ranking from 0.4558 (AOI and SWI) to 0.8886 (FTSE100 and S&P500). It is worth to comment that the USA stock market is highly correlated with the other six stock markets (with correlations oscillating between 0.7127 and 0.8886).

As for the relationships between foreign exchange markets, although correlations are positive, they are much weaker than in stock markets, ranging from 0.0627 (AUD and CHF) to 0.7395 (AUD and CAD). We notice the weak correlation between the CHF and the rest of currencies under study that could be related to its safe-haven characteristics (Grisse and Nitschka, 2015).

Concerning the relationship between the domestic currency and the national stock market, the estimated correlations coefficients are always positive. The higher correlations are found in Canada (0.8291), Australia (0.6816) and Japan (0.6023), followed by the UK (0.5797), USA (0.4408), the Euro area (0.3697) and Switzerland (0.2890).

Regarding the cross relationships between stock and foreign-exchange markets, our results show that there are positive correlations, weaker than in stock markets and similar to the evidence obtained for the currency markets, ranking from 0.0477 (CHF and NIKKEI 225) to 0.8428 (AUD and SP500). Once again, the CHF presents a week correlation with all foreign stock markets. Interestingly, for the AUD, EUR and JPY exchange rates, in four out of the six cases under study the correlation with other stock markets is higher than that with the domestic stock market. For the GBP and the USD, this is detected in two and three cases, respectively. Finally, for the CAD and the CHF exchange rates, the correlation with the domestic stock markets is higher than those with the foreign stock markets.

Table 2 shows the estimated correlations between the permanent components results for pre-GFC sample (1 January 1990 to 8 August 2007). As can be seen, the correlations between stock markets register a substantial decrement by comparison with the values obtained for the full sample, with the only exceptions of the relationships between the EURO STOXX 50 with the SMI, the FTSE100 and the SP500 and the SMI with the FTSE100. As regards to the correlations between foreign markets, they are all once again smaller than those computed for the stock markets (observing three negative values) and smaller than they were for the full sample. Finally, with reference to the relationship between foreign exchange markets and stock markets, there is evidence of a substantial reduction of the estimated correlations in comparison with to those obtained for the full sample (with the exception of the CHF with the AOI, EURO STOXX 50 and FTSE100 indices). It is interesting to note that in the cases of CAD with AOI and NIKKEI225 and CHF with TSX and SP500, the correlations exhibit negative values.

Table 1: Correlations between permanent volatility components, full sample (1 January 1990 to 31 December 2015)

	AOI	TSX	EUROSTOXX	NIKKEI225	SMI	FTSE100	SP500	AUD	CAD	EUR	JPY	CHF	GBP	USD
AOI	1	0.84615	0.57519	0.54427	0.45578	0.79973	0.75282	0.68159	0.81948	0.48418	0.60703	0.0811	0.67112	0.55672
TSX	0.84615	1	0.64456	0.58237	0.5065	0.86237	0.86475	0.73866	0.82914	0.57513	0.67177	0.0729	0.67736	0.56467
EURSTOXX	0.57519	0.64456	1	0.60632	0.85674	0.86063	0.82243	0.64671	0.54589	0.36973	0.53373	0.12272	0.33776	0.36932
NIKKEI225	0.54427	0.58237	0.60632	1	0.62522	0.62172	0.71269	0.76655	0.51924	0.24008	0.60231	0.04765	0.3522	0.30972
SMI	0.45578	0.5065	0.85674	0.62522	1	0.69929	0.72454	0.61284	0.40108	0.25336	0.51912	0.28897	0.21713	0.30813
FTSE100	0.79973	0.86237	0.86063	0.62172	0.69929	1	0.88861	0.73367	0.76001	0.48672	0.62786	0.0831	0.57973	0.53625
SP500	0.75282	0.86475	0.82243	0.71269	0.72454	0.88861	1	0.84279	0.74833	0.43844	0.65179	0.10666	0.50416	0.4408
AUD	0.68159	0.73866	0.64671	0.76655	0.61284	0.73367	0.84279	1	0.73945	0.37853	0.68693	0.06267	0.47993	0.39642
CAD	0.81948	0.82914	0.54589	0.51924	0.40108	0.76001	0.74833	0.73945	1	0.483	0.60875	0.0903	0.68168	0.60278
EUR	0.48418	0.57513	0.36973	0.24008	0.25336	0.48672	0.43844	0.37853	0.483	1	0.39003	0.29944	0.68371	0.52551
JPY	0.60703	0.67177	0.53373	0.60231	0.51912	0.62786	0.65179	0.68693	0.60875	0.39003	1	0.04865	0.49889	0.55512
CHF	0.0811	0.0729	0.12272	0.04765	0.28897	0.0831	0.10666	0.06267	0.0903	0.29944	0.04865	1	0.06098	0.08393
GBP	0.67112	0.67736	0.33776	0.3522	0.21713	0.57973	0.50416	0.47993	0.68168	0.68371	0.49889	0.06098	1	0.59618
USD	0.55672	0.56467	0.36932	0.30972	0.30813	0.53625	0.4408	0.39642	0.60278	0.52551	0.55512	0.08393	0.59618	1

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US Dollar effective exchange rates, respectively.

Table 2: Correlations between permanent volatility components, pre-GFC period (1 January 1990-8 August 2007)

	AOI	TSX	EUROSTOXX	NIKKEI225	SMI	FTSE100	SP500	AUD	CAD	EUR	JPY	CHF	GBP	USD
AOI	1	0.2504	0.2057	0.341	0.2717	0.2377	0.3023	0.2691	-0.415	0.2111	0.3141	0.2247	0.0602	0.0086
TSX	0.2504	1	0.4849	0.2314	0.3941	0.4935	0.6758	0.2293	0.0673	0.4444	0.3857	-0.043	0.1152	0.0728
EURSTOXX	0.2057	0.4849	1	0.349	0.8602	0.9344	0.8269	0.2269	0.0945	0.2009	0.2622	0.1297	0.0357	0.2011
NIKKEI225	0.341	0.2314	0.349	1	0.3933	0.366	0.3532	0.2448	-0.062	0.1322	0.2679	0.2788	0.1317	0.1671
SMI	0.2717	0.3941	0.8602	0.3933	1	0.8114	0.6559	0.226	0.0614	0.1152	0.353	0.209	0.0054	0.2559
FTSE100	0.2377	0.4935	0.9344	0.366	0.8114	1	0.8171	0.2797	0.0505	0.2333	0.2693	0.1169	0.0495	0.2002
SP500	0.3023	0.6758	0.8269	0.3532	0.6559	0.8171	1	0.2197	-0.008	0.3247	0.292	-0.016	0.0521	0.1105
AUD	0.2691	0.2293	0.2269	0.2448	0.226	0.2797	0.2197	1	-0.006	0.4799	0.478	0.4185	0.417	0.3725
CAD	-0.415	0.0673	0.0945	-0.062	0.0614	0.0505	-0.008	-0.006	1	-0.063	0.1042	-0.028	0.0416	0.431
EUR	0.2111	0.4444	0.2009	0.1322	0.1152	0.2333	0.3247	0.4799	-0.063	1	0.242	0.2968	0.5981	0.244
JPY	0.3141	0.3857	0.2622	0.2679	0.353	0.2693	0.292	0.478	0.1042	0.242	1	0.2459	0.1868	0.4842
CHF	0.2247	-0.043	0.1297	0.2788	0.209	0.1169	-0.016	0.4185	-0.028	0.2968	0.2459	1	0.445	0.3258
GBP	0.0602	0.1152	0.0357	0.1317	0.0054	0.0495	0.0521	0.417	0.0416	0.5981	0.1868	0.445	1	0.1755
USD	0.0086	0.0728	0.2011	0.1671	0.2559	0.2002	0.1105	0.3725	0.431	0.244	0.4842	0.3258	0.1755	1

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates, respectively.

Table 3: Correlations between permanent volatility components, post-GFC period (9 August 2007-31 December 2015)

	AOI	TSX	EUROS-TOXX	NIKKEI225	SMI	FTSE100	SP500	AUD	CAD	EUR	JPY	CHF	GBP	USD
AOI	1	0.0327	-0.064	-0.011	0.1685	0.5939	0.0056	0.0219	0.0439	-0.278	0.0651	-0.025	0.0201	0.011
TSX	0.0327	1	0.7277	0.7016	0.4963	0.373	0.8673	0.7806	0.893	0.5315	0.8248	0.0206	0.7888	0.7171
EURSTOXX	-0.064	0.7277	1	0.7289	0.5599	0.2747	0.8712	0.8092	0.711	0.3857	0.709	0.0832	0.4159	0.4358
NIKKEI225	-0.011	0.7016	0.7289	1	0.4576	0.2853	0.7926	0.8794	0.7156	0.2484	0.8117	0.0213	0.4101	0.4121
SMI	0.1685	0.4963	0.5599	0.4576	1	0.3067	0.6453	0.552	0.4039	0.205	0.4682	0.0775	0.2313	0.296
FTSE100	0.5939	0.373	0.2747	0.2853	0.3067	1	0.3592	0.3199	0.325	0.097	0.3177	-0.007	0.2849	0.2636
SP500	0.0056	0.8673	0.8712	0.7926	0.6453	0.3592	1	0.8805	0.8137	0.4031	0.8054	0.0528	0.5393	0.5254
AUD	0.0219	0.7806	0.8092	0.8794	0.552	0.3199	0.8805	1	0.8138	0.3332	0.8545	0.0132	0.4525	0.453
CAD	0.0439	0.893	0.711	0.7156	0.4039	0.325	0.8137	0.8138	1	0.5172	0.8382	0.0076	0.7226	0.6728
EUR	-0.278	0.5315	0.3857	0.2484	0.205	0.097	0.4031	0.3332	0.5172	1	0.4256	0.2026	0.6792	0.6839
JPY	0.0651	0.8248	0.709	0.8117	0.4682	0.3177	0.8054	0.8545	0.8382	0.4256	1	0.0104	0.645	0.6025
CHF	-0.025	0.0206	0.0832	0.0213	0.0775	-0.007	0.0528	0.0132	0.0076	0.2026	0.0104	1	-0.002	0.0293
GBP	0.0201	0.7888	0.4159	0.4101	0.2313	0.2849	0.5393	0.4525	0.7226	0.6792	0.645	-0.002	1	0.7759
USD	0.011	0.7171	0.4358	0.4121	0.296	0.2636	0.5254	0.453	0.6728	0.6839	0.6025	0.0293	0.7759	1

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates, respectively.

Table 3 reports the estimated correlations between the permanent components results for post-GFC sample (9 August 2007 to 31 December 2015). Results suggest, in general, an increased in the estimated correlations both with respect to the full sample period and in particular with respect to the pre-GFC period, although with some exceptions. In regard to the correlations between stock markets, there are important reductions in the correlation, in comparison with to those presented in Tables 1 and 2, in the cases of the AOI with all the other stock indices (expect for the FTSE100, where there is an increase in comparison with to the pre-GFC), the SMI with respect to FTSE100 and SP500 and the FTSE100 with respect to SP500. Note also that the OAI presents now negative correlations with respect to EUROSTOXX and NIKEI225. Turning to the case of the correlations between foreign markets, the case of the CHF stands out, experiencing significant drops in comparison with both those estimated for the full sample and the pre-GFC (registering even negative correlation with respect to the GBP). Finally, as for the correlations between foreign exchange markets and stock markets, the only exception in the general pattern of increased values is once again the CHF, presenting even a negative correlation with respect to the FTSE100. A negative correlation is also obtained for the EUR with respect to the AOI.

In sum, our results suggest a reinforcement of correlation between stock and foreign markets permanent volatility during the post-GFC period. This finding is consistent with earlier literature in that the linkage between markets intensifies during periods of increasing economic and financial instability (see, e. g., Kolb, 2011), implying a loss of diversification just when it is needed most.

3.2.3. Correlations between transitory components

Tables 4 to 6 present the correlation results between transitory volatility components. Comparing these results with those in Tables 1 to 3, we observe significant reduction in the correlations in all cases, with the only exception of the relation between AOI and TSX for the post-GFC period. Moreover, there are a greater number of negative correlations than in the case of the permanent component of volatility between markets and there are no substantial differences between the pre-GFC and post-GFC periods.

Table 4: Correlations between transitory volatility components, full sample (1 January 1990 to 31 December 2015)

	AOI	TSX	EUROS-TOXX	NIKKEI225	SMI	FTSE100	SP500	AUD	CAD	EUR	JPY	CHF	GBP	USD
AOI	1	0.73041	-0.1226	-0.1713	0.01118	0.74177	-0.0084	0.16332	0.03628	0.05188	0.11245	0.04725	0.06157	-0.14047
TSX	0.73041	1	-0.1540	-0.1600	0.02642	0.75808	-0.1011	0.20729	0.08368	0.05641	0.1953	0.03137	0.07126	-0.15947
EURSTOXX	-0.1226	-0.1540	1	0.14032	-0.2501	-0.2944	0.24788	-0.2994	-0.20108	-0.14343	-0.2072	-0.01328	-0.0341	0.05388
NIKKEI225	-0.1713	-0.1600	0.14032	1	0.00215	-0.1686	-0.2473	-0.2602	-0.07013	-0.01766	-0.1904	-0.00898	0.00477	0.04414
SMI	0.01118	0.02642	-0.2501	0.00215	1	0.05368	-0.1104	0.07573	0.27493	0.05626	0.03611	0.05096	-0.0242	-0.00213
FTSE100	0.74177	0.75808	-0.2944	-0.1686	0.05368	1	-0.0820	0.24534	0.0887	0.07398	0.18542	0.05629	0.07083	-0.17113
SP500	-0.0084	-0.1011	0.24788	-0.2473	-0.1104	-0.0820	1	-0.0145	0.0511	0.00602	-0.0497	-0.00032	-0.0769	-0.00928
AUD	0.16332	0.20729	-0.2994	-0.2602	0.07573	0.24534	-0.0145	1	0.25351	0.13198	0.4733	0.01014	0.07949	-0.07922
CAD	0.03628	0.08368	-0.2010	-0.0701	0.27493	0.0887	0.0511	0.25351	1	0.10424	0.14363	0.0016	0.04877	-0.05264
EUR	0.05188	0.05641	-0.1434	-0.0176	0.05627	0.07398	0.00602	0.13198	0.10424	1	0.15535	0.33521	0.20651	-0.2148
JPY	0.11245	0.1953	-0.2072	-0.1904	0.03611	0.18542	-0.0497	0.4733	0.14363	0.15535	1	0.0108	0.10932	-0.3081
CHF	0.04725	0.03137	-0.0132	-0.0089	0.05096	0.05629	-0.0003	0.01014	0.0016	0.33521	0.0108	1	0.01283	-0.01992
GBP	0.06157	0.07126	-0.0341	0.00477	-0.0242	0.07083	-0.0769	0.07949	0.04877	0.20651	0.10932	0.01283	1	-0.08486
USD	-0.1404	-0.1594	0.05388	0.04414	-0.0021	-0.1711	-0.0092	-0.0792	-0.05263	-0.21479	-0.3081	-0.01992	-0.0848	1

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates, respectively.

Table 5: Correlations between transitory volatility components, pre-GFC period (1 January 1990-8 August 2007)

	AOI	TSX	EUROS-TOXX	NIKKEI225	SMI	FTSE100	SP500	AUD	CAD	EUR	JPY	CHF	GBP	USD
AOI	1	0.0141	-0.158	-0.096	0.0142	-0.018	0.0087	0.0819	0.1638	0.0281	-0.007	0.127	0.0468	0.0825
TSX	0.0141	1	0.0356	-0.033	-0.081	0.0714	0.577	-0.017	-0.01	-0.018	0.1943	0.045	-0.002	-0.026
EURSTOXX	-0.158	0.0356	1	0.1614	-0.264	0.5851	0.0806	-0.109	-0.13	-0.116	-0.019	-0.255	-0.047	-0.149
NIKKEI225	-0.096	-0.033	0.1614	1	-0.027	0.0839	-0.034	-0.045	-0.029	-0.01	0.0337	-0.085	0.0246	-0.124
SMI	0.0142	-0.081	-0.264	-0.027	1	-0.34	-0.123	0.024	0.0194	0.0996	-0.007	0.1065	-0.001	0.0263
FTSE100	-0.018	0.0714	0.5851	0.0839	-0.34	1	0.1139	-0.06	-0.05	-0.072	0.0009	-0.137	-0.052	-0.037
SP500	0.0087	0.577	0.0806	-0.034	-0.123	0.1139	1	-0.012	-0.016	-0.057	0.1316	0.0074	-0.008	-0.022
AUD	0.0819	-0.017	-0.109	-0.045	0.024	-0.06	-0.012	1	0.186	0.0973	-0.076	0.1084	0.0674	0.2468
CAD	0.1638	-0.01	-0.13	-0.029	0.0194	-0.05	-0.016	0.186	1	0.058	-0.038	0.1142	0.1602	0.2538
EUR	0.0281	-0.018	-0.116	-0.01	0.0996	-0.072	-0.057	0.0973	0.058	1	-0.121	0.178	0.0875	0.2047
JPY	-0.007	0.1943	-0.019	0.0337	-0.007	0.0009	0.1316	-0.076	-0.038	-0.121	1	-0.032	-0.031	-0.252
CHF	0.127	0.045	-0.255	-0.085	0.1065	-0.137	0.0074	0.1084	0.1142	0.178	-0.032	1	0.1267	0.2309
GBP	0.0468	-0.002	-0.047	0.0246	-0.001	-0.052	-0.008	0.0674	0.1602	0.0875	-0.031	0.1267	1	0.0943
USD	0.0825	-0.026	-0.149	-0.124	0.0263	-0.037	-0.022	0.2468	0.2538	0.2047	-0.252	0.2309	0.0943	1

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates, respectively.

Table 6: Correlations between transitory volatility components, post-GFC period (9 August 2007-31 December 2015)

	AOI	TSX	EUROS-TOXX	NIKKEI225	SMI	FTSE100	SP500	AUD	CAD	EUR	JPY	CHF	GBP	USD
AOI	1	0.6493	-0.034	-0.033	0.0461	-0.234	0.0074	-0.014	-0.243	0.398	0.0173	-0.009	0.0465	-0.239
TSX	0.6493	1	-0.123	-0.039	0.0157	-0.058	-0.089	-0.005	-0.431	0.1887	0.1311	-0.007	0.0651	-0.311
EURSTOXX	-0.034	-0.123	1	0.0253	0.0007	-0.005	0.3356	-0.001	0.3099	-0.031	-0.352	-0.006	-0.027	0.033
NIKKEI225	-0.033	-0.039	0.0253	1	-0.13	-0.012	-0.149	0.6858	0.0097	-0.001	-0.15	0.0074	-0.039	-0.004
SMI	0.0461	0.0157	0.0007	-0.13	1	0.0339	0.1349	-0.076	-0.03	0.0146	0.0802	0.0113	-0.048	-0.024
FTSE100	-0.234	-0.058	-0.005	-0.012	0.0339	1	0.009	-0.002	0.0031	-0.122	-0.027	0.0034	-0.007	0.1083
SP500	0.0074	-0.089	0.3356	-0.149	0.1349	0.009	1	-0.069	0.0254	-0.007	-0.084	-0.004	-0.129	-0.012
AUD	-0.014	-0.005	-0.001	0.6858	-0.076	-0.002	-0.069	1	-0.064	0.0003	-0.122	0.0224	-0.12	-0.009
CAD	-0.243	-0.431	0.3099	0.0097	-0.03	0.0031	0.0254	-0.064	1	0.0282	-0.182	-3E-04	-0.037	0.1285
EUR	0.398	0.1887	-0.031	-0.001	0.0146	-0.122	-0.007	0.0003	0.0282	1	-0.007	-0.031	0.0423	-0.305
JPY	0.0173	0.1311	-0.352	-0.15	0.0802	-0.027	-0.084	-0.122	-0.182	-0.007	1	-0.009	0.1408	-0.07
CHF	-0.009	-0.007	-0.006	0.0074	0.0113	0.0034	-0.004	0.0224	-3E-04	-0.031	-0.009	1	-0.015	0.0006
GBP	0.0465	0.0651	-0.027	-0.039	-0.048	-0.007	-0.129	-0.12	-0.037	0.0423	0.1408	-0.015	1	-0.065
USD	-0.239	-0.311	0.033	-0.004	-0.024	0.1083	-0.012	-0.009	0.1285	-0.305	-0.07	0.0006	-0.065	1

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates, respectively.

As shown in Table 4, when examining the correlations in the transitory volatility component between stock markets in 12 out of the 21 cases we find negative correlations. The case of the SP500 stands out since, with the only exception of its relation with Eurostoxx, their correlations are always negative. Regarding the relationships between foreign exchange markets, is interesting to note that the JPY presents negative correlations with all the other exchange rate under study. Finally, as respects to the connections between foreign exchange markets and stock markets, in 21 out of the 49 cases, the estimated correlations are negative, being especially interesting the cases of the Euro area, Japan and the USA, where we detect negative correlations between the domestic currency and the domestic stock market.

Turning to the case of the pre-GFC period, results in Table 5, we observe that in 10 out of 21 cases the correlations between stock markets are negative correlations, presenting the SMI negative correlations with all markets except with the AOI. As concern the correlations between foreign exchange markets, once again JPY is the only one presenting negative values with all the other exchange rate markets. Regarding the correlations between foreign exchange markets and stock markets, in 31 out of the 49 cases, the estimated values are negative, finding negative correlations between the domestic currency and the domestic stock market in four cases (Canada, the Euro area, UK and USA).

Finally, and in relation to the post-GFC period, results in Table 6 indicate a negative association between stock markets in 11 out of the 21 considered case, a negative relation between foreign exchange markets in 14 out of the 21 cases, and a negative interaction between foreign exchange markets and stock markets in 30 out of the 49 cases (being the correlations between the domestic currency and the domestic stock market in all cases, except for Switzerland).

In sum, our findings suggests that correlations between permanent volatility components are much higher than between transitory volatility components, indicating that, in the markets under study, the long run volatility relationships (reflecting the perceived evolution of fundamental factors) are stronger than the short run linkages volatility (incorporating market sentiments and investor behaviour).

3.2.4. Intra-spilovers

3.2.4.1. Full Sample (1 January 1990 to 31 December 2015)

Table 7 displays the results for the full sample. As can be seen, we find evidence of unidirectional spillovers, both in long-run and short-run volatility, from stock markets to foreign exchange markets in the Australian case. For Japan, Switzerland and the UK, our results suggest bidirectional spillovers, both in long-run and short-run volatility, between stock and foreign exchange markets. For Canada and the Euro area, we find evidence of unidirectional spillovers in the long-run volatility running from the foreign exchange market to the stock market. For Canada we also find evidence of strong unidirectional spillovers in the short-run volatility running from the foreign exchange market to the stock market and weak unidirectional spillovers in the short-run volatility running from the stock market to the foreign exchange market. Finally, our results suggest the presence of unidirectional spillovers, both in long-run and short-run volatility, from foreign exchange markets to stock markets in the USA.

Table 7: Intra-spillovers volatility estimations, full sample (1 January 1990 to 31 December 2015)

Country/Direction	Long-run volatility		Short-run volatility	
AOI to AUD	0.011411*	(0.00098)	0.19465*	(0.023)
AUD to AOI	0.003358	(0.00358)	0.007661	(0.002)
TSX to CAD	0.00269	(0.009487)	-0.430337***	(0.233755)
CAD to TSX	0.004555*	(0.000517)	0.002086*	(0.000144)
EUROSTOXX to EUR	0.033416	(0.069866)	0.250929	(0.389304)
EUR to EUROSTOXX	0.000269*	(0.0000631)	0.000155	(0.000396)
NIKKEI225 to JPY	0.149279*	(0.029798)	-0.605199*	(0.058416)
JPY to NIKKEI225	0.001494*	(0.000318)	0.011049*	(0.002389)
SMI to CHF	-0.097682**	(0.033759)	0.005672**	(0.002544)
CHF to SMI	0.001042***	(0.000555)	0.040986**	(0.01797)
FTSE100 to GBP	-0.024905**	(0.011627)	-0.207482***	(0.1254)
GBP to FTSE100	0.001726*	(0.000246)	0.001981*	(0.000382)
SP500 to USD	-0.0419	(0.0389)	-0.076563	(0.171378)
USD to SP500	0.000751*	(0.00011)	0.00185*	(0.000332)

Notes:

AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.
The results are based on equations (4a)-(4b) and (5a)-(5b) for the long-run and short-run volatility, respectively.
*,**, *** indicate that the coefficients are significant at 1%, 5% and 10%, respectively.
In parentheses are standard errors of estimated coefficients.

3.2.4.2. Sub-samples: Pre-GFC and post-GFC

As seen in Table 8, for the pre-GFC period (1 January 1990-8 August 2007), in general, we obtain less evidence of intra-spillovers than in the full sample period. Only for Switzerland and the UK, our results suggest bidirectional spillovers in long-run volatility between stock and foreign exchange markets. For Australia and the Euro area, we find unidirectional spillovers in the long-run volatility running from the foreign exchange market to the stock market. As for the short-run volatility, our results indicate the existence of unidirectional spillovers running from the stock market to the foreign exchange market in Australia, Canada, Japan and Switzerland, as well as bidirectional spillovers between these markets in the Euro area.

Table 8: Intra-spillovers volatility estimations, pre-GFC period (1 January 1990-8 August 2007)

Country/Direction	Long-run volatility		Short-run volatility	
AOI to AUD	0.001765	(0.002237)	0.054219*	(0.022653)
AUD to AOI	0.003953**	(0.00201)	0.00298	(0.003231)
TSX to CAD	-0.025792	(0.027608)	-0.05101***	(0.028362)
CAD to TSX	0.000274	(0.00019)	-0.000404	(0.001445)
EUROSTOXX to EUR	-0.069835	(0.074856)	-0.67392**	(0.357294)
EUR to EUROSTOXX	0.000151**	(7.68E-05)	-0.001616*	(0.000493)
NIKKEI225 to JPY	0.03584	(0.027455)	0.711716*	(0.180158)
JPY to NIKKEI225	0.000694	(0.000469)	-0.000362	(0.000834)
SMI to CHF	-0.440568*	(0.131721)	0.233516*	(0.078509)
CHF to SMI	0.000502*	(0.000123)	-0.001095	(0.001325)
FTSE100 to GBP	-0.061185**	(0.032156)	-0.027685	(0.021126)
GBP to FTSE100	0.000302**	(0.00015)	-0.004298	(0.005869)
SP500 to USD	-0.019506	(0.019369)	-1.362785	(1.641133)
USD to SP500	0.000318	(0.000228)	1.88E-05	(5.83E-05)

Notes:
AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.
The results are based on equations (4a)-(4b) and (5a)-(5b) for the long-run and short-run volatility, respectively.
*,**, *** indicate that the coefficients are significant at 1%, 5% and 10%, respectively.
In parentheses are standard errors of estimated coefficients.

For the post-GFC period (9 August 2007-31 December 2015), we find evidence bidirectional spillovers, both in long-run and short-run volatility, between stock and foreign exchange markets in the cases of Australia and Japan. For Canada and USA, our results suggest the presence of unidirectional spillovers, both in long-run and short-run volatility, running from foreign exchange markets to stock markets. Finally for Switzerland we find unidirectional spillovers in long-run short-run volatility from foreign exchange markets to stock markets and weak evidence of unidirectional spillovers in short-run volatility from stock markets to foreign exchange markets.

In sum, during the pre-GFC there was a weak evidence of intra-spillovers between stock ad foreign exchange markets. However, the presence of intra-spillovers increases substantially during the post-GFC period.

3.2.5. Inter-spillovers

3.2.5.1. Full Sample (1 January 1990 to 31 December 2015)

As can be seen in Table 10, for Australia we find some evidence in favour of inter-spillovers between Australia stock market and al-

Table 9: Intra-spillovers volatility estimations, post-GFC period (9 August 2007-31 December 2015)

Country/Direction	Long-run volatility		Short-run volatility	
AOI to AUD	-0.007522*	(0.00139)	0.689879*	(0.07419)
AUD to AOI	0.008786*	(0.003747)	0.000566*	(0.000187)
TSX to CAD	8.02E-05	(0.021139)	0.077954	(0.062386)
CAD to TSX	0.01469*	(0.001715)	-0.010428*	(0.001447)
EUROSTOXX to EUR	0.958903	(0.67116)	-0.105437	(0.157834)
EUR to EUROSTOXX	7.54E-05*	(3.14E-05)	0.000527	(0.000427)
NIKKEI225 to JPY	0.335102*	(0.066706)	-0.311701*	(0.048538)
JPY to NIKKEI225	0.003582*	(0.000757)	0.016446*	(0.002885)
SMI to CHF	-0.019401	(0.013799)	-0.018094***	(0.011309)
CHF to SMI	0.014233**	(0.00628)	-0.025488	(0.034049)
FTSE100 to GBP	-0.001776	(0.019282)	0.397525	(0.306084)
GBP to FTSE100	0.000507	(0.000342)	-0.000568	(0.000476)
SP500 to USD	0.098071	(0.102325)	-0.044264	(0.129094)
USD to SP500	0.001267*	(0.000237)	0.004994*	(0.00105)

Notes:
AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.
The results are based on equations (4a)-(4b) and (5a)-(5b) for the long-run and short-run volatility, respectively.
*,**, *** indicate that the coefficients are significant at 1%, 5% and 10%, respectively.
In parentheses are standard errors of estimated coefficients.

most all foreign exchange market in the long-run and short-run. Therefore, external foreign exchange markets contain useful information to explain the evolution of Australian stock market.

Regarding the rest of countries, we find some evidence of inter-spillovers in the short-run and in favour of bidirectional causality (with the exception of Switzerland). The cases of UK and USA stand out due to the high percentage of significant spillovers, both in the short-run and the long-run, from external exchange rate markets to domestic stock markets. This finding is in line with the much higher stock market internalization of US and UK companies. Moreover, the high percentage of significant short-run spillovers from the US stock market to external exchange rate markets is consistent with the strong global propagation of US domestic shocks reported by Diebold and Yilmaz (2009).

Table 10: Inter-spillovers volatility estimations, full sample (1 January 1990 to 31 December 2015)

Country/Direction	Long-run volatility		Short-run volatility		Country/Direction	Long-run volatility		Short-run volatility	
AOI					**TSX**				
USD	-1.84E-03	(7.37E-03)	-0.084547	(2.12E-01)	AUD	0.046948*	(0.003654)	0.311279*	(0.029315)
CAD	-6.05E-03	(3.88E-03)	1.36E+00*	(2.11E-01)	USD	-0.005978	(0.021104)	0.453976**	(0.240543)
EUR	9.50E-04	(9.40E-03)	-2.46E-01	(3.37E-01)	EUR	0.036944	(0.027894)	0.270036	(0.382682)
JPY	-3.35E-04	(2.52E-03)	-5.87E-03	(5.45E-02)	JPY	-0.007192	(0.007367)	-0.063183	(0.062045)
CHF	1.65E-03	(3.19E-03)	4.76E-03	(1.00E-02)	CHF	-0.001801	(0.009161)	0.001103	(0.011376)
GBP	-0.004157	(6.32E-03)	1.37E-01	(1.01E-01)	GBP	-0.013002	(0.017782)	0.226059**	(0.11419)
AUD					**CAD**				
SP500	2.14E-02*	(2.55E-03)	-0.030503*	(5.67E-03)	TSX	0.00417*	(0.001481)	5.13E-05	(0.000231)
TSX	-5.94E-03*	(3.05E-03)	2.38E-02*	(3.30E-03)	SP500	5.98E-03*	(6.18E-04)	-0.00457*	(0.000414)
EUROSTOXX	2.27E-05	(2.06E-03)	2.39E-02*	(5.71E-03)	EUROSTOXX	-0.000593	(0.000543)	0.001464*	(0.000408)
NIKKEI225	-2.85E-03*	(9.44E-04)	1.36E-02**	(5.44E-03)	NIKKEI225	0.000329	(0.000227)	-0.000909**	(0.000386)
SMI	3.81E-05	(1.84E-03)	1.20E-02	(1.01E-02)	SMI	-0.000196	(0.000493)	-0.000841	(0.000752)
FTSE100	-1.92E-02*	(4.61E-03)	-6.04E-03*	(2.81E-03)	FTSE100	-0.004504*	(0.001231)	-0.000908*	(0.000203)
EUROSTOXX					**NIKKEI225 to**				
AUD	0.08729*	(0.013683)	-0.241412*	(0.033287)	AUD	0.319193*	(0.02174)	-0.211936*	(0.032679)
CAD	-0.138269*	(0.035872)	0.891683*	(0.270681)	CAD	-0.330474*	(0.049455)	0.825742*	(0.263848)
USD	0.084551	(0.076308)	-0.244636	(0.268323)	EUR	-0.299039**	(0.13453)	1.263195*	(0.422384)
JPY	-0.016158	(0.026139)	-0.025435	(0.069671)	USD	0.124065	(0.104724)	-0.019417	(0.263653)
CHF	-0.015805	(0.032972)	-0.002166	(0.012773)	CHF	0.022215	(0.045312)	-0.012659	(0.012549)
GBP	0.02043	(0.064799)	-0.228894***	(0.128138)	GBP	0.082158	(0.088075)	-0.29292**	(0.125962)
EUR	-0.000769***	(0.000452)	-5.66E-06	(0.000254)	**JPY**	0.002192	(0.002303)	-0.000942	(0.001501)
AOI	0.000951*	(0.000281)	0.000617**	(0.000262)	AOI	0.004126**	(0.001385)	0.010684*	(0.001555)
TSX	3.09E-05	(2.02E-04)	-0.000734***	(0.000453)	TSX	-0.001748**	(0.000899)	0.003376	(0.002644)
SP500	0.000112	(7.40E-05)	0.000317	(0.000425)	EUROSTOXX	0.001091	(0.001016)	0.003667	(0.002664)
NIKKEI225	0.000149	(0.000159)	0.002546*	(0.000803)	SP500	0.005094*	(0.000818)	0.002471	(0.004728)
SMI	-0.000577	(0.0004)	0.000121	(0.000224)	SMI	-0.005366	0.002031	-0.001732	(0.001319)
FTSE100					FTSE110				

Table 10: Inter-spillovers volatility estimations, full sample (1 January 1990 to 31 December 2015) (cont.)

Country/Direction	Long-run volatility		Short-run volatility		Country/Direction	Long-run volatility		Short-run volatility	
SMI					**FTSE100**				
AUD	0.12635*	(0.015028)	0.003109	(0.00316)	AUD	0.033051*	(0.003406)	0.272113*	(0.033023)
CAD	-0.191037*	(0.037632)	-0.000441	(0.001843)	CAD	-0.0481*	(0.009389)	-2.028787*	(0.26714)
EUR	-0.103629	(0.101914)	0.003247**	(0.001247)	EUR	0.009049	(0.024579)	-0.687589***	(0.427482)
JPY	-0.000155	(0.02761)	-0.000383	(0.000521)	JPY	-0.007757	(0.006546)	-0.234503*	(0.069186)
USD	0.157724**	(0.080474)	0.001675	(0.001393)	CHF	-0.001132	(0.008262)	0.009144	(0.012722)
GBP	-0.010578	(0.067428)	-0.005762**	(0.00279)	USD	0.021581	(0.019188)	0.121067	(0.269411)
CHF					**GBP**				
AOI	0.086922*	(0.006829)	0.004493	(0.005885)	AOI	0.000753	(0.00079)	0.002641*	(0.000764)
TSX	-0.297168*	(0.058263)	-0.005633	(0.006075)	TSX	0.001183*	(0.000467)	-0.000304	(0.000788)
EUROSTOXX	0.041728	(0.089931)	-0.015491	(0.010293)	EUROSTOXX	-0.000374	(0.000302)	0.003846*	(0.001336)
NIKKEI225	-0.05754*	(0.014549)	0.000872	(0.009835)	NIKKEI225	0.000596*	(0.000126)	0.003976*	(0.001276)
SP500	0.003225	(0.056156)	-0.001536	(0.010464)	SMI	0.000196	(0.000272)	0.01162*	(0.002412)
FTSE100	-0.043009***	(0.026839)	0.005381	(0.005184)	SP500	-0.000668**	(0.000345)	0.000774	(0.001361)
SP500									
AUD	0.151454*	(0.01012)	-0.363247*	(0.021841)					
CAD	-0.115766*	(0.024093)	-0.114631	(0.180014)					
EUR	0.090468	(0.06377)	0.604088**	(0.287605)					
JPY	-0.010655	(0.01699)	0.142639**	(0.046596)					
CHF	-0.004547	(0.021424)	-0.004246	(0.008548)					
GBP	-0.015954	(0.04169)	-0.195092*	(0.086021)					
USD									
AOI	-0.000267	(0.000681)	3.87E-04**	(2.03E-04)					
TSX	0.001059*	(0.000402)	-0.000817*	(0.00021)					
EUROSTOXX	-0.000698*	(0.000264)	-0.001189*	(0.000356)					
NIKKEI225	5.13E-05	(0.00011)	-3.31E-06	(3.40E-04)					
SMI	0.000976*	(0.000239)	-0.001359**	(0.000643)					
FTSE100	0.000161	(0.000603)	-0.000205	(0.00018)					

Notes: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates. The results are based on equations (6a)-(6b) and (7a)-(7b) for the long-run and short-run volatility, respectively. *,**, *** indicate that the coefficients are significant at 1%, 5% and 10%, respectively. In parentheses are standard errors of estimated coefficients.

3.2.5.2. Sub-samples: Pre-GFC and post-GFC

For the pre-GFC period (1 January 1990-8 August 2007), comparing the results in Table 11 with those in Table 10, there is few evidence of inter-spillovers in Australia, Canada and the Euro area and some evidence of inter-spillovers in the short-run for the rest of the countries in Japan, Switzerland and United States (when foreign exchange market help to explain stock market).

For the post-GFC period (9 August 2007-31 December 2015), we find a substantial increment of the evidence in favour inter-spillovers (Table 12).

Table 11: Inter-spillovers volatility estimations, pre-GFC period (1 January 1990-8 August 2007)

Country/Direction	Long-run volatility		Short-run volatility		Country/Direction	Long-run volatility		Short-run volatility	
AOI					**TSX**				
USD	-0.003565	(0.004386)	3.487047	(6.436488)	AUD	-0.015486	(0.023322)	0.004076	(0.006385)
CAD	-0.008162**	(0.004284)	0.158199	(0.110838)	USD	-0.082662**	(0.036995)	2.498286	(1.751083)
EUR	-0.00617	(0.005634)	0.064522	(0.294976)	EUR	0.148261*	(0.052584)	-0.101111	(0.080246)
JPY	0.002465***	(0.001387)	-0.086797	(0.093205)	JPY	0.02409**	(0.011937)	-0.024798	(0.025837)
CHF	-0.010021	(0.007249)	1.165903*	(0.231752)	CHF	-0.09741***	(0.059093)	-0.027063	(0.062804)
GBP	0.005615	(0.004709)	-0.053541	(0.065753)	GBP	-0.027402	(0.038918)	0.003419	(0.017887)
AUD					**CAD**				
SP500	-0.001014	(0.001088)	-0.016801	(0.017636)	AOI	-0.002455*	(0.000915)	0.000468	(0.000503)
TSX	0.001059	(0.000688)	0.005727	(0.011652)	SP500	-0.000793**	(0.000418)	-0.002503	(0.002677)
EUROSTOXX	-0.001738**	(0.00081)	-0.016642***	(0.008348)	EUROSTOXX	-0.000158	(0.000312)	-0.003519*	(0.00127)
NIKKEI225	0.001103*	(0.00028)	-0.002738	(0.00433)	NIKKEI225	8.56E-05	(0.000107)	-0.000221	(0.000657)
SMI	0.001187**	(0.000602)	-0.007816	(0.01195)	SMI	0.000455**	(0.000231)	-0.000954	(0.001814)
FTSE100	0.002204**	(0.001124)	0.019936	(0.031814)	FTSE100	0.000427	(0.000425)	0.000128	(0.00483)
EUROSTOXX					**NIKKEI225**				
AUD	0.065301	(0.050335)	-0.02393	(0.029183)	AUD	-0.096554	(0.070083)	0.071224	(0.04691)
CAD	-0.118712***	(0.069516)	-0.155075	(0.136781)	CAD	-0.172372***	(0.096748)	0.152086	(0.219509)
USD	0.057388	(0.077052)	-8.99583	(8.0079)	EUR	-0.068128	(0.137055)	-0.04432	(0.589699)
JPY	0.015805	(0.023632)	0.437084*	(0.115927)	USD	0.027646	(0.107413)	-55.63356*	(12.92925)
CHF	-0.5391*	(0.126339)	-1.003032*	(0.292977)	CHF	0.05867	(0.178464)	-0.262199	(0.46181)
GBP	0.070509	(0.083139)	-0.090894	(0.081646)	GBP	0.068941	(0.114385)	0.242391**	(0.131528)
EUR					**JPY**				
AOI	-0.000972	(0.000723)	0.000537**	(0.000245)	AOI	0.001126	(0.003985)	-0.00019	(0.00064)
TSX	0.00093*	(0.000239)	0.000398	(0.000869)	TSX	0.006382*	(0.001291)	-0.009763*	(0.002297)
SP500	-0.000425	(0.00036)	-7.43E-05	(0.001316)	EUROSTOXX	-0.006722*	(0.001478)	0.003458	(0.001624)
NIKKEI225	0.000304*	(9.27E-05)	-0.000375	(0.000323)	SP500	-0.001322	(0.001972)	-0.000588	(0.00344)
SMI	0.000162	(0.000202)	-0.000303	(0.000893)	SMI	0.010104*	(0.001124)	0.002413	(0.00233)
FTSE100	0.000511	(0.000369)	-0.001998	(0.002372)	FTSE100	0.001156	(0.002018)	0.004078	(0.006203)

Table 11: Inter-spillovers volatility estimations, pre-GFC period (1 January 1990-8 August 2007) (cont.)

Country/Direction	Long-run volatility		Short-run volatility		Country/Direction	Long-run volatility		Short-run volatility	
SMI					**FTSE100**				
AUD	0.0194	(0.033535)	-0.00917	(0.012443)	AUD	-0.258603	(0.19116)	0.089486**	(0.0449)
CAD	-0.086465	(0.06564)	-0.714396*	(0.135987)	CAD	-1.126237	(2.073805)	-1.724695*	(0.487101)
EUR	-0.164893	(0.122878)	0.096968	(0.112693)	EUR	0.986944	(1.726895)	0.75761***	(0.405618)
JPY	0.033759	(0.028948)	0.034252**	(0.01651)	JPY	0.210563	(0.253221)	0.142518*	(0.059477)
USD	0.054767	(0.095698)	0.087052	(0.07515)	CHF	-1.70309*	(0.522065)	-0.194105	(0.122624)
GBP	0.098716	(0.087041)	0.02611	(0.036491)	USD	3.617837*	(1.166061)	0.21341	(0.273888)
SMI					**GBP**				
AOI	3.83E-05	(0.000482)	0.001158**	(0.000724)	AOI	-0.000128	(0.001116)	0.000796	(0.000885)
TSX	-0.000129	(0.000198)	0.001408**	(0.000834)	TSX	0.000317	(0.000466)	0.000217	(0.001036)
EUROSTOXX	-0.000187	(0.000185)	0.00129	(0.001346)	EUROSTOXX	0.000496	(0.000432)	-0.003102**	(0.001656)
NIKKEI225	0.000207*	(6.47E-05)	0.000424	(0.001164)	NIKKEI225	0.000418*	(0.000151)	0.00297**	(0.001446)
SP500	-0.000215	(0.00022)	-0.009597*	(0.001917)	SMI	7.56E-05	(0.000335)	-0.000496	(0.002476)
FTSE100	-4.71E-05	(0.000314)	0.001177**	(0.000549)	SP500	-0.000745	(0.000513)	0.005145**	(0.002381)
SP500									
AUD	0.008738	(0.014068)	-0.023353	(0.026971)					
CAD	-0.010641	(0.027583)	-0.161152	(0.293285)					
EUR	0.047266	(0.053787)	-0.046843	(0.244246)					
JPY	0.016433	(0.012073)	0.008458	(0.035793)					
CHF	-0.395091**	(0.171459)	0.046201	(0.073015)					
GBP	0.000788	(0.036581)	-0.031811	(0.079081)					
USD									
AOI	-0.003052**	(0.001006)	0.000616*	(0.000242)					
TSX	0.000743***	(0.000415)	-0.001354*	(0.000284)					
EUROSTOXX	-0.001569*	(0.000386)	0.000878**	(0.000453)					
NIKKEI225	0.000205	(0.000135)	2.24E-05	(0.000396)					
SMI	0.00228*	(0.000305)	0.000411	(0.000678)					
FTSE100	0.000716	(0.000655)	-0.000458*	(0.000188)					

Notes: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates. The results are based on equations ()-(). *,**, *** indicate that the coefficients are significant at 1%, 5% and 10%, respectively. In parentheses are standard errors of estimated coefficients.

Table 12: Inter-spillovers volatility estimations, post-GFC period (9 August 2007-31 December 2015)

Country/Direction	Long-run volatility		Short-run volatility		Country/Direction	Long-run volatility		Short-run volatility	
AOI					**TSX**				
USD	-0.009102	(0.018944)	0.036573	(0.079856)	AUD	0.070152*	(0.007389)	0.096564	(0.066463)
CAD	0.050081*	(0.009718)	-0.447322*	(0.066861)	USD	0.058577	(0.044284)	0.072182	(0.072948)
EUR	-0.223082**	(0.1157)	0.174137**	(0.094298)	EUR	-0.180589	(0.245916)	-0.039105	(0.078828)
JPY	0.013162	(0.009666)	0.107029	(0.071779)	JPY	-0.049219**	(0.022386)	0.254252*	(0.064128)
CHF	0.001125	(0.002016)	0.00258	(0.01379)	CHF	0.001977	(0.004655)	-0.007279	(0.01232)
GBP	-0.001523	(0.01879)	0.662306*	(0.225892)	GBP	0.168336*	(0.048744)	0.706274	(0.201884)
AUD					**CAD**				
SP500	0.011516**	(0.005878)	0.002323*	(0.000618)	AOI	0.002282**	(0.001341)	0.003367*	(0.001091)
TSX	-0.005519	(0.005969)	-0.001755*	(0.000415)	SP500	0.009403*	(0.001529)	0.024399*	(0.002614)
EUROSTOXX	-0.01173*	(0.004196)	-0.002497*	(0.000641)	EUROSTOXX	-0.003801*	(0.001128)	-0.012025*	(0.002832)
NIKKEI225	-0.010794*	(0.003089)	-0.002504*	(0.000677)	NIKKEI225	0.001378**	(0.000668)	0.012002*	(0.002078)
SMI	0.03301*	(0.003197)	0.001759	(0.001404)	SMI	0.000441	(0.000887)	0.002872	(0.005904)
FTSE100	-0.000433	(0.005016)	0.000593**	(0.000307)	FTSE100	-0.001909	(0.001361)	0.000877	(0.00129)
EUROSTOXX					**NIKKEI225**				
AUD	0.237982*	(0.029225)	0.414915**	(0.141043)	AUD	0.483953*	(0.033282)	-0.195055*	(0.069133)
CAD	-0.383899*	(0.085176)	0.124438	(0.126613)	CAD	-0.625647*	(0.090017)	0.319978*	(0.043945)
USD	0.147946	(0.163948)	-0.045287	(0.150787)	EUR	-2.009149**	(0.976174)	-0.049027	(0.059361)
JPY	-0.152204**	(0.084335)	0.2627***	(0.143266)	USD	0.218328	(0.173681)	-0.043516	(0.054091)
CHF	0.001704	(0.017553)	0.024402	(0.026151)	CHF	0.011639	(0.018545)	-0.002942	(0.009385)
GBP	0.379698**	(0.163507)	-0.757213***	(0.42841)	GBP	0.374687**	(0.17226)	-0.534387*	(0.154212)
EUR					**JPY**				
AOI	-0.000133***	(7.65E-05)	-1.75E-05	(0.000198)	AOI	0.000327	(0.001543)	-0.004258*	(0.001555)
TSX	0.000126	(9.65E-05)	0.000839**	(0.000298)	TSX	0.006084*	(0.002083)	0.011612*	(0.0025)
SP500	-4.65E-05	(8.24E-05)	-0.000581	(0.000441)	EUROSTOXX	-0.003681*	(0.00129)	0.011862*	(0.004052)
NIKKEI225	1.95E-05	(3.58E-05)	-0.0002	(0.000353)	SP500	0.000128	(0.001752)	4.45E-05	(0.003688)
SMI	0.00016*	(4.64E-05)	-0.002221**	(0.001003)	SMI	0.008071*	(0.000993)	-0.022068*	(0.008413)
FTSE100	5.46E-05	(7.34E-05)	-0.000248	(0.000219)	FTSE100	-0.001328	(0.001565)	-0.002822	(0.001837)

Table 12: Inter-spillovers volatility estimations, post-GFC period (9 August 2007-31 December 2015) (cont.)

Country/Direction	Long-run volatility		Short-run volatility		Country/Direction	Long-run volatility		Short-run volatility	
SMI					**FTSE100**				
AUD	-0.014465	(0.022548)	0.189186*	(0.060799)	AUD	-0.000331	(0.006064)	0.032146	(0.102272)
CAD	0.062416	(0.069854)	-0.020606	(0.052559)	CAD	-0.025824	(0.019467)	0.034825	(0.088703)
EUR	-0.182042	(0.749343)	0.001364	(0.071107)	EUR	-0.266079	(0.217283)	-0.08691	(0.121563)
JPY	-0.063518	(0.069109)	0.20332*	(0.058614)	JOY	0.022401	(0.019654)	-0.06612	(0.098912)
USD	-0.068684	(0.134959)	-0.066231	(0.0648)	CHF	7.33E-05	(0.004012)	-0.003786	(0.018934)
GBP	0.086497	(0.133061)	0.416112**	(0.184651)	USD	0.018594	(0.037791)	-0.013602	(0.110579)
CHF					**GBP**				
AOI	-0.005957	(0.013542)	-0.00306	(0.006595)	AOI	-0.000125	(0.000442)	0.000438	(0.000414)
TSX	-0.007665	(0.016438)	-0.000443	(0.010559)	TSX	0.004238*	(0.000816)	0.001955*	(0.000664)
EUROSTOXX	0.018021	(0.011488)	0.0318**	(0.016306)	EUROSTOXX	-0.000258	(0.000374)	0.00274*	(0.001025)
NIKKEI225	-0.004816	(0.006696)	-0.002815	(0.012571)	NIKKEI225	0.000753*	(0.00022)	0.00146**	(0.000791)
SP500	-0.008256	(0.015564)	-0.009298	(0.015701)	SMI	0.000567**	(0.000289)	0.000989	(0.002247)
FTSE100	-0.001639	(0.013833)	0.001215	(0.00781)	SP500	-0.001605*	(0.000521)	-0.001071	(0.000995)
SP500									
AUD	0.349377*	(0.027937)	0.11587	(0.128424)					
CAD	-0.404882*	(0.076723)	-0.026129	(0.110812)					
EUR	0.217479	(0.818511)	-0.148381	(0.149934)					
JPY	-0.113735	(0.075354)	-0.372875**	(0.123678)					
CHF	0.008002	(0.015705)	0.012172	(0.023708)					
GBP	0.516697*	(0.145864)	-0.521158	(0.391423)					
USD									
AOI	-4.29E-05	(0.000581)	0.000454	(0.000482)					
TSX	0.002385*	(0.00089)	-0.003*	(0.000791)					
EUROSTOXX	-0.001109**	(0.000491)	-0.005136*	(0.001192)					
NIKKEI225	0.000343	(0.000287)	0.003127*	(0.000919)					
SMI	0.000731**	(0.000379)	0.009771*	(0.002612)					
FTSE100	-0.000248	(0.000593)	0.001029**	(0.000573)					

Notes: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US Dollar effective exchange rates. The results are based on equations (6a)-(6b) and (7a)-(7b) for the long-run and short-run volatility, respectively. *,**, *** indicate that the coefficients are significant at 1%, 5% and 10%, respectively. In parentheses are standard errors of estimated coefficients.

In particular, we observe that for Australia there is some evidence of inter-spillovers in the short-run and long-run suggesting that the volatility of external foreign exchange market are relevant to explain the volatility of the domestic stock market .

For Canada, we find some evidence in both the long-run and the short-run volatility spillovers from external exchange rate market to the domestic stock market and bidirectional volatility spillovers in the short-run and long-run with Japan. In relation with the Euro area, we find some evidence of bilateral volatility spillovers with Australia in the long-run and a high percentage of significant spillovers, both in the short-run and the long-run, running from external stock markets to the domestic exchange rate market. As regard to Japan, we find evidence of inter-spillovers in the short-run and long-run and in favour of bidirectional causality in the short-run and in the long-run with Canada, as well as bidirectional causality in the long-run with the Euro area and in the short-run with Australia. With respect to Switzerland, the results suggest some inter-spillovers the short-run running from external stocks market to domestic foreign exchange market. As concerns the UK, our results indicate the existence of inter-spillovers in the short-run running from external exchange rates to the domestic stock market. Referring to the United States, we find some evidence of bilateral spillovers in the long-run with Canada and in the short-run with Japan, as well as some instance of unilateral spillovers in the short-run and long-run with other countries under study. Finally, it is very noticeable that we do not find any evidence of long-run volatility spillovers for Switzerland, nor for the UK running from domestic the stock market to the external foreign exchange markets in the long-run or in the short-run

All in all, our findings suggest that inter-spillovers increase substantially during the post-GFC period, providing support to the literature documenting that cross-country and cross-markets linkages increases in the time of growing economic and financial instability.

3.2.6. Granger-causality analysis

In this subsection we present results from the Granger (1969) approach to causality to explore the relationship between the 14 markets under study, given that the previous analysis of correlation does not necessarily imply causation in any meaningful sense of that word.

Tables 13 to 15 display the result of the pairwise intra-spillovers. Regarding the entire sample (Table 13), we find evidence of bidirectional causality for Japan (both in long-run and short-run volatility), bilateral causality in long-run volatility for Switzerland and the UK, and bilateral causality in short-run volatility for Canada. The results also suggest the presence of Granger causality (at least at the 5% significance level) running one-way from the foreign market to stock market in Australia (both in long-run and short-run volatility) and from the stock market to the foreign exchange market in the Euro area (in long-run volatility), in the UK (in short-run volatility), and in the USA (both in long-run and short-run volatility).

Table 13: Intra-spillovers Granger causality, full sample (1 January 1990 to 31 December 2015)

Null Hypothesis	Long-run volatility		Short-run volatility	
	F-statistic	p-value	F-statistic	p-value
AOI does not Granger cause AUD	0.15227	0.8588	2.6221	0.0727
AUD does not Granger cause AOI	64.9456	1.00E-28	176.313	3.00E-75
TSX does not Granger cause CAD	59.4183	3.00E-26	110.976	4.00E-48
CAD does not Granger cause TSX	1.01183	0.3636	1.91268	1.48E-01
EUROSTOXX does not Granger cause EUR	9.233	0.0001	1.38918	0.2494
EUR does not Granger cause EUROSTOXX	0.25686	0.7735	0.68887	0.5022
NIKKEI225 does not Granger cause JPY	25.5034	9.00E-12	13.0576	2.00E-06
JPY does not Granger cause NIKKEI225	29.5599	2.00E-13	55.2204	2.00E-24
SMI does not Granger cause CHF	3.60548	2.72E-02	3.05451	0.0472
CHF does not Granger cause SMI	44.7976	5.00E-20	39.857	6.00E-18
FTSE100 does not Granger cause GBP	28.7695	4.00E-13	21.7695	4.00E-10
GBP does not Granger cause FTSE100	3.56451	0.0284	0.95063	0.3866
SP500 does not Granger cause USD	34.0228	2.00E-15	18.2244	1.00E-08
USD does not Granger cause SP500	0.93759	0.3916	0.15594	0.8556

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, Canadian dollar, British pound and US Dollar effective exchange rates

Turning to the case of the results for the pre-GFC period (1 January 1990-8 August 2007), Table 14 suggests the existence of bidirectional causality in long-run volatility for the Euro Area and Switzerland, and bilateral causality in short-run volatility for the UK. There is also evidence of unilateral causality from the stock market to the foreign exchange market for Australia (in long-run volatility) and for Canada (both in long-run and short-run volatility), as well as unilateral causality running from the foreign market to stock market in Japan (both in long-run and short-run volatility), Switzerland (in short-run volatility) and for the UK (in long-run volatility).

Table 14. Intra-spillovers Granger causality, pre-GFC period (1 January 1990-8 August 2007)

Null Hypothesis	Long-run volatility		Short-run volatility	
	F-statistic	p-value	F-statistic	p-value
AOI does not Granger cause AUD	2.7869785	0.06171481	0.99634	0.3693
AUD does not Granger cause AOI	0.84982454	0.42755942	1.62655	0.1967
TSX does not Granger cause CAD	3.9058	0.0202	3.63886	0.0264
CAD does not Granger cause TSX	1.284	0.277	1.84162	0.1587
EUROSTOXX does not Granger cause EUR	4.26743	0.0141	4.53323	0.0108
EUR does not Granger cause EUROSTOXX	3.35427	0.035	2.56563	0.077
NIKKEI225 does not Granger cause JPY	2.6639	0.0698	2.53391	0.0795
JPY does not Granger cause NIKKEI225	17.6385	2.00E-08	16.7825	5.00E-08
SMI does not Granger cause CHF	7.17147	0.0008	2.32783	0.0976
CHF does not Granger cause SMI	15.237	3.00E-07	5.65037	0.0035
FTSE100 does not Granger cause GBP	2.44804	0.0866	5.38613	0.0046
GBP does not Granger cause FTSE100	11.0965	2.00E-05	9.28863	9.00E-05
SP500 does not Granger cause USD	2.10125	0.1224	2.14169	0.1176
USD does not Granger cause SP500	0.91601	0.4002	0.36373	0.6951

Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates

Table 15: Intra-spillovers Granger causality, post-GFC period (9 August 2007-31 December 2015)

Null Hypothesis	Long-run volatility		Short-run volatility	
	F-statistic	p-value	F-statistic	p-value
AOI does not Granger cause AUD	3.01751	0.0491	4.89271	0.0076
AUD does not Granger cause AOI	19.1346	6.00E-09	49.841	7.00E-22
TSX does not Granger cause CAD	2.00406	0.135	2.12089	0.1202
CAD does not Granger cause TSX	41.0816	3.00E-18	29.5162	2.00E-13
EUROSTOXX does not Granger cause EUR	2.43539	0.0878	1.56494	0.2093
EUR does not Granger cause EUROSTOXX	5.22806	0.0054	2.01706	0.1333
NIKKEI225 does not Granger cause JPY	14.1079	8.00E-07	53.7623	2.00E-23
JPY does not Granger cause NIKKEI225	20.427	2.00E-09	14.1077	8.00E-07
SMI does not Granger cause CHF	0.72843	0.4828	1.27592	0.2794
CHF does not Granger cause SMI	4.6346	0.0098	1.27875	0.2786
FTSE100 does not Granger cause GBP	1.21202	0.2978	1.15406	0.3156
GBP does not Granger cause FTSE100	1.29751	0.2734	1.54178	0.2143
SP500 does not Granger cause USD	0.4156	0.66	0.46463	0.6284
USD does not Granger cause SP500	20.605	1.00E-09	11.6658	9.00E-06

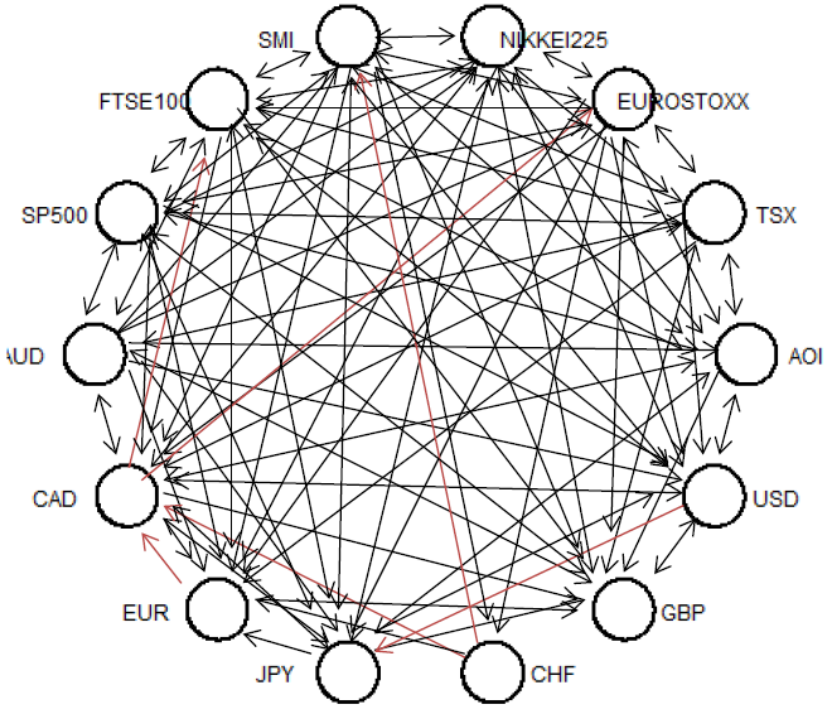
Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US Dollar effective exchange rates

As can be seen in Table 15, for the post-GFC period (9 August 2007-31 December 2015), we find evidence of bidirectional causality for Australia and Japan (both in long-run and short-run volatility). The results also suggest the presence of Granger causality running one-way from the foreign market to stock market in Canada and the USA (both in long-run and short-run volatility) and in the Euro area and Switzerland (in long-run volatility).

As for the inter-spillovers, Figure 4 to 9 synthetically displays the main results for our Granger-causality analysis. Instead of presenting the detailed results (that are available from the authors upon request), we provide a visualization of the complex causality network among the 14 variables in our sample[7]. The colour of the arrows indicates significance of the causality relationships detected among the variables: black and red links correspond, respectively, to the 1% and 5% level of significance.

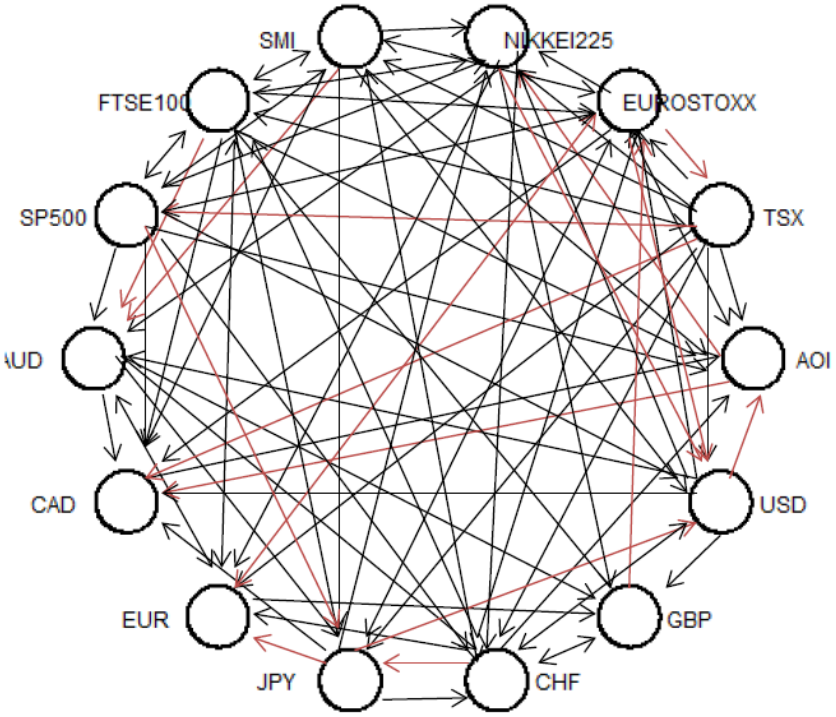
[7] The full results of the Granger-causality tests, not shown here to save space, are available from the authors upon request.

Figure 4: Causal relationships in long-run volatility, full sample (1 January 1990 to 31 December 2015)



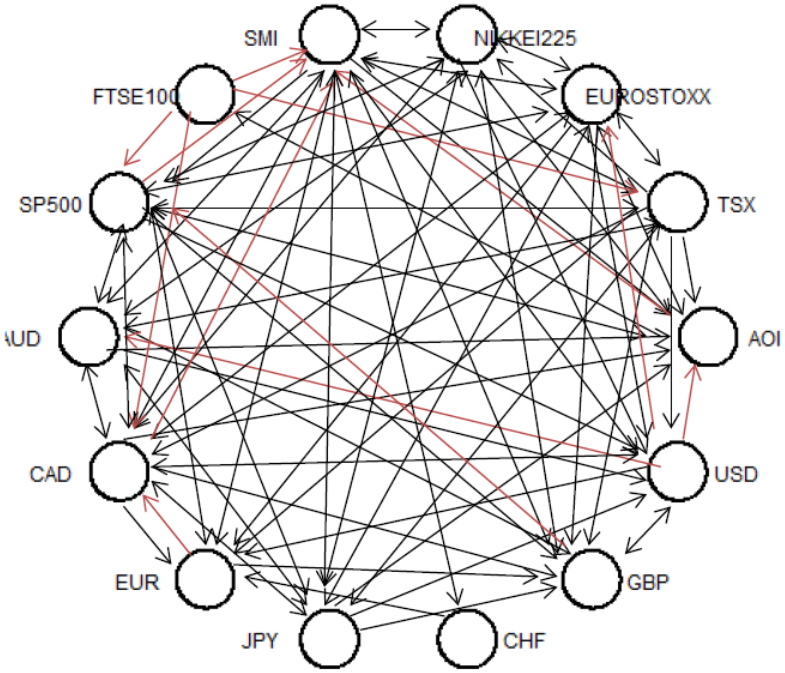
Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.

Figure 5: Causal relationships in long-run volatility, pre-GFC period (1 January 1990-8 August 2007)



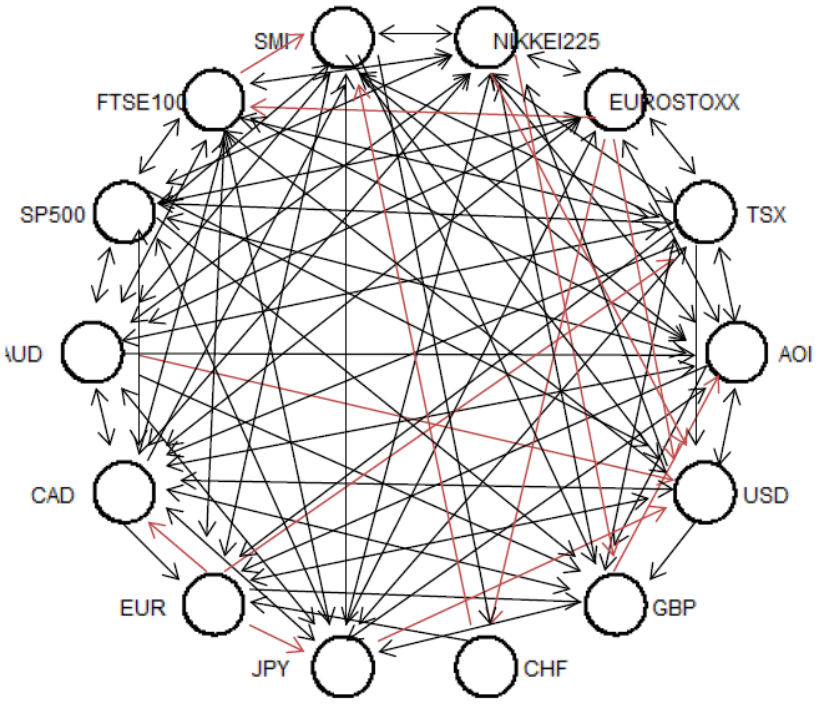
Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.

Figure 6: Causal relationships in long-run volatility, post-GFC period (9 August 2007-31 December 2015)



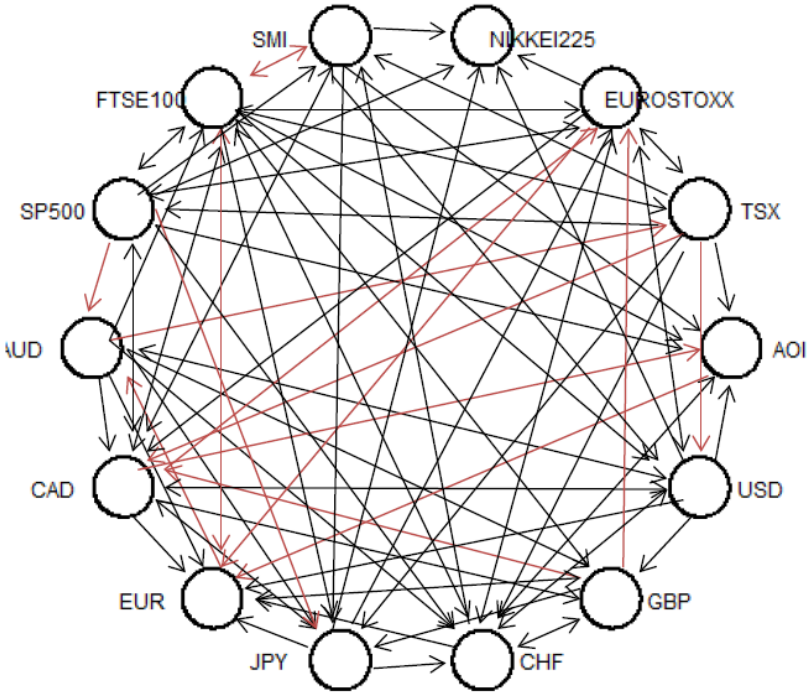
Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.

Figure 7: Causal relationships in short-run volatility, full sample (1 January 1990 to 31 December 2015)



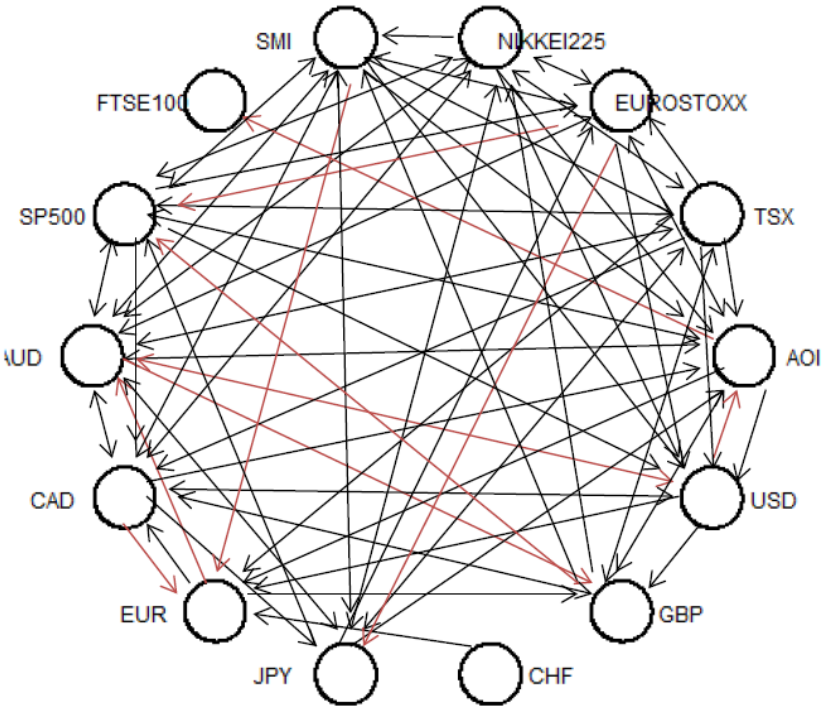
Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.

Figure 8: Causal relationships in short-run volatility, pre-GFC period (1 January 1990-8 August 2007)



Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.

Figure 9: Causal relationships in short-run volatility, post-GFC period (9 August 2007-31 December 2015)



Note: AOI, TSX, EUROSTOXX, NIKKEI225, SMI, FTSE100, SP500, AUD, CAD, EUR, JPY, CHF, GBP and USD stand for Australian All Ordinaries Index, Toronto Stock Exchange index, Eurostoxx 50 Index, Nikkei 225 index, Swiss Market Index, Financial Times Stock Exchange 100 Index, Standard & Poor's 500 composite index, Australian dollar, Canadian dollar, Euro, Japanese yen, Swiss franc, British pound and US dollar effective exchange rates.

According to Figures 4 to 6, while in the full sample there are 52 bidirectional causality relationships in long-run volatility out of the 91 possible pair-wise combinations between the 14 markets under study[8], we only detect 27 for the pre-GFC period and 37 for the post-GFC period.

During the full sample (Figure 4), in 27 out of the 49 possible cases, we also find evidence of Granger-causality in long-run volatility running from foreign-exchange markets to stock markets, while in 41 out for the 49 cases our results suggest Granger-causality in long-run volatility running from stock markets to foreign-exchange stock markets. Finally, while in 23 out of 42 possible pairwise combinations we find evidence of Granger-causality in long-run volatility among foreign-exchange markets, for the stock markets we detect causality in all cases.

For the pre-GFC period, depicted in Figure 5, our results indicate that in 14 out of the 49 possible cases, there is Granger-causality running from foreign-exchange markets to stock markets, while in 29 out for the 49 cases, the opposite is true. Regarding the long-run volatility among foreign-exchange markets, we find Granger-causality in 20 out of 42 possible cases, while for the stock markets we detect causality in 30 out of 42 cases.

As can be seen in Figure 6, in 32 out of the 49 possible cases, we find evidence of Granger-causality in long-run volatility running from foreign-exchange markets to stock markets during the post-GFC period, while in 21 out for the 49 cases we find the opposite result. Finally, while in 30 out of 42 possible pairwise combinations we find evidence of Granger-causality in long-run volatility among foreign-exchange markets, for the stock markets we detect causality only in 21 out of 42 cases.

Turning to the case of short-run volatility, comparing Figures 4 and 7, we observe a reduction of the number of significant Granger-Causality relationships for the full sample: 48 bidirectional causality relationships out of the 91 possible cases; 29 (out of 49) unilateral causality relationships running from foreign-exchange markets to stock markets and 34 (out of 49) unilateral causality relationships running from stock markets to foreign-exchange markets; 20 (out of 42) causality relationships among foreign exchange markets and 38 (out of 42) causality relationships among stock markets

As for the pre-GFC period (Figure 8), in 19 out of the 49 possible cases we find evidence of Granger-causality running from foreign-exchange markets to stock markets, while in 24 out for the 49 cases, the causality relationship runs in the opposite direction. Additionally, we find short-run volatility causality interlinkages among foreign-exchange markets in 26 out of 42 possible cases, as well as short-run volatility causality among the stock markets under study in 25 out of 42 cases. Finally, we detect short-run volatility bidirectional causality relationships in 24 out of the 91 possible pairwise combinations.

Regarding the post-GFC period, in Figure 9, in 21 out of the 49 possible cases we observe evidence of Granger-causality in short-run volatility running from foreign-exchange markets to stock markets, while in 25 out for the 49 cases we find evidence of short-run volatility running from stock markets to foreign-exchange markets. Furthermore, , while in 18 out of 42 possible pairwise combinations our results indicate Granger-causality in short-run volatility among foreign-exchange markets, for

[8] Recall that the number of possible pairs between our sample of foreign exchange and stock markets is given by the following formula $\frac{n!}{r!(n-r)!} = \frac{14!}{2!(14-2)!} = 91.$

the stock markets we detect causality in 26 out of 42 cases. Finally, we find short-run volatility bidirectional causality relationships in 31 out of the 91 possible pair-wise combinations.

In summary, our analysis of pairwise Granger-causality relationships suggests that both for the whole sample and for the pre-GFC period stock markets played a dominant role in the transmission of long-run volatility, whereas during the post-GFC period the exchange-rate markets were the main long-run volatility triggers. As for the short-run volatility spillovers, in all samples the stock markets were volatility transmitter to exchange-rate markets. Finally, compared with the pre-GFC period, the net of Granger-causality relationships among the exchange-rate and stock markets under study becomes denser and stronger in the post-GFC period.

4. Concluding remarks

The recent GFC has underlined that the cross-market and cross-border transmission of shocks can be rapid and powerful due to the strong interlinkages in international financial markets. As Eichengreen (2016) contend, macroeconomic and financial volatility is likely to remain a fact of twenty-first century economic life, implying that a good understanding of international spillovers is essential for policy coordination and design.

This study builds upon an existing literature examining volatility transmission between financial assets that trade both within and across countries, focusing on the volatility spillovers between foreign-exchange and stock markets. In particular, in what we believe is the first study to do so, we use the C-GARCH volatility model to distinguish the long-run and short-run volatility components, shedding some light on the importance of both components in the transitory of volatility in these markets. Additionally, we make use of the SVAR framework (Sohel Azad *et al.*, 2015) to analyse the short-run and lung-run volatility spillsovers among the exchange-rate and stock markets in major world economies and the Granger causality approach to assess whether there is evidence in favour of bidirectional or unidirectional causality between them.

The main findings of our research can be summarized as follows. (i) The estimated permanent and transitory components of the conditional variance exhibit several well-known peaks in volatilities; (ii) the long-run volatility relationships are stronger than the short-run linkages volatility with a reinforcement during the post-global financial crisis period; (iii) the presence of intra-spillovers and inter-spillovers increases substantially during the post-global financial crisis period and (iv) in all samples, the stock markets play a dominant role in the transmission of long-run and short-run volatility, except for in the period after the Global Financial Crisis, where the foreign-exchange markets are the main long-run volatility triggers.

Taken together, we find unambiguous support for volatility spillovers increasing the likelihood of financial crises, in line to previous studies that have documented the effect of extreme market turmoil on foreign-exchange and stock markets (see, e. g., Hartmann *et al.* 2003; Cumperayot *et al.* 2006, Ranaldo and Söderlind 2010; or Lin 2012).

The results presented in this paper should be of value to macro-prudential and monetary policymakers, as they provide evidence on the time-varying relationship between different components of financial volatility. Our find-

ings may also provide useful insight into the file of volatility forecasting, option pricing and futures hedging strategies, among other, that could be useful to portfolio managers, risk strategists and insurers and that we leave for a future study.

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