Volatility Spillover between Stock Prices and Exchange Rates: New Evidence across the Recent Financial Crisis Period

ABSTRACT

We employ an Exponential Generalized Autoregressive Conditional Heteroskedasticity (EGARCH) model to examine the volatility spillover effects between stock prices and exchange rates in three developed and three emerging countries across the recent pre-financial-crisis, crisis and post-crisis periods. The evidence indicates asymmetric volatility spillover effects between stock prices and exchange rates in both developed and emerging economies during the financial crisis. The findings of the significant volatility spillover effects between exchange rates and stock prices imply that the markets are informationally inefficient, and one market has significant predictive power on the other.

JEL classification: C32, F21, G15.

Keywords: Exchange rates, stock prices, EGARCH, volatility spillover

1. INTRODUCTION

The volatility of asset prices has received considerable attention in the literature, particularly in recent years. Increasing financial integration, cross border capital movements and various financial crises around the globe have led several researchers (Antell and Vaihekoski, 2007; Kanas, 2000; Walid et al., 2011; Wu, 2005; Yang and Doong, 2004) to investigate the volatility spillover effect between stock and foreign exchange markets.

Research efforts aimed at a better understanding of the transmission mechanism of the volatility in stock and foreign exchange returns, and of how information is transmitted from one market to the other, are understandable given the importance of these phenomena for option pricing, hedging, risk management, portfolio selection and regulatory policy formulation. For example, if the volatility transmits from one asset to another, both assets cannot be included in the same portfolio in order to diversify risk. Improved knowledge about the quality and quantity of the volatility spillover across asset markets, in turn, can aid better decision making for portfolio managers, multinational firms, investors and policy makers alike.

Volatility is typically defined as a measure of dispersion of returns of an asset or market index. Generally, the higher the volatility, the more riskier the asset. A number of studies (e.g., Giannellis et al., 2010) find that conditional volatility of asset prices responds asymmetrically to innovations (good or bad news). In the context of volatility transmission between exchange rates and stock prices, Apte (2001), Kanas (2000), Walid et al. (2011), and Yang and Doong (2004) find significant asymmetric volatility spillovers between the asset markets.

Many economic theories such as the *Balance of Payment Approach* (Dornbush and Fisher, 1980) and the *Portfolio Approach* (Branson, 1983;

Frankel, 1983) as well as empirical studies such as Aggarwal (1981) and Ajayi et al. (1998) suggest that there is interdependence between the volatility of stock and foreign exchange markets. Moore and Wang (2014) argue that the sign, size and direction of this interdependence depends upon the financial integration and market efficiency of the country, and whether the economy is export or import dominant. Most of the existing research on the inter-temporal dependence of the volatility of asset markets (e.g., Raghavan and Dark, 2008; Yang and Doong, 2004) tends to focus on developed countries, with less attention being paid to the relationship in question from the perspective of both emerging and developed countries. This is striking when considering that country specific variables such as the degree of capital mobility, trade volumes and the interrelationship between macroeconomic variables may also impact volatility transmission between foreign exchange and stock markets.

Motivated by the above mentioned arguments, this study examines the interrelationship between volatility of stock and foreign exchange markets in three developed countries (Ireland, Netherland and Spain) and three emerging economies (Brazil, South Africa and Turkey). The specific questions we address are whether the shock in one asset market increases the shock in the other, and whether the impact is the same for both positive and negative shocks of the same magnitude.

Ireland, Netherlands and Spain are selected because they represent the Euro Zone, the biggest economic zone in the world. Brazil, South Africa and Turkey are chosen because they are three of the largest emerging and developing economies (in three different continents) by either nominal or inflation-adjusted gross domestic product (GDP) (IMF, 2012) and – unlike other large emerging economies such as China and India.- their foreign exchange markets (and currencies) are unmanaged. Another contribution of our study lies in the adoption of a disaggregated framework that discriminates between pre-crisis, crisis and post-crisis periods in order to ascertain the extent to which the recent financial crisis affected the relationship in question, an aspect which has not been given any attention in prior work for the countries considered in the present study.

The remainder of the paper is organised as follows. Section 2 provides a review of relevant literature on the relationship between exchange rates and stock prices. Section 3 discusses the econometric approach and the data employed. Section 4 provides a first pass at the data while Section 5 presents the empirical results. The implications of the findings and some concluding remarks are offered in Section 6.

2. A BRIEF REVIEW OF THE LITERATURE

Theoretical models examining the relationship between exchange rates and stock prices draw from both Traditional and Portfolio approaches. Traditional or flow-oriented models (Dornbusch and Fischer, 1980) of exchange rates focus on the current account or trade balances. These models posit that movements in exchange rates affect the competitiveness and profitability of firms resulting in the increase or decrease of stock prices. The depreciation in exchange rates results in an increase in local firm's export leading to an increase in stock prices. By contrast, an appreciation causes a decrease in stock prices. Here, the exchange rate is the lead variable, determining a positive correlation between exchange rates and stock prices.

On the other hand, Portfolio or Asset Market approaches (Branson, 1983; Frankel, 1983) postulate that it is capital flows, not trade flows that determine exchange rates. In these models, exchange rates are determined by demand and supply of domestic assets (stocks and bonds). An increase in stock prices leads to an increase in demand for domestic assets resulting in an appreciation of the domestic currency. By contrast, the decrease in stock prices causes exchange rates to depreciate. Here, stock price is the lead variable and the postulated relationship is negative.

Solnik (2000) points out that financial crises have a negative effect on exchange rates and stock prices in both developed and emerging markets. However, while in developed countries a crisis is usually triggered by a stock market crash (such as the Wall Street crash of 1929, and the stock market falls witnessed in the 2000s), in emerging economies it is normally prompted by a currency crisis (e.g. Asian currency crisis of 1997). Therefore, stock prices are thought to be the lead variable in developed countries while exchange rates are the lead variable in the emerging countries.

Turning to the empirical literature, early work on the relationship between exchange rates and stock prices tended to focus on the first moment (mean) of distribution of asset returns. Ajayi and Mougoue (1996) find a significant short- and long-term relationship between the variables in eight developed countries. They suggest that an increase in stock prices results in an increase in exchange rates in the USA and the UK. The relationship is explained in terms of economic agents treating rising stock prices as a sign of higher inflation expectations which, in turn leads to a lower demand for local currency, with the latter depreciating as a result. In stark contrast, Aggarwal (1981) finds a negative correlation between USA stock prices and trade-weighted dollars. This result is rationalised in terms of a decline in stock prices pushing foreign investors to sell their assets denominated in local currency, leading to a depreciation of the currency. However, Bahmani-Oskooee (1992), Granger et al. (2000) and Nieh and Lee (2001) argue in favour of the existence of bi-directional causality in the relationship.

A few studies have examined the second moment (variance) distribution of the variables. For example, Raghavan and Dark (2008), Yang and Doong (2004) and Kanas (2000) analyse the volatility spillover effects between stock and foreign exchange markets in developed countries, while Walid et al. (2011), Wu (2005) and Apte (2001) concentrate on emerging countries. It is noteworthy that there is a dearth of literature that has investigated volatility spillover effects from both developed and emerging countries' perspective using the same methodology and time span. This is an important shortcoming because, as argued by Moore and Wang (2014), the sources and nature of the linkage between exchange rates and stock prices in developed economies are different from those in emerging economies.

Raghavan and Dark (2008) find a significant unidirectional return and volatility spillover from the USD/AUD exchange rates to Australian All Ordinaries Index (AOI) by using daily data on the USD/AUD and the Australian All Ordinaries Index (AOI) from 2 January 1995 to 31 December

2004. The major drawback of this study is that it ignores the possibility of volatility asymmetry in financial asset prices, i.e. that positive and negative shocks may induce a different degree of volatility.

Yang and Doong (2004) investigate the mean and volatility spillover from one market to another in G-7 countries using weekly (Friday) closing exchange rates and stock market indices. Employing a bivariate Exponential Generalized Autoregressive Conditional Heteroskedasticity (EGARCH) model, they find an asymmetric spillover effect from stock markets to foreign exchange markets in France, Italy, Japan and the USA. However, the volatility in exchange rates is found to have a less pronounced impact on the volatility in stock prices. One potential limitation of this study is that weekly closing data could contain the 'Friday effect' on stock indices and exchange rates, and hence skew the data.

Kanas (2000) examines the volatility spillover between stock and foreign exchange rate markets in the USA, the UK, Canada, Japan, Germany and France, using daily data and employing a bivariate EGARCH model. The study concludes that there is a significant symmetric volatility spillover from stock returns to exchange rate changes for all countries except Germany. However, the volatility spillovers from exchange rates changes to stock returns were not significant for any of the countries examined. One possible explanation for the result of an insignificant spillover is that the use of daily data cannot capture the effect of trade flows on exchange rate changes.

Walid et al. (2011) examine the impact of exchange rate changes on stock market volatility in four emerging markets (Hong Kong, Singapore, Malaysia and Mexico). Using weekly data and employing a two regime Markov Switching-EGARCH model, they find evidence of regime switching behaviour in volatility of emerging countries' stock markets, and that the relationship between exchange rates and stock prices is regime dependent. Their evidence also indicates that the volatility in foreign exchange markets spills over to stock markets asymmetrically.

Apte (2001) examines the volatility spillover effect between stock and foreign exchange markets in India using the bivariate EGARCH model and daily data from 02 January 1991 to 24 April 2000. Contrary to the findings of Kanas (2000) and Yang and Doong (2004), the study finds a significant volatility spillover from the foreign exchange market to the stock market and an insignificant volatility spillover from the stock market to the foreign exchange market. Mishra et al. (2007) point out that the main limitation of this study is that it generated the data on stock indices from 1991 to 1994 by simulation. By using an EGARCH model and by extending the sample period, Mishra et al. (2007) find a bi-directional volatility spillover between stock and foreign exchange markets in India.

Wu (2005) examines the volatility spillover effects between stock and foreign exchange markets in Japan, South Korea, Indonesia, Philippines, Singapore, Thailand and Taiwan for the period 1997-2000, splitting the data into pre-Asian financial crisis and post-crisis periods. The study finds a bi-directional spillover effect between the variables during the recovery period in almost all countries.

It is clear from the above review of relevant literature that the findings on volatility spillover effects between stock prices and exchange rates are rather mixed, with no clear consensus from which to discern a conventional wisdom. The results vary from country to country, also depending on the methodology adopted as well as the quantity, quality and time span of data employed. There is therefore value in investigating further the effects of volatility spillover between exchange rates and stock prices, particularly by comparing the experience of both developed and emerging markets within the same framework, across pre-crisis, crisis and post-crisis periods using the same methodology, time span and latest dataset.

3. ECONOMETRIC APPROACH AND DATA DESCRIPTION

We employ the multivariate extension of the Exponential Generalised Autoregressive Conditional Heteroskedasticity (EGARCH) model proposed by Nelson (1991). This model has some advantages over other GARCH models. For example, there is no need for imposing a non-negativity constraint on model parameters since the log of the conditional variance is modelled, thus allowing for the detection of asymmetric effects in volatility. The model specification is as follows.

Mean equations:

$$S_t = \beta_{s,0} + \sum_{i=1}^{k} \beta_{s,i} S_{t-i} + \sum_{i=1}^{k} \beta_{e,i} E_{t-i} + \alpha_s \lambda_{s,t-1} + \epsilon_{s,t} \tag{1}$$

$$E_t = \beta_{e,0} + \sum_{i=1}^{k} \beta_{e,i} E_{t-i} + \sum_{i=1}^{k} \beta_{s,i} S_{t-i} + \alpha_e \lambda_{e,t-1} + \epsilon_{e,t} \tag{2}$$

$$\epsilon_{s,t}/\Omega_{t-1} \approx N\left(0, \sigma_{s,t}^2\right) \tag{3}$$

$$\epsilon_{e,t}/\Omega_{t-1} \approx N\left(0, \sigma_{e,t}^2\right) \tag{4}$$

Conditional variance equations:

$$\sigma_{s,t}^2 = exp\left\{ \alpha_{s,0} + \sum_{i=1}^{k} \beta_{s,i} log\left(\sigma_{s,t-i}^2\right) + \delta_{s,s}\left[\left(|Z_{s,t-1}| - E|Z_{s,t-1}|\right) + \pi_{s,s_{z_{s,t-1}}}\right] + \delta_{s,e}\left[\left(|Z_{e,t-1}| - E|Z_{e,t-1}| + \pi_{s,e_{z_{e,t-1}}}\right)\right]\right\} \tag{5}$$

$$\sigma_{e,t}^2 = exp\left\{ \alpha_{e,0} + \sum_{i=1}^{k} \beta_{e,i} log\left(\sigma_{e,t-i}^2\right) + \delta_{e,e}\left[\left(|Z_{e,t-1}| - E|Z_{e,t-1}|\right) + \pi_{e,e_{z_{e,t-1}}}\right] + \delta_{e,s}\left[\left(|Z_{s,t-1}| - E|Z_{s,t-1}| + \pi_{e,s_{z_{s,t-1}}}\right)\right]\right\} \tag{6}$$

$$\sigma_{s,e,t} = \rho_{s,e,t}\ \sigma_{s,t}\ \sigma_{e,t} \tag{7}$$

$$\sigma_{e,s,t} = \rho_{e,s,t}\ \sigma_{e,t}\ \sigma_{s,t} \tag{8}$$

In equations (5) and (6) the conditional variance in one market depends on its own lags and cross market standardised innovations. The persistence of volatility is measured by β. The volatility spillover effect is captured by the coefficient δ. If $\delta_{s,e}$ is significantly different from zero then the volatility of exchange rates spills over to volatility of stock prices. Asymmetric impact is measured by the coefficient π. Asymmetry exists if π is negative and significantly different from zero. A positive and significant δ alongside a negative and significant π implies that negative shocks in one market have a larger impact on the volatility of the other market than positive shocks of the same absolute value. In other words, ‘bad news’ has greater impact on volatility than ‘good news’.

We use weekly (Wednesday) closing spot exchange rates (local currency per US Dollar) and weekly stock price indices of Brazil, Ireland Netherland, Spain, South Africa and Turkey. The data are obtained from Datastream. Weekly Wednesday data are used because daily data contain too much noise, Friday data contain weekend effects, and monthly data cannot capture the short-term dynamic relationship between exchange rates and stock prices (see also Walid et al., 2011).

The stock indices used in the study consist of Brazil BOVESPA, Ireland SE Overall (ISEQ), Amsterdam SE All Share, IBEX 35 (Spain), FTSE/JSE All Shares (South Africa) and ISE National All Share (Turkey). These are the main stock indices of the respective countries. The exchange rates are USD Euro, USD Brazilian Real, USD South African Rand and USD Turkish Lira. Following the standard rationale provided in relevant literature, we use nominal exchange rates in that short-term investors are not worried about inflation effects as they do not buy goods in the basket used to construct the inflation rate.

The full sample period covers from 03/01/2001 to 26/12/2012, yielding 626 observations. The period is justified by the major growth in international financial liberalization, financial integration and foreign direct investment in the 2000s; a representative decade to measure the short time dynamic relationship between stock and foreign exchange markets. Furthermore, the sample period allows us to investigate the relationship between exchange rate movements and stock market volatility during ‘good’ and ‘bad’ times.

The global financial crisis of 2007-2008, resulted in the downturn in stock markets around the world. The active phase of the crisis can be dated from August 7, 2007, when BNP Paribas terminated withdrawals from three hedge funds recording a complete evaporation of liquidity (IMF, 2012). The downturn in stock markets around the world continued until March 2009. From August 2007 to March 2009, the stock indices in Ireland, Netherlands and Spain decreased by 75%, 55% and 45%, respectively. Brazilian, South African and Turkish stock indices were down by 24%, 25% and 50%, respectively, during the crisis period. Brazilian Real, South African Rand and Turkish Lira depreciated by 19%, 32% and 28% over that period, whereas the Euro appreciated by 1% against the US Dollar during the same period.

Based on recursive estimates, the full sample period is divided into three sub-periods: pre-crisis, crisis and post-crisis. The pre-crisis period is from 03/01/2007 to 25/07/2007, yielding 343 observations. The crisis period is from 01/08/2007 to 25/03/2009, totalling 87 observations, and the post-crisis period is from 01/04/2009 to 26/12/2012, yielding 196 observations.

The weekly return series are calculated as $R_t = \ln (P_t / P_{t-1})$, where P_t is the weekly price at time t. The plots of stock prices and exchange rate series, for all countries in our sample (not reported to conserve space though available upon request) show that volatility occurs in bursts.

4. A FIRST PASS AT THE DATA

Descriptive statistics of weekly return series of stock indices for Ireland, Netherlands, Spain, Brazil, South Africa and Turkey are reported in Table 1. Panel A shows descriptive statistics for the full sample (January 2001 to December 2012). The mean returns in developed stock markets (Ireland, Netherlands and Spain) were negative, whereas the mean returns in the emerging stock markets (Brazil, South Africa and Turkey) were positive. This reveals that stock markets in emerging countries performed better than in developed countries during the full sample period. Stock market volatility in emerging markets, especially in Turkey and Brazil, was higher than the volatility in the developed countries' stock markets. During the full sample period, the highest return and volatility was in the Turkish stock market, and the lowest return and volatility was in the Spanish stock market. This suggests that there was a trade-off between risk and return.

< Table 1 here >

Panel B of Table 1, which presents descriptive statistics of the pre-crisis period, reveals that all countries except the Netherlands had positive stock returns and the volatility in stock markets was lower in most countries compared with the full sample period. Panel C shows that stock returns were negative and the volatility was high in all countries during the financial crisis. However, stock markets crawled back to positive returns and low volatility during the recovery period, as indicated by the data presented in Panel D.

< Table 2 here >

Table 2 exhibits descriptive statistics for weekly changes in exchange rates. Panel A of Table 2, covering the full sample period, reveals that the Euro appreciated, and Brazilian Real, South African Rand and Turkish Lira depreciated against the US Dollar. However, the volatility in emerging foreign exchange markets was higher than that experienced in developed economies' markets.

As Panels B and C indicate, all exchange rates, except the Turkish Lira in the pre-crisis period, appreciated in 'good times' and depreciated in 'bad times'. Again, there was high volatility in all foreign exchange markets during the financial crisis compared with the pre-crisis period. However, the volatility decreased gradually during the recovery period, as shown in Panel D.

It is worth highlighting that all stock return series (except for Ireland during the crisis period) are negatively skewed indicating that the distributions have long left tails, while all the series of exchange rate changes (except for the US Dollar and the Euro during the full sample and crisis period), are positively skewed indicating that most of the distributions have long right tails. Unsurprisingly, the coefficients of kurtosis for all series are greater than three, indicating that they are leptokurtic in nature (as confirmed by the Jarque-Bera test statistics, which reject the normality hypothesis for all series at the customary 5% significance level).

The test for an ARCH effect indicates that the squared residuals are autocorrelated in all series. Therefore, the weekly returns of both series have all common characteristics (typical of financial data) such as volatility clustering and leptokurtosis, which means that the volatility of all series can be modelled by GARCH type models.

5. RESULTS

Prior to undertaking EGARCH estimations, our preliminary testing phase entailed assessing the integration and cointegration properties of the series. Standard ADF unit root tests (results not reported to conserve space but available from the authors upon request) revealed that the time series are integrated of order (1) in (log) levels but stationary in their first differences. Hence, the series in levels can be used to test for a cointegrating relationship.

< Table 3 here >

The results of the Johansen cointegration tests are reported in Table 3. For the full sample period (Panel A), we found conitegrating relationships between stock prices and exchange rates for Brazil and Turkey. However, the variables do not cointegrate in the case of Ireland, the Netherlands, Spain and South Africa. The results justify the inclusion of the error correction terms in the mean equations (1) and (2) for Brazil and Turkey in the full sample period.

For the pre-crisis period (Panel B), we found statistically insignificant trace and maximum eigenvalue statistics in all countries except Turkey. During the period of the financial crisis (Panel C), the variables cointegrate only in the case of Brazil, while during the post-crisis (recovery) period (Panel D) stock prices and exchange rates are cointegrated only in the case of South Africa.

Hence, error correction terms are included in mean equations (1) and (2) for Brazil, South Africa and Turkey in the crisis, post-crisis and pre-crisis periods, respectively.

The preceding results show that there is no long run relationship between stock prices and exchange rates in developed countries. This finding is consistent with those by Yang and Doong (2004), Nieh and Lee (2001) and Granger et al. (2000). However, stock prices and exchange rates in emerging countries are found to co-move at least in one sample period. This indicates that there is a long term relationship between the variables in emerging countries, which is in line with the findings by Wu (2005), and Apte (2001). It may be that other factors such as interest rates and inflation cause exchange rates and stock prices in emerging markets to move together.

< Table 4 here >

Table 4 presents the EGARCH estimations. Panel A reports the results for the full sample period. Volatility persistence of stock prices and exchange rates, measured by β, is common across all countries for the full sample period, as the βs are all statistically significant. There are volatility spillover effects from stock prices to exchange rates for the Netherlands and Turkey, as δ in the conditional variance equation of exchange rates is significant, and from exchange rates to stock prices for Brazil, as δ in the conditional variance equation of stock prices is significant. The negative sign of the significant π indicates that unexpected ‘bad news’ has a greater impact on the volatility than unexpected ‘good news’. However, the insignificant π for the Netherlands and

Turkey suggests that spillover effects are symmetric, which means that good and bad news have an equal impact on volatility.

The results for the pre-crisis period (Panel B) display an insignificant δ for all countries, indicating that there is no volatility spillover between the markets at all in ‘good times’. Nevertheless, the volatility persistence of stock prices and exchange rates are found to be common for all countries during the pre-crisis period.

The EGARCH test results for the period of the financial crisis are reported in Panel C. Again, the results indicate that the volatility in stock prices and exchange rates are persistent during the financial crisis. There are asymmetric volatility spillover effects from stock prices to exchange rates for Ireland, the Netherlands and Turkey, and a symmetric spillover effect (in the same direction) for South Africa during the crisis. However, the spillover effect for Brazil is bi-directional and asymmetric. The results also indicate that the sign of the asymmetric spillover effects is negative for all countries, which means that ‘bad news’ has a greater impact on volatility than ‘good news’ during the financial crisis.

Panel D shows that there is no volatility spillover between the markets for all countries except Ireland. The asymmetric volatility spillover runs from stock prices to exchange rates and the sign is positive, which means that ‘good news’ has a greater impact on volatility than ‘bad news’. This may be because ‘good news’ on stock prices may have a greater impact on demand for local currency as foreign investors want to increase their holding of rising stock. On the other hand, ‘bad news’ may induce a less pronounced tendency to sell declining stock denominated in local currency (as this would entail acceptance of a loss).

In comparing the findings between developed and emerging economies, the volatility spillover from stock prices to exchange rates confirms that stock prices is the lead variable in developed economies. The findings are mixed in the case of the emerging economies. There are instances of a bi-directional volatility spillover between the markets, a unidirectional volatility spillover from exchange rates to stock prices in Brazil, and a unidirectional volatility spillover from stock prices to exchange rates in South Africa and Turkey. The bi-directional spillover can be explained by a process whereby an increase in exchange rates causes an increase in output, export and ultimately stock prices (particularly in export dominated countries). The demand for local currencies increases as a result of the increased stock prices through the wealth effect, and this, in turn, causes a consequent appreciation of the local currency.

Our findings are consistent with those by Kanas (2000), and Yang and Doong (2004), who also found a volatility spillover from stock prices to exchange rates for developed countries. However, contrary to evidence unveiled by Raghavan and Dark (2008), our study has not produced evidence in support of a volatility spillover in the opposite direction. Our findings also corroborate those by Mishra et al. (2007) and Wu (2005), who found a bi-directional volatility spillover between stock prices and exchange rates in emerging countries. Furthermore, as per the results obtained by Walid et al. (2011), and Apte (2001), we find a unidirectional volatility spillover from exchange rates to stock prices in emerging economies.

< Table 5 here >

In order to assess the robustness of our results, we undertook some diagnostic and sensitivity checks. Table 5 presents the results of diagnostic checks on the EGARCH model. The results indicate that the model adequately describes the volatility spillover effect between stock prices and exchange rates. The fact that the Ljung-Box statistics are not significant in all cases indicates that there are no residual linear or non-linear dependencies. The insignificant Kolmogorov-Smirnov statistics also show that the hypothesis of residual normality cannot be rejected in all cases.

To gauge the sensitivity of our results we also re-run our cointegration and EGARCH estimations using Nominal Effective Exchange Rates (NEER) instead of nominal bi-lateral exchange rates. The results (not reported to conserve space but available from the authors upon request) are broadly in line with those reported in Tables 3 and 4, thus corroborating our earlier findings.

6. CONCLUSIONS

In this paper, we have re-examined empirically the volatility spillover effects between exchange rates and stock prices in selected developed and emerging countries across pre-financial-crisis, crisis and post-crisis periods using an EGARCH model.

Our results indicate that there is a unidirectional volatility spillover effect running from stock prices to exchange rates in developed countries. The direction of the volatility spillover between the two markets is opposite in emerging countries. However, there is evidence of a bi-directional volatility spillover between markets in Brazil.

Significantly, we also found that there are asymmetric volatility spillover effects between exchange rates and stock prices in both developed and emerging countries, particularly during the financial crisis period.

Whilst acknowledging that additional variables we did not control for (such as interest rates and inflation) may also play a role on the volatility spillover effects between exchange rates and stock prices (which constitutes, in itself, a profitable extension for future research), two important implications flow from our findings. First, evidence that stock and foreign exchange markets are interrelated, in both developed and emerging countries, implies that lagged information from one market can be used to forecast changes in the other. This also signifies that markets are 'informationally' inefficient, with one market having significant predictive power on the other. Second, the finding of the volatility spillover effect between stock prices and exchange rates in all countries except Spain has important implications for portfolio managers and investors, suggesting that they should not include both assets in the same basket if aiming to diversify risk in their asset portfolio.

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Table 1: Descriptive statistics of weekly return of stock indices

	Ireland	*Netherlands*	*Spain*	*Brazil*	*South Africa*	*Turkey*
Panel A. Full sample. January 2001 – December 2012						
Mean	-0.0021	-0.0020	-1.33E-06	0.0020	0.0023	0.0026
SD	0.0335	0.0333	0.0301	0.0374	0.0293	0.0550
Skewness	-0.7580	-0.6838	-0.4181	-0.6929	-0.1352	-0.6611
Kurtosis	7.4641	8.2071	5.498013	6.8087	4.8488	7.5508
J-B	386.19**	503.61**	120.57**	427.79**	60.66**	390.21**
Panel B. Pre-crisis period. January 2001 – July 2007						
Mean	0.0012	-0.0004	0.0014	0.0035	0.0037	0.0052
SD	0.0250	0.0348	0.0275	0.0351	0.0259	0.0560
Skewness	-0.6854	-0.3433	-0.3661	-0.2290	-0.2761	-0.5811
Kurtosis	4.7493	10.7431	5.3807	4.3779	4.4710	8.3066
J-B	70.38**	861.09**	88.41**	30.04**	35.18**	420.54**
Panel C. Crisis period. August 2007 – March 2009						
Mean	-0.0021	-0.0098	-0.0068	-0.0030	-0.0031	-0.0081
SD	0.0607	0.0435	0.0413	0.0543	0.0425	0.0587
Skewness	0.1223	-0.5655	-0.1712	-1.1295	0.2732	-0.6117
Kurtosis	3.5947	3.8736	3.7650	6.9693	3.5599	3.7597
J-B	51.48**	57.31**	62.51**	74.74**	52.19**	7.4324**
Panel D. Post-crisis period. April 2009 – December 2012						
Mean	0.0019	0.0022	0.0002	0.0019	0.0032	0.0056
SD	0.0300	0.0286	0.0368	0.0319	0.0233	0.0343
Skewness	-0.5478	-0.3134	-0.4181	-0.2839	-0.1507	-1.1018
Kurtosis	5.5974	4.7736	3.5134	2.9967	3.8025	8.8428
J-B	64.57**	28.75**	32.19**	22.62**	45.97**	316.83**

Notes: SD and J-B denote standard error and Jarque-Bera, respectively. Jarque-Bera is the test of null hypothesis that the residuals are normally distributed. ** denotes the level of significance at 5%. The statistic has a χ^2 distribution with two degrees of freedom. The critical value at the 5% level of significance is 5.9.

Table 2: Descriptive statistics of weekly changes in exchange rates

	Ireland	*Netherlands*	*Spain*	*Brazil*	*South Africa*	*Turkey*
	Panel A. Full sample. January 2001 – December 2012					
Mean	-0.0009	-0.0009	-0.0009	0.0001	0.0005	0.0019
SD	0.0138	0.0138	0.0138	0.0242	0.0262	0.0292
Skewness	-0.4445	-0.4445	-0.4445	1.6546	1.0295	4.0427
Kurtosis	8.9054	8.9054	8.9054	18.2200	9.3754	36.1597
J-B	619.67**	619.67**	619.67**	6317**	779.89**	20240**
	Panel B. Pre-crisis period. January 2001 – July 2007					
Mean	-0.0010	-0.0010	-0.0010	-0.0001	-0.0002	0.0018
SD	0.0125	0.0125	0.0125	0.0237	0.0231	0.0278
Skewness	0.1156	0.1156	0.1156	1.0265	0.6578	5.0391
Kurtosis	3.3265	3.3265	3.3265	10.820	5.4879	47.733
J-B	6.28**	6.28**	6.28**	931.66**	112.87**	2996**
	Panel C. Crisis period. August 2007 – March 2009					
Mean	0.0001	0.0001	0.0001	0.0020	0.0032	0.0028
SD	0.0198	0.0198	0.0198	0.0379	0.0360	0.0337
Skewness	-0.3618	-0.3618	-0.3618	2.0061	1.1948	1.5062
Kurtosis	6.0261	6.0261	6.0261	15.1398	8.2427	11.202
J-B	34.69**	34.69**	34.69**	585.78**	118.95**	273.63**
	Panel D. Post-crisis period. April 2009 – December 2012					
Mean	1.09E-05	1.09E-05	1.09E-05	-0.0005	-0.0004	0.0004
SD	0.0141	0.0141	0.0141	0.0163	0.0217	0.0139
Skewness	0.1165	0.1165	0.1165	0.3537	0.2585	-0.0406
Kurtosis	3.5630	3.5630	3.5630	4.1891	3.4195	2.9917
J-B	6.04**	6.04**	6.04**	15.55**	53.60**	54.26**

Notes: see Table 1.

Table 3: Cointegration test results

	Ireland		Netherlands		Spain		Brazil		South Africa		Turkey	
No. of CE(s)	*Trace*	*Max-Eigen*	*Trace*	*Max-Eigen*	*Trace*	*Max-Eigen*	*Trace*	*Max-Eigen*	*Trace*	*Max-Eigen*	*Trace*	*Max-Eigen*
Panel A. Full Sample. January 2001 – December 2012												
None	5.74	3.92	10.93	6.70	8.02	5.45	21.27**	18.31**	7.48	6.66	33.59**	29.58**
At most 1	1.82	1.82	3.22	3.22	2.57	2.57	2.96	2.96	0.82	0.82	4.01**	3.01**
Panel B. Pre-crisis period. January 2001 – July 2007												
None	6.26	5.75	10.05	8.47	11.39	10.67	11.40	10.91	4.36	4.08	45.90**	45.48**
At most 1	0.51	0.51	1.58	1.58	0.72	0.01	0.49	0.49	0.28	0.28	0.42**	0.42**
Panel C. Crisis period. August 2007 – March 2009												
None	6.93	6.91	6.44	6.39	4.84	4.84	17.60**	15.11	4.71	4.17	9.02	7.18
At most 1	0.02	0.02	0.05	0.05	0.01	0.01	2.49	2.49	0.53	0.53	1.83	1.83
Panel D. Post-crisis period. April 2009 – December 2012												
None	14.22	11.31	15.15	12.06	7.40	5.82	11.23	10.07	15.62**	14.43	10.87	9.82
At most 1	2.90	2.90	3.59	3.59	1.58	1.58	1.15	1.15	0.18	0.18	1.04	1.04

Notes: The model is specified on the basis of the Akaike Information Criterion (AIC). The null hypothesis is that the number of Cointegration Equations (CE) are less than or equal to the number specified. Trace and Max-Eigen are the standard Johansen test statistics for testing for cointegration. The critical values for ‘no conintegration’ and ‘at most one conintegrating relationship’ (for both Trace and Max-Eigen) at the 5% significance level are 15.49 and 3.84 respectively. ** denotes the level of significance at 5%.

Table 4: EGARCH estimations

	Ireland		Netherlands		Spain		Brazil		South Africa		Turkey	
	Stock	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*
Panel A. Full Sample. January 2001 – December 2012												
β	0.95**	0.68**	0.75**	0.38*	0.97**	0.90**	0.21**	0.49**	0.87**	0.76**	0.41**	0.53**
	(52.6)	(62.1)	(55.6)	(82.2)	(52.0)	(52.6)	(57.6)	(82.1)	(72.7)	(82.6)	(53.6)	(50.1)
δ	-0.24	0.14	-0.17	0.29**	-0.20	-0.23	0.28	-0.17**	-0.28	0.21	-0.23	0.20**
	(7.45)	(4.02)	(7.40)	(1.05)	(5.80)	(3.95)	(4.78)	(4.12)	(6.08)	(6.15)	(5.25)	(2.03)
π	.45	-.30**	-.24**	.42	.56**	-.39**	-.40**	.37	-.20**	-.29**	-.30	-.38**
	(5.45)	(3.07)	(2.32)	(4.57)	(3.17)	(1.93)	(2.09)	(3.93)	(2.75)	(2.02)	(3.65)	(2.99)
Panel B. Pre-crisis period. January 2001 – July 2007												
β	0.75**	0.88**	0.91**	0.78*	0.67**	0.65**	0.31**	0.29**	0.32**	0.36**	0.51**	0.23**
	(41.7)	(20.1)	(63.6)	(29.2)	(51.1)	(34.5)	(42.1)	(20.1)	(20.0)	(30.5)	(30.3)	(60.5)
δ	0.22	0.19	0.13	0.24	0.42	0.34	0.48	0.17	0.18	0.21	0.20	0.22
	(4.02)	(5.12)	(7.40)	(4.01)	(4.40)	(4.56)	(5.18)	(4.12)	(5.08)	(4.35)	(5.33)	(5.01)
π	-.31	.50	-.44**	.31**	-.76*	-.51**	-.55	.64**	-.31**	-.44**	-.55**	.31**
	(5.45)	(4.17)	(3.12)	(2.97)	(4.47)	(1.93)	(4.09)	(3.03)	(2.75)	(2.02)	(3.65)	(2.99)
Panel C. Crisis period. August 2007 – March 2009												
β	0.91**	0.87**	0.30**	0.52*	0.40**	0.37**	0.76**	0.86**	0.71**	0.67**	0.30**	0.23**
	(52.6)	(62.1)	(55.6)	(82.2)	(52.0)	(52.6)	(57.6)	(82.1)	(72.7)	(82.6)	(53.6)	(50.1)
δ	0.21	0.23**	0.27	0.26**	0.19	0.21	0.20**	0.17**	0.28	0.21**	0.24	0.20**
	(5.40)	(3.01)	(5.01)	(2.00)	(5.01)	(4.90)	(1.22)	(1.11)	(4.08)	(1.15)	(5.25)	(1.03)
π	-.53**	-.45**	-.37**	-.21**	.27	-.35**	-.25**	-.34**	-.23**	.20	-.25**	-.41**
	(1.05)	(1.77)	(3.02)	(2.90)	(4.02)	(1.91)	(1.09)	(3.12)	(2.14)	(5.25)	(2.50)	(5.32)
Panel D. Post-crisis period. April 2009 – December 2012												
β	0.35**	0.48**	0.72**	0.80*	0.57	0.68**	0.41**	0.30**	0.67**	0.80**	0.21**	0.33**
	(53.0)	(30.2)	(45.6)	(72.0)	(30.1)	(42.0)	(54.0)	(80.0)	(42.5)	(50.0)	(33.0)	(35.3)
δ	0.20	0.16**	0.57	0.39	0.29	0.14	0.58	0.37	0.22	0.20	0.27	0.23
	(7.45)	(2.01)	(5.43)	(5.05)	(5.22)	(4.95)	(5.34)	(4.23)	(4.08)	(4.15)	(1.25)	(5.01)
π	-.51**	.50**	-.44	-.31**	-.76	-.51**	.55	-.64**	-.31**	.44	-.55**	-.31**
	(2.45)	(2.67)	(4.12)	(2.97)	(4.47)	(1.90)	(4.09)	(3.03)	(2.05)	(5.01)	(3.35)	(2.49)

Notes: Stock and Ex (exchange rates) denote the conditional variance equations (5) and (6), respectively). The persistence of volatility, volatility spillover from one market to another, and the asymmetric spillover effect are measured by β, δ and π respectively. The numbers in parentheses are the t-statistics with robust standard errors. ** denotes the level of significance at 5%.

Table 5: EGARCH model diagnostics

	Ireland		Netherlands		Spain		Brazil		South Africa		Turkey	
	Stock	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*	*Stock*	*Ex*
Panel A. Full Sample. January 2001 – December 2012												
LB(10)	11.38	10.54	15.67	20.76	7.90	8.65	9.97	10.10	8.80	7.45	9.20	9.04
$LB^2(10)$	7.76	9.92	5.69	7.43	8.45	8.80	7.77	5.54	5.65	4.09	9.90	8.53
K-S(D)	0.02	0.2	0.01	0.03^{**}	0.02	0.01	0.01	0.04^{**}	0.01	0.01	0.02	0.01
Panel B. Pre-crisis period. January 2001 – July 2007												
LB(10)	12.19	12.10	17.77	18.70	8.01	9.55	9.02	17.17	18.60	17.48	11.29	15.05
$LB^2(10)$	6.16	7.12	6.19	8.03	9.40	4.83	6.02	7.14	9.02	7.01	12.91	7.22
K-S(D)	0.01	0.03^{**}	0.01	0.02	0.02	0.01	0.01	0.03^{**}	0.01	0.01	0.02	0.01
Panel C. Crisis period. August 2007 – March 2009												
LB(10)	10.22	7.17	14.17	17.16	10.20	9.25	10.02	13.11	19.82	18.20	12.22	12.02
$LB^2(10)$	5.01	6.02	12.09	10.42	13.00	9.83	9.23	13.51	10.62	12.00	17.91	9.52
K-S(D)	0.01	0.1	0.01	0.03^{**}	0.01	0.01	0.01	0.04^{**}	0.01	0.01	0.02	0.01
Panel D. Post-crisis period. April 2009 – December 2012												
LB(10)	17.30	11.50	12.60	10.60	10.80	7.15	9.07	11.11	9.85	17.40	10.25	7.01
$LB^2(10)$	8.70	6.90	5.09	7.44	8.05	8.01	9.19	11.50	10.15	13.10	16.80	16.50
K-S(D)	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.03^{**}	0.04^{**}	0.02	0.02

Notes: Stock and Ex (exchange rates) denote the conditional variance equations (5) and (6), respectively. LB(10) and LB2(10) are the Ljung-Box statistics for standardised residuals and squared standardised residuals distributed as a chi-square with 10 degrees of freedom. K-S (D) is the Kolmogorov-Smirnov normality test. ** denotes the level of significance at 5%