# Volatility Spillover between Developed and Developing Countries: The global Foreign Exchange Market's Channel

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## Abstract

In this paper, we investigate the "statics and dynamics" return and volatility spillovers transmission across developed and developing countries. Quoted against the U.S. dollar, we study twenty-three global currencies over 2005 – 2016. Focusing on the spillover index methodology, the generalised VAR framework is employed. Our findings indicate no evidence of bi-directional return and volatility spillovers between developed and developing countries. However, a unidirectional volatility spillover from developed to developing countries is highlighted. Furthermore, our findings document significant bi-directional volatility spillovers within the European region (Eurozone and non-Eurozone currencies) with the British Pound (GBP) and the Euro (EUR) as the most significant transmitters of volatility. The findings reiterate the prominence of volatility spillovers to financial regulators.

**JEL Codes:** G01, G1, F3

**Keywords:** Foreign Exchange Market, Volatility Spillover, Return Spillover, VAR Framework, Variance Decomposition, Financial Crisis, Financial Interdependence

## 1. Introduction

The increasing financial interdependence, particularly during the current era of global economic events and financial turbulence has prompted considerable interest of market participants and academic research. While much attention has been paid to the magnitude of return and volatility spillovers across global stock markets, little is known about the foreign exchange channel. In particular, the foreign exchange markets' channel between developed and developing countries. Some studies of this kind investigate the return co-movements and volatility spillover, primarily across the developed countries (Andersen et al. 2001; Pérez-Rodrìguez 2006; Boero et al. 2011; and Rajhans and Jain (2015). Others considered the regional spillover transmission and produced insignificant results.

However, given the trillions of dollars of exchange rate trading in international financial markets; it is important to fully understand and investigate in greater depth the potential spillovers of international currencies. This is an important aspect that is taken into serious account by the investors for the formation of their position and portfolios. Before the recent financial turmoil, the contribution of the foreign exchange market's spillover channel to the global financial instability, for some, appeared to be less worrisome. Whereas in fact, the behaviour of the stock prices (which extensively studied) is mainly explained by volatilities in the foreign exchange market (Kim, 2003).

Thus, in this paper, we provide new insights into the incomplete investigation of the global intra-foreign exchange market's spillover channel. Our key question is whether the effect of return and volatility spillovers is bidirectional between developed and developing countries. This is because of the recent financial crisis which originated in major financial hubs in developed countries - primarily in the U.S - that developing countries are not responsible for; nevertheless, are seriously affected by it. To study the return and volatility spillovers transmission, we model the daily spot exchange rates for 23 global currencies. According to the BIS (2013), the USD, EUR, GBP, AUD, CAD, JPY and CHF are the most traded globally and account for almost 90 per cent of the global foreign exchange turnover. In particular, we adopt the generalised vector autoregressive (VAR) approach focusing on the variance decomposition of Diebold and Yilmaz (2009).

The innovative feature of this approach besides being rigorous it allows the aggregation of valuable information across markets into a single spillover index. The unique structure of the spillover index is designed to unleash an in-depth analysis of the negative spillovers' transmission across markets, i.e., how a shock in a particular market is due to exogenous/endogenous shocks to other markets.

Since financial crises are almost difficult to predict; nevertheless, it is important to identify fluctuations in volatility over a different time period. Thus, we examine the time-varying net volatility spillover using the autoregressive conditional heteroskedasticity (ARCH) model. The time-varying volatility identifies the specific points of significant shifts in the volatility spillover during the years of our sample (2005 – 2016). We provide evidence of significant volatility clustering during the 2008 financial crisis. The ARCH model, which is first introduced by Engle (1982) is widely used in the literature ( Bollerslev et al. 1994, Kaur 2004, and Basher et al. 2007) for its ability to capture persistence in time-varying volatility based on squared returns. And most importantly, to investigate the nature of the net volatility and net pairwise spillover effects, we implement Diebold and Yilmaz, (2012) methodology. By doing so, we are able to show the difference between the amount of the gross volatility shocks within our sample, that were transmitted to and received from, developed and developing countries. To enhance the reliability of the findings, we provide evidence in different dimensions (using a sample of twenty-three global currencies over 2005-2016). The first is the static analysis approach, which provides results in the form of spillover tables. The second is the dynamic analysis, which yields the spillover plots. Third, is the time-varying net volatility results, which we provide in the form of figures. Finally, the net volatility and net pairwise spillover effects.

The analysis is based on a large daily spot exchange rates' dataset, which covers a long period pre-and-post the most recent events in the global economy. In particular, the paper provides results based on extensive empirical analyses, such as the spillover index (both static and dynamic analyses), time-varying net volatility, net volatility and net pairwise volatility effects.

Guided by the empirical approach described above, the main findings indicate that there is no evidence of bidirectional volatility spillovers between developed and developing countries. Although unsurprisingly, the results highlight evidence of unidirectional volatility spillovers pouring from developed to developing countries. In particular, the volatility spillovers from developed to developing countries seem to be specifically strong following the collapse of Lehman Brothers in 2008. Another curious outcome of the findings is that developed countries are the highest receiver and transmitter of volatility spillover, dominated by the British pound sterling, Australian dollar, and the Euro, whereas developing countries are a net receiver of volatility spillover. The findings, therefore indicate that the currency crisis tends to be regional (Glick and Rose 1998; Yarovaya and others 2016).

Meanwhile, in light of the recent financial crisis, the analytical results demonstrate that the cross-country spillovers activities between developed and developing countries are insignificant. While the financial risk which was propagated during the 2008 financial crisis, engulfed the global economy. That being said, because of the recent financial markets' development, such as financial engineering, (collateral debt obligation, credit default swap and derivative securities) financial risks triggered different means of spreading across the global economy, which still needs to be discovered, understood and spoken appropriately.

The rest of this paper is organised as follows: Section (2) discusses some critical arguments of related literature. Section (3) then introduces the data used in the analysis and the empirical methodology applied in section (4). In section (5), we provide empirical results, including the robustness and some descriptive statistics. Section (6) discusses the time-varying volatility. Section (7) introduces the net spillovers and net pairwise volatility spillovers. Section (8) concludes. Section (9) discusses the study limitations and future research.

## 2. Related Literature

This brief review of the literature is focused on the foreign exchange market's spillover channel, which is one of the most intensely debated issues in recent literature. However, the significance of the foreign exchange market's spillover channel to the financial markets' stability acknowledged three decades ago. For example, Engle et al. (1990) established the first thread-tying efforts of the intra-day exchange rate's volatility spillover within one country (heat waves) and across borders (meteor shower). The "heat waves" is a hypothesis that indicates that volatility in one market may continue in the same market the next day. Whereas, the "meteor shower" is a phenomenon, which implies that volatility in one market may spillover to another market.

In this paper, the authors provide evidence of transmitted volatility spillover from one market to another. This opening up, particularly after the 2008 financial crisis, amplified the importance of the spillover channels in the stock and the foreign exchange markets. This is due to the repercussions of the shocking types of financial risks stemming from the interconnected nature of the financial markets. Thus, there is a shred of growing evidence in the literature that supports the association of return and volatility spillovers with global economic events and financial crises. (See, Diebold and Yilamz 2009; Beirne et al. 2009; Yilamz 2009; Gebka 2012; Jung and Maderitsch 2014; Ghosh 2014; Choudhry and Jayasekera 2014; Antonakakis et al. 2015; and Mozumder et al. 2015, for reviews). Also, the recent financial crisis demonstrates the severity of the cross-market volatility spillovers, which transmitted across countries through the stock and foreign exchange markets' channels. (see Fedorova and Saleem 2009; Mohanty et al. 2011; Maghyereh and Awartani 2013; Jouini 2013; Shinagawa 2014; Do et al. 2015 for reviews). Another important feature of the foreign exchange spillover channel that its effect act differently during, before and after the economic events and financial crises episodes. For example, based on VAR models, Diebold and Yilamz (2009) examined nineteen global equity markets from the 1990s to 2009. They find striking evidence that return spillover displays a slightly increasing trend but no bursts, while, volatility spillover displays no trend but strong bursts associated with crises events.

In addition, the effect of return and volatility spillovers may extend to the business cycle mechanism. Several studies (Imbs 2004; Eickmeier 2007; Imbs 2010; and

Claessens et al. 2011) argue that volatility spillover inflicts business cycle synchronisation between countries through different channels. These channels mainly include the exchange rate, confidence, trade, and financial integration channel. Antonakakis et al. (2015) suggest that the spillover effect could also be transmitted through business cycle across countries. According to Eickmeier (2007), the confidence channel represents the response from domestic agents to the potential spillover coming from foreign shocks to the local economy.

Several studies attempt to empirically analyse the exchange rate co-movements and volatility spillover across countries. In particular, the financial transmission between the Euro (EUR), British pound (GBP), Australian dollar (AUD), Swiss franc (CHF), and the Japanese yen vis-á-vis the U.S. dollar. For instance, Boero et al. (2011), Rajhans and Jain (2015) find a high correlation between the Euro and British pound against the U.S. dollar and that the British pound is a net receiver. Nikkinen et al. (2006) study the future expected volatility linkages among major European currencies (the Euro, British pound and the Swiss franc) against the U.S. dollar. They find future volatility linkages between the major currencies and that the British pound and the Swiss franc are significantly affected by the implied volatility of the Euro. Boero et al. (2011) find an increase in co-movements between the Euro and the British pound after the introduction of the Euro compared to the pre-euro era. A different perspective is offered by Antonakakis (2012), using the VAR model, the author finds significant return co-movements and volatility spillover between major exchange rates before the introduction of the Euro and lowers during the post-euro periods.

Baruník et al. (2017) analyse asymmetries in volatility spillovers on the foreign exchange market. Applying high-frequency data of the most actively traded currencies over 2007–2015, the authors find that negative spillovers dominate positive spillovers. Katusiime (2019) evaluates the spillover effects between foreign exchange, and find conditional volatility among currency rates and commodity price in Uganda. Most recently, Fasanya et al. (2020) investigate the dynamic spillovers and connectedness between the COVID-19 pandemic; and global foreign exchange markets. They find a high degree of interdependence between the global covid-19 occurrences and returns volatility of the majorly traded currency pairs.

In this paper, we base our measurements of return and volatility spillovers on vector autoregressive (VAR) models, which have been laid out in recent studies (Palanska 2018; Mensi et al. 2018; Fasanya et al. 2020). In comparison to other methodologies such as MGARCH and the realised volatility (RV) estimator; the VAR provides strikingly accurate results using high-frequency data. This is because the realised volatility (RV) estimator is considered biased at a high-frequency sampling (Barndor-Nielsen et al. 2010; and Floros 2020).

The previously discussed papers establish the evidence of return co-movements and volatility spillover across developed countries' exchange rates. It is also important to examine the behaviour of asset return and volatility spillovers of the foreign exchange markets between developed and developing countries. Notwithstanding, only a few of the literature (which focused mainly on central Europe's foreign exchange markets) have produced limited results. For example, using a multivariate GARCH model, Lee (2010) studies volatility transmission across ten emerging foreign exchange markets. Here, the author provides evidence of regional and cross countries' volatility spillover. Bubák et al. (2011) examine the volatility transmission across three central European's emerging markets, in particular, among Czech, Hungarian and Polish currencies. Their main finding is a significant intra-regional volatility spillover across central Europe's foreign exchange markets.

In comparison to the above studies, this paper provides a thorough investigation of return and volatility spillovers between developed and developing countries. In particular, the transmission through the foreign exchange market's channel. We examine broad data samples from twenty-three developed and developing countries (which have received somewhat limited attention) before, during and after the 2008 financial crisis. The extended data sample from 2005 to 2016 emphatically help in a way, to unfold the effect of return and volatility spillovers across global foreign exchange markets, which currently dominate the focus of policymakers as well as financial managers.

## 3. Database and Methodology

### 3.1. Database

The underlying data employed in this paper consists of daily spot exchange rates of currencies comprises a total of twenty-three developed and developing countries across the world vis-á-vis the U.S. dollar. Taken from DataStream Thomson Reuters through the WM/Reuters channel; the sample period starts on 31 May 2005 and ends on 01 June 2016. Our study period facilitates the production of comprehensive and precise measures of return spillover and volatility spillovers pre-and-post the 2008 financial crisis. The series under investigation include currencies from eleven developed countries, the British pound (GBP), Euro (EUR), Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), Japanese yen (JPY), Icelandic krona (ISK),

Czech Republic koruna (CZK), Hong Kong dollar (HKD) Singapore dollar (SGD), and South Korean won (KRW). And currencies from twelve developing countries, including Russian ruble (RUB), Turkish lira (TRY), Indian rupee (INR), Indonesian rupiah (IDR), Argentine peso (ARS), Malaysian ringgit (MYR), Thai baht (THB), Mexican peso (MXN), Saudi Arabian riyal (SAR), United Arab Emirates dirham (AED), South African rand (ZAR) and Nigerian Naira (NGN). According to the Bank for International Settlement (BIS) report (2013), our underlying chosen samples include the most actively traded currencies across the financial markets globally.

### 3.2. Obtaining Daily Returns

To obtain the daily returns series, we calculate the daily change in the log price of close data. When price data is not available for a given day due to a holiday or in the case of omitted value; we use the previous day value. As spot rates are non-stationary, we calculate the daily returns as:

$r_t = ln(y_t) - ln(y_{t-1})$, where $y_t$ is the spot exchange rate at time t, with t = 1, 2……, T, and the natural logarithm ln. Table 1 provides a variety of descriptive statistics for returns.

### 3.3 Obtaining Daily Return Volatilities

A different approach could be employed to achieve the global foreign exchange market historical volatility. However, in this paper, we employ the improved estimators of security price fluctuations of Garman and Klass (1980) and Alizadeh et al. (2002). The instinct of this methodology is that the underlying volatility estimators are based on historical opening, closing, high and low prices and transaction volume. The underlying model assumption is that the diffusion process governs security prices:

$$P(t) = \emptyset\big(B(t)\big) \tag{1}$$

Where P represents the security price, $t$ is time, $\emptyset$ is a monotonic time-independent transformation, and $B\,\langle t\rangle$ is a diffusion process with differential representation. Monotonicity and time-independence both employed to assure that the same set of sample paths generates the sample maximum and minimum values of $B$ and $P$ Garman and Klass (1980).

$$dB = \sigma\, dz \tag{2}$$

Where $dz$ is the standard Gauss-Wiener process and $\sigma$ is an unknown constant to be estimated. Implicitly the phenomenon is dealing with the transformed "price" series, and the geometrical price would mean logarithm of the original price, and volatility would mean "variance" of the original logarithmic prices. The original root of Garman and Klass methodology is the Brownian motion, where they added three different estimation methods. They based their methodology estimation on the notion of historical opening, closing, high and low prices and the transaction volume; through which they provided the following best analytic scale-invariant estimator:

$$\sigma_t = \sqrt{\frac{N}{n} . \sum_{i=1}^{N} \frac{1}{2} . (\log\left(\frac{H_i}{L_i}\right))^2 - (2.\log(2) - 1).\ \log\,(\frac{C_i}{O_i})^2} \tag{3}$$

Where $\sigma_t$ is an unknown constant to be estimated, $N$ is the number of trading days in the year and $n$ is the chosen sample. $H$ is today's high, $L$ is today's low, $O$ and $C$ are today's opening and closing, respectively. Explaining the coefficients of the above formulae is beyond the scope of this paper for now. However, to obtain the foreign exchange market's volatilities, we use intra-day high, low, opening and closing data. When price data is not available for a given day due to a holiday or in the case of omitted value, we use the previous day value. Table 2 shows descriptive statistics for the global foreign exchange market's volatilities.

## 4. Methodology

To examine return and volatility spillovers across our sample, we use the generalised vector autoregressive (VAR) methodology. In particular, our investigation is based on the variance decompositions proposed by Diebold and Yilmaz (2009). The concept of variance decomposition is very rigorous and helpful as it allows the aggregation of valuable information across markets into a single spillover index. In other words, how shocks in market A is due to exogenous shocks to other markets. We can express this phenomenon through variance decomposition concomitant with an N-variable VAR by adding the shares of the forecast error variance for each asset $i$ coming from shocks to an asset $j$, for all $j \neq i$ tallying up across all $i$ = 1,........, N. Then considering the example of simple covariance stationary first-order two-variable VAR,

$$x_t = \Phi x_{t-1} + \varepsilon_t \tag{4}$$

Where $x_t = (x_{1t,} x_{2t})$ and Φ is a parameter matrix. In the following empirical work, $x$ will be either a vector of foreign exchange returns or a vector of foreign exchange return volatilities. The moving average representation of the VAR is given by:

$$x_t = \Theta(L)\varepsilon_t \tag{5}$$

Where $\Theta\,(L) = (1 - \Phi L)^{-1}$ which for simplicity could be rewritten as:

$$x_t = A(L)\, u_t \tag{6}$$

Where, $A(L) = \Theta(L)Q^{-1}$, $u_t = Q_t\, \varepsilon_t$, $E(u_t\, u') = 1$, and $Q^{-1}$ is the unique Cholesky factorisation of the covariance matrix of $\varepsilon_t$. Then considering the 1-step-ahead forecast, the precise approach would be the Wiener-Kolmogorov linear least-squares forecast as:

$$x_t + 1, t = \Phi x_t \tag{7}$$

With corresponding 1-step-ahead error vector:

$$e_t + 1, t = x_{t+1} - x_{t+1,t} = A_0\, u_{t+1} = \begin{bmatrix} a_{0,11} & a_{0,12} \\ a_{o,21} & a_{0,22} \end{bmatrix} \begin{bmatrix} u_{1,t+1} \\ u_{2,t+1} \end{bmatrix} \tag{8}$$

And comprises the following covariance matrix;

$$E\left(e_{t,+1,t}\, e'_{t+1,t}\right) = A_0 A'_0. \tag{9}$$

To clarify, the variance of the 1-step-ahead error in forecasting $x_{1t}$ is $a_{0,11}^2 + a_{0,12}^2$; and the variance of the 1-step-ahead error in forecasting $x_{2t}$ is $a_{0,21}^2 + a_{0,22}^2$. Diebold and Yilmaz (2009) utilised the mechanism of variance decompositions to split the forecast error variances of each variable into parts attributable to a broader system shock. This facilitates answering the question of what fraction of the 1-step-ahead error variance in forecasting $x_1$ is due to shocks to $x_1$ and shocks to $x_2$. Likewise, what portion of the 1-step-ahead error variance in forecasting $x_2$ is due to shocks to $x_1$ and shocks to $x_2$.

4.1. The spillover Index

The spillover index of Diebold and Yilmaz (2009) represents the fractions of the 1-step-ahead error variances in forecasting $x_i$ due to shocks to $x_j$, for $i, j = 1,2, i \neq j$. These two variables construct the spillover index with two possible spillovers outcomes. First, $x_{1t}$ which represents shocks that affect the forecast error variance of $x_{2t}$ with the contribution $(a_{0,21}^2)$. Second, $x_{2t}$ similarly represents shocks that affect the forecast error variance of $x_{1t}$ with a contribution of $(a_{0,12}^2)$ totalling the spillover to $a_{0,12}^2 + a_{0,21}^2$. This can be expressed relative to the total forecast error variation as a ratio percentage projecting the spillover index as:

$$s = \frac{a_{0,12}^2 + a_{0,21}^2}{trace(A_0 A'_0)} \times 100 \tag{10}$$

The spillover index can be sufficiently generalised to wider dynamic environments, particularly for the general case of a $p^{th}$-order N-variable VAR, using H-step-ahead forecast as:

$$s = \frac{\sum_{h-0}^{H-1} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} a_{h,ij}^2}{\sum_{h=o}^{H-1} trace(A_h A'_h)} \times 100 \tag{11}$$

To examine the data, the spillover index described above allows the aggregation degree of cross-market spillovers across the large data, which consists of 2872 sample into a single spillover measure. We use second-order 23 variables with 10-step-ahead forecasts.

4.2. Net Spillovers

To generate the net volatility spillovers, we follow (Diebold and Yilmaz 2012) by first calculating the directional spillovers. It can be done by normalising the elements of the generalised variance decomposition matrix. This way, we can measure the directional volatility spillovers received by (developing) countries from the developed countries or vice versa as follows:

$$S_{i.}^{\dot{g}} = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{\dot{g}}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{\dot{g}}(H)} .100 = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{\dot{g}}(H)}{N} .100. \tag{12}$$

Thus, from the above equation, the net volatility spillover can be obtained from market $i$ to all other markets $j$ as follows:

$$S_{i}^{\dot{g}}(H) = S_{.i}^{\dot{g}} - S_{.i}^{\dot{g}}(H). \tag{13}$$

4.3. Net pairwise spillovers

Given the net volatility spillover described in equation (12), which provides the net volatility of each market contribution to others; then it is relatively easy to examine the net pairwise volatility as follows:

$$S_{ij}^{\dot{g}}(H) = \left( \frac{\tilde{\theta}_{ji}^{\dot{g}}(H)}{\sum_{i,k=1}^{N} \tilde{\theta}_{ik}^{\dot{g}}(H)} - \frac{\tilde{\theta}_{ij}^{\dot{g}}(H)}{\sum_{j,k=1}^{N} \tilde{\theta}_{jk}^{\dot{g}}(H)} \right) .100 \tag{14}$$

$$= \left( \frac{\tilde{\theta}_{ji}^{\dot{g}}(H) - \tilde{\theta}_{ij}^{\dot{g}}(H)}{N} \right) .100 \tag{15}$$

Similarly, the net pairwise volatility spillover between market $i$ and $j$ represented by the difference between the gross volatility shocks communicated from market $i$ to market j included those communicated from j to $i$.

4.4. ARCH Model

The basic autoregressive conditional heteroscedasticity (ARCH) model is constructed from two equations (a mean equation and a variance equation). The mean equation, which defines the behaviour of the time series data mean. So, the mean equation is the linear regression function, which contains constant and other explanatory variables. In the following equation, the mean function only contains an intercept:

$$y_t = \beta + e_t \tag{16}$$

Considering Eq. (16), the time series is expected to vary about its mean ($\beta$) randomly. In this case, the error of the regression is distributed normally and heteroskedastic. The variance of the current error period depends on the information that is revealed in the proceeding period (Poon 2005). However, the variance equation defines the error variance behaviour where the variance $e_t$ is given the symbol $h_t$ as follows:

$$h_t = a + a_1 e_{t-1}^2 \tag{17}$$

It is clear from Eq. (17) that $h_t$ depends on the squared error in the proceeding time period (Bollerslev et al. 1994). Also, in the same equation, the parameters have to be positive to ensure the variance $h_t$, is positive. In addition, the large multiplier (LM) test can also be used to examine the presence of ARCH effects in the data, (i.e., whether $\alpha>0$). However, to carry out this test, we estimate the mean equation, then saved and squared the estimated residuals, $\hat{e}_t^2$. Then, for the first order ARCH model, we regressed $\hat{e}_t^2$ on the lagged residuals $\hat{e}_{t-1}^2$ and the following constant:

$$\hat{e}_t^2 = y_0 + y_1\hat{e}_{t-1}^2 + v_t \quad (18)$$

Where, $v_t$ represents the random term; and the null and alternative hypothesis are:

$$H_0: y_1 = 0$$

$$H_1: y_1 \neq 0$$

Table (7) shows the result of the large multiplier (LM) test, which confirms the presence of ARCH in the data. So, the forecasted error variance is an in-sample prediction model essentially based on estimated variance function as follows:

$$\hat{h}_{t+1} = \hat{a}_0 + \left(r_t - \hat{\beta}_0\right)^2 \quad (19)$$

Figure (5) demonstrates the forecast error variance $\left(r_t - \hat{\beta}_0\right)^2$ ; which reflects the years of our sample (2005 – 2016).

## 5. Empirical Results

### 5.1. Descriptive Statistics

Tables 1 and 2 provide descriptive statistics of return and volatility spillovers. The underlying data consists of twenty-three global currencies vis-á-vis the U.S. dollar and the sample size is 2871. Returns are calculated as a daily change in log price of close data (as described in the data section) and return volatilities as signified in Eq. (3). Currencies under research are selected based on the most actively traded globally for both developed and developing countries. The augmented dicky-fuller (ADF) test results (Tables 1 and 2) for each currency is statistically significant, which means the currencies under investigation are stationery. For the return's series (Table 1), fourteen currencies recorded little negative means denoting slight appreciation (during the sample period) against the U.S. dollar. Whereas seven currencies recorded small depreciation including the Swiss franc (CHF), Singaporean dollar (SGD), Thai baht (THB), Hong Kong dollar (HKD), Saudi Arabian riyal (SAR), United Arab dirham (AED) and the South African rand (ZAR). Kurtosis coefficients are significantly high for developing countries in both returns and volatility spillovers. These are exciting facts indicate that the data distribution is leptokurtic. A distribution that is Leptokurtic is said to have a positive statistical value with higher peaks around the mean compared to normal distribution; which in most circumstances leads to thick tails on both sides. This means the risk to the developing countries' currencies is coming from outlier events setting the ground for extreme remarks to arise. Also, the root means square-deviation of volatility spillovers' series (Table 2) shows significant dispersion for eight developing countries. These countries including India, Indonesia, Argentina, Malaysia Thailand, Mexico, South Africa and Nigeria. For more elaboration on the data, see Tables (1 and 2) below.

5.2. Return and Volatility Spillovers: Static Analysis (Spillover Tables)

The spillover index methodology we apply in this paper comprises two steps. Firstly, we provide full static-sample analysis. Secondly, we successively proceed to interpret the dynamic rolling-sample version. By employing the spillover index, we extract return and volatility spillovers throughout the entire sample (2005 – 2016). Thus, we present the spillover indexes for both return and volatility in Tables 3 and 4. The variables $(i, j)$ placed under each table represent the contribution projected to the variance of the 70-day-ahead real foreign exchange (returns Table 1 and volatility Table 2) forecast error of country $i$ coming from innovations to the foreign exchange (returns Table 1 and volatility Table 2) of country $j$.

In both tables, the lower corner of the first column from the right sums the "contributions from others" and similarly from the left sums the "contribution to others." The spillover tables designed to describe the input and output decomposition of the spillover index. Both products "input and output" help to successfully scrutinise the effect of return and volatility spillovers of global foreign exchange markets across developed and developing countries. With regard to return spillover (Table 3), touching on developed countries' "contribution to others", we observe that the GBP and the EUR are responsible for the most significant shares of the error variance in forecasting 70-day-ahead, totalling 102 and 100 per cent respectively. Also, some developing countries receive significant ''return contribution'' from the developed countries such as Thailand (100%) and Mexico (75%).

Table 1: Descriptive Statistics, Global Foreign Exchange Market Returns, 2005 -2016.

| Country | United Kingdom | European Union | Australia | Canada | Japan |
|---|---|---|---|---|---|
| Mean | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Standard Error | 0.005 | 0.006 | 0.008 | 0.006 | 0.007 |
| Kurtosis | 3.230 | 2.023 | 11.717 | 2.861 | 4.121 |
| Skewness | 0.408 | -0.048 | 0.830 | -0.036 | -0.127 |
| Minimum | -0.029 | -0.036 | -0.067 | 0.033 | -0.044 |
| Maximum | 0.039 | 0.029 | 0.095 | 0.158 | 0.039 |
| ADF | -51.4786** | -53.4031** | -55.7591** | -54.8177** | -58.9361 |

| Country | Switzerland | Iceland | Hong Kong | Czech Republic | Singapore |
|---|---|---|---|---|---|
| Mean | -0.000 | 0.000 | -0.000 | 0.000 | -0.000 |
| Standard Error | 0.007 | 0.010 | 0.000 | 0.008 | 0.003 |
| Kurtosis | 80.611 | 56.384 | 265.198 | 3.729 | 4.424 |
| Skewness | -2.676 | 0.238 | -9.076 | 0.222 | 0.057 |
| Minimum | -0.157 | -0.134 | -0.032 | -0.050 | -0.022 |
| Maximum | 0.095 | 0.147 | 0.030 | 0.053 | 0.026 |
| ADF | -53.7565** | -55.5139** | -44.7012** | -54.0658** | -54.7277** |

| Country | South Korea | Russia | Turkey | India | Indonesia |
|---|---|---|---|---|---|
| Mean | 0.000 | 0.000 | 0.000 | 0.000 | 0.042 |
| Standard Error | 0.007 | 0.009 | 0.008 | 0.004 | 0.851 |
| Kurtosis | 32.781 | 45.221 | 7.001 | 5.945 | 2729.823 |

| | | | | | |
|---|---|---|---|---|---|
| Skewness | 0.408 | 0.736 | 0.788 | 1.172 | 51.701 |
| Minimum | -0.103 | -0.141 | -0.053 | -0.035 | -0.098 |
| Maximum | 0.107 | 0.143 | 0.070 | 0.037 | 97.952 |
| ADF | -50.3963** | -50.9994** | -53.9350** | -52.8286** | -54.2572** |

| Country | Argentine | Malaysia | Thailand | Mexico | Saudi Arabia |
|---|---|---|---|---|---|
| Mean | 0.000 | 0.000 | -0.000 | 0.000 | 0.000 |
| Standard Error | 0.007 | 0.004 | 0.005 | 0.007 | 0.012 |
| Kurtosis | 1657.464 | 5.182 | 149.717 | 13.351 | 42.832 |
| Skewness | 36.964 | -0.369 | 1.659 | 0.962 | 0.568 |
| Minimum | -.0.031 | -0.035 | -0.104 | -0.061 | -0.133 |
| Maximum | 0.355 | 0.029 | 0.115 | 0.081 | 0.153 |
| ADF | -36.8414** | -53.5359** | -53.5815** | -23.8200** | -53.5792** |

| Country | United Arab Emirates | South Africa | Nigeria |
|---|---|---|---|
| Mean | -0.000 | 0.000 | 0.025 |
| Standard error | 0.008 | 0.011 | 1.385 |
| Kurtosis | 77.821 | 25.199 | 2870.718 |
| Skewness | 0.769 | 1.691 | 53.572 |
| Minimum | -0.108 | -0.065 | -0.986 |
| Maximum | 0.122 | 0.175 | 74.250 |
| ADF | -53.5681** | -28.1001** | -37.4842** |

*Notes: Returns are in real terms and measured by calculating the daily change in the log price of close data and the sample size is 2871. * P < 0.1; ** P < 0.05; *** P < 0.01.*

Table 2: Descriptive Statistics, Global Foreign Exchange Market Volatility, 2005 – 2016.

| Country | United Kingdom | European Union | Australia | Canada | Switzerland |
|---|---|---|---|---|---|
| Mean | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 |
| Standard error | 0.000 | 0.002 | 0.072 | 0.000 | 0.009 |
| Kurtosis | 111.561 | 2866.973 | 1433.442 | 107.130 | 2802.957 |
| Skewness | 8.004 | 53.520 | 37.873 | 7.968 | 52.685 |
| Minimum | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Maximum | 0.002 | 0.150 | 2.765 | 0.002 | 0.506 |
| ADF | -31.2667** | -53.5757** | -30.9404** | -32.0489** | -53.5742** |

| Country | Japan | Iceland | Czech Republic | Hong Kong | Singapore |
|---|---|---|---|---|---|
| Mean | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Standard error | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| Kurtosis | 259.795 | 1429.986 | 65.781 | 760.508 | 709.547 |
| Skewness | 12.947 | 35.395 | 6.512 | 25.702 | 20.668 |
| Minimum | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Maximum | 0.003 | 0.088 | 0.003 | 0.000 | 0.001 |
| ADF | -42.3771** | 25.7536** | -30.9438** | -15.8937** | -28.6243** |

| Country | South Korea | Russia | Turkey | India | Indonesia |
|---|---|---|---|---|---|
| Mean | 0.001 | 0.003 | 0.430 | 0.003 | 0.191 |
| Standard error | 0.088 | 0.155 | 23.055 | 0.128 | 2.665 |
| Kurtosis | 2871.851 | 2871.755 | 2871.999 | 1214.471 | 226.509 |

| | | | | | |
|---|---|---|---|---|---|
| Skewness | 53.588 | 53.587 | 53.591 | 34.377 | 14.893 |
| Minimum | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Maximum | 4.751 | 8.310 | 1235.575 | 4.7415 | 42.769 |
| ADF | -53.5699** | -53.5818** | -53.5817** | -53.6088** | -19.8196** |

| Country | Argentine | Malaysia | Thailand | Mexico | Saudi Arabia |
|---|---|---|---|---|---|
| Mean | 0.000 | -0.000 | 0.001 | 0.000 | 0.000 |
| Standard error | 0.000 | 0.004 | 0.088 | 0.000 | 0.000 |
| Kurtosis | 38.627 | 2843.605 | 2871.925 | 658.920 | 2785.065 |
| Skewness | 5.767 | 53.194 | 53.589 | 22.598 | 52.431 |
| Minimum | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Maximum | 0.002 | 0.246 | 0.726 | 0.014 | 0.029 |
| ADF | -36.8414** | -53.5359** | -53.5815** | -23.8200** | -53.5792** |

| Country | United Arab Emirates | South Africa | Nigeria |
|---|---|---|---|
| Mean | 0.000 | 0.000 | 0.025 |
| Standard error | 0.000 | 0.021 | 0.541 |
| Kurtosis | 2854.287 | 2868.012 | 750.063 |
| Skewness | 53.347 | 53.535 | 25.985 |
| Minimum | 0.000 | 0.000 | 0.000 |
| Maximum | 0.003 | 1.161 | 18.821 |
| ADF | -53.5681** | -28.1001** | -37.4842** |

Notes: Volatilities are for daily spot closing returns. We employ high-frequency intra-day data (high, low, opening and closing) to obtain the returns volatilities using formulae (3) described above. The sample size is 2871, consult text for more elaboration. * P < 0.1; ** P < 0.05; *** P < 0.01.

Moreover, due to the single European market, return spillover amongst developed countries is sizeable and positive. This means there are tremendous cross-market interconnectedness and financial interdependence amid developed countries. Considering the global foreign exchange volatility spillover, Table 4; it is clear that developed countries contribute significantly to their "own" total volatility spillover. This result is in line with the argument that the currency crisis tends to be regional (Glick and Rose 1998; Yarovaya et al. 2016). The results also show that intra-regional volatility spillover transmission tends to be significantly higher than the inter-regional volatility spillover. Our finding is also in line with Melvin and Melvin, (2003); Cai et al. (2008) and Barunik et al. (2016) that significant volatility spillover transmitted amid currencies within a particular market.

Also, from Table 4, we find that the pound sterling, Euro and the Australian dollar are the main contributors of volatility spillover to others. Again, the result is in line with the findings presented by Antonakakis (2012); and Barunik et al. (2016) who find the GBP and the EUR to be the dominant net transmitters and receivers of volatility spillover during the period (2000 – 2013). Following the discussion of the static version of volatility spillover transmission across global foreign exchange markets; a key finding is that developed countries contribute substantially to the total volatility transmitted (that is, contributions to others) and received (that is, contributions from others).

So far, we have shown evidence of return and volatility spillovers based on the static version analysis of the spillover indexes presented in Table 3 (return) and Table 4 (volatility). The indexes of 15.1% (for return) and 26.5% (volatility) represent the extracted cross-country spillover for the full sample (January 2005 –July 2016). This means virtually 26.5% of the forecast error variance comes from the spillover. Aside from scrutinising the broader static effect of return and volatility spillovers across the global foreign exchange markets, we now turn to provide a different fashion of the dynamic movement of return and volatility spillover effect.

Table 3

Spillover Table. Global Foreign Exchange (FX) Market Return, 31/05/2005 – 01/06/2016

From

| To | UK | EU | AUS | CAN | CHE | JPN | ISL | CZE | HKG | SGP | KOR | RUS | TUR | IND | IDN | ARG | MYS | THA | MEX | SAU | ARE | ZAF | NGA | From Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UK | **99.0** | 0.0 | 0.0 | 0.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | **1** |
| EU | 0.0 | **99.9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| AUS | 0.0 | 0.0 | **99.3** | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **1** |
| CAN | 0.7 | 0.0 | 0.0 | **69.1** | 0.0 | 11.6 | 10.3 | 4.9 | 0.4 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.3 | 1.2 | 0.0 | 0.2 | 0.0 | 0.0 | **31** |
| CHE | 0.0 | 0.0 | 0.0 | 0.0 | **100** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| JPN | 0.4 | 0.0 | 0.0 | 11.4 | 0.0 | **75.8** | 0.9 | 6.0 | 0.5 | 0.5 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.3 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | **24** |
| ISL | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 3.8 | **88.2** | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.5 | 6.3 | 0.0 | 0.0 | 0.0 | 0.0 | **12** |
| CZE | 0.3 | 0.0 | 0.0 | 22.1 | 0.1 | 11.3 | 1.1 | **61.5** | 0.3 | 1.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | **38** |
| HKG | 0.1 | 0.0 | 0.0 | 0.8 | 0.0 | 0.5 | 0.1 | 0.2 | **97.8** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | **2** |
| SGP | 0.3 | 0.0 | 0.0 | 5.8 | 0.0 | 3.8 | 0.4 | 7.8 | 0.2 | **80.9** | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | **19** |
| KOR | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.4 | 0.2 | 0.1 | 22.7 | 0.0 | **76.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | **24** |
| RUS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **99.6** | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| TUR | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | **99.7** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| IND | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **99.9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| IDN | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | **99.7** | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| ARG | 0.2 | 0.0 | 0.0 | 1.6 | 0.0 | 5.4 | 0.5 | 2.7 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | **85.1** | 0.0 | 1.4 | 0.8 | 0.0 | 0.0 | 1.6 | 0.0 | **15** |
| MYS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **99.9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0** |
| THA | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.4 | 0.2 | 0.1 | 22.7 | 0.0 | 76.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.3** | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | **100** |
| MEX | 0.1 | 0.0 | 0.0 | 2.5 | 0.0 | 5.9 | 63.8 | 1.8 | 0.1 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.3 | **24.7** | 0.0 | 0.0 | 0.0 | 0.0 | **75** |
| SAU | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **99.3** | 0.0 | 0.0 | 0.0 | **1** |
| ARE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | **99.8** | 0.0 | 0.0 | **0** |
| ZAF | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1. 4 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | **98.0** | 0.0 | **2** |
| NGA | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | **99.3** | **1** |
| **Contribution to others** | **3** | **0** | **0** | **45** | **0** | **43** | **78** | **24** | **47** | **3** | **78** | **0** | **0** | **0** | **0** | **3** | **0** | **5** | **13** | **0** | **0** | **2** | **0** | **347** |
| **Contribution including own** | **102** | **100** | **99** | **114** | **100** | **119** | **166** | **86** | **145** | **84** | **154** | **100** | **100** | **100** | **100** | **89** | **100** | **5** | **38** | **99** | **100** | **100** | **99** | **15.1%** |

Note: The fundamental variance decomposition is based on weekly (VAR) of order 2 identified using Cholesky factorisation. The value of $(i, j)$variables is the estimated contribution to the variance of the 70-day-ahead real foreign exchange (FX) return forecast error of country $i$ coming innovations to real FX returns of country $j$.

Table 4

Spillover Table: Global Foreign Exchange (FX) Market Volatility, 31/05/2005 – 01/06/2016

| | | From | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UK | EU | AUS | CAN | JPN | CHE | ISL | HKG | CZE | SGP | KOR | RUS | TUR | IND | IDN | ARG | MYS | THA | MEX | SAU | ARE | ZAF | NGA | From Others |
| To | UK | **97.4** | 0.0 | 0.2 | 0.4 | 0.0 | 0.1 | 0.2 | 0.0 | 0.6 | 0.1 | 0.0 | 0.2 | 0.3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | 0.1 | **3** |
| | EU | 39.4 | **59.0** | 0.3 | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.2 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | **41** |
| | AUS | 24.8 | 6.2 | **62.5** | 1.5 | 0.0 | 0.3 | 0.7 | 0.0 | 0.2 | 0.2 | 0.1 | 0.1 | 1.4 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 1.4 | 0.1 | 0.1 | 0.2 | 0.0 | **37** |
| | CAN | 24.6 | 5.4 | 15.0 | **53.2** | 0.0 | 0.1 | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 | 0.1 | 0.3 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | **47** |
| | JPN | 0.1 | 0.1 | 0.1 | 0.1 | **98.1** | 0.0 | 0.4 | 0.0 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | **2** |
| | CHE | 17.8 | 26.8 | 0.4 | 0.6 | 0.0 | **53.0** | 0.0 | 0.3 | 0.3 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | **47** |
| | ISL | 14.4 | 10.7 | 1.2 | 0.3 | 0.1 | 0.4 | **69.4** | 0.4 | 0.1 | 0.4 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 1.9 | 0.0 | 0.0 | 0.1 | 0.0 | **31** |
| | HKG | 0.9 | 1.0 | 1.5 | 0.1 | 0.1 | 0.0 | 0.3 | **94.5** | 0.1 | 0.0 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.1 | 0.0 | 0.0 | 0.1 | 0.3 | **5** |
| | CZE | 33.7 | 38.8 | 0.8 | 0.4 | 0.0 | 0.1 | 0.1 | 0.0 | **25.3** | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.1 | 0.0 | **75** |
| | SGP | 26.9 | 14.2 | 10.2 | 1.3 | 0.1 | 0.4 | 0.2 | 1.9 | 0.5 | **43.1** | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.2 | 0.0 | 0.3 | 0.3 | 0.0 | 0.1 | 0.0 | **57** |
| | KOR | 8.1 | 1.7 | 9.2 | 1.3 | 0.1 | 0.1 | 1.0 | 0.2 | 0.5 | 7.1 | **64.7** | 0.0 | 2.2 | 0.4 | 0.1 | 0.1 | 0.4 | 0.0 | 1.7 | 0.1 | 0.0 | 1.0 | 0.1 | **35** |
| | RUS | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | **98.1** | 0.0 | 0.1 | 0.1 | 0. | 0.1 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | **2** |
| | TUR | 13.2 | 4.3 | 10.2 | 3.5 | 0.1 | 1.2 | 0.6 | 0.0 | 1.8 | 1.1 | 0.4 | 0.1 | **61.9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.1 | 0.0 | 0.5 | 0.0 | **38** |
| | IND | 6.8 | 1.6 | 4.8 | 0.9 | 0.3 | 0.1 | 0.3 | 0.2 | 0.1 | 2.9 | 1.7 | 0.2 | 2.0 | **76.1** | 0.2 | 0.0 | 0.3 | 0.0 | 1.1 | 0.1 | 0.0 | 0.3 | 0.0 | **24** |
| | IDN | 0.0 | 0.1 | 0.0 | 0.1 | 0.3 | 0.1 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.2 | 0.1 | 0.0 | **98.2** | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | **2** |
| | ARG | 0.1 | 0.0 | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.2 | **98.3** | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | **2** |
| | MYS | 7.2 | 3.8 | 5.3 | 2.1 | 0.1 | 0.2 | 0.1 | 0.8 | 0.2 | 13.0 | 2.1 | 0.1 | 1.2 | 2.5 | 0.2 | 0.1 | **59.6** | 0.0 | 1.2 | 0.1 | 0.0 | 0.2 | 0.0 | **40** |
| | THA | 1.8 | 1.3 | 1.0 | 0.1 | 0.1 | 0.2 | 0.1 | 0.3 | 0.1 | 3.3 | 0.2 | 0.0 | 0.4 | 0.8 | 0.1 | 0.0 | 0.6 | **89.4** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **11** |
| | MEX | 14.4 | 2.7 | 8.7 | 8.4 | 0.0 | 1.1 | 0.2 | 0.2 | 2.0 | 3.6 | 0.4 | 0.1 | 4.7 | 0.3 | 0.3 | 0.0 | 0.2 | 0.0 | **52.7** | 0.1 | 0.0 | 0.0 | 0.0 | **47** |
| | SAU | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | **98.5** | 0.6 | 0.0 | 0.0 | **2** |
| | ARE | 0.0 | 0.0 | 0.1 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | **98.6** | 0.0 | 0.0 | **1** |
| | ZAF | 18.5 | 5.1 | 10.7 | 4. | 0.1 | 0.3 | 0.7 | 0.1 | 2.1 | 2.6 | 0.2 | 0.1 | 9.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.7 | 0.0 | 0.0 | **39.5** | 0.0 | **60** |
| | NGA | 0.1 | 0.2 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | **98.8** | **1** |
| Contribution to others | | **253** | **124** | **80** | **26** | **2** | **5** | **5** | **5** | **9** | **35** | **6** | **2** | **23** | **5** | **2** | **1** | **3** | **1** | **16** | **2** | **1** | **3** | **1** | **610** |
| Contribution including own | | **351** | **183** | **143** | **79** | **100** | **58** | **75** | **99** | **35** | **78** | **71** | **100** | **85** | **81** | **100** | **99** | **63** | **90** | **68** | **100** | **100** | **42** | **99** | **26.5%** |

Note: The fundamental variance decomposition is based on daily (VAR) of order 2 identified using Cholesky factorisation. The value of $(i, j)$ variables is the estimated contribution to the variance of the 70-day-ahead foreign exchange volatility forecast error of country $i$ coming from innovation to the foreign exchange volatility of country $j$.

5.3. Return and Volatility Spillovers: Dynamic Analysis (Spillover Plots)

To address the extent of the spillover effect between developed and developing countries we use 200-day rolling samples, which is about six months. The 200-day rolling sample used to demonstrate the spillover variations over time between developed and developing countries since the data we use spans over 2005-2016. The dynamic movement of return and volatility spillovers is designed to capture the effect of the potential recurring movement of spillover by using returns and volatility indexes shown in Tables 3 and 4. The indexes are the sums of all variance decompositions represented in the form of "contribution to others." Employing the indexes, we estimate the model to scrutinise the evolution of global foreign exchange markets during the years of the sample (2005 – 2016). Hence, we capture the magnitude and disparities of the spillover for return and volatility, which we present graphically in the form of spillover plots.

The era of the 2000s, which began with a recession, mainly in developed countries across the European Union and the U.S. undisputedly, documented painful economic events in our history. In particular, the 2008 global financial turmoil. Thus, Figure 1 for (return spillover) captured some of the critical events, whereas Figure 2, (volatility spillover) appears to be most eventful. Interestingly, the 200-day rolling samples epitomised in Figures 1 and 2 highlights some of the significant economic events that occurred during the years of the sample (2005 – 2016). As the estimation window moves towards the year 2016, we have captured the following critical economic events;

(1). The U.S housing bubble worries, according to Liebowitz (2008) foreclosure rates increased by 43 per cent during the 2$^{nd}$ and the 4$^{th}$ quarter of the year 2006.

(2). The increase of foreclosures and mortgage default rates reached about 55 per cent for (prime), and 80 per cent (subprime) hugely devalued mortgage-back-securities at the end of 2007, causing a severe credit crunch.

(3). During the same year of 2007, the British bank Northern Rock collapsed.

(4). Followed by Lehman Brothers, the biggest U.S. investment bank then, filed for bankruptcy on September 15, 2008.

(5). Following the above events, among others, comes the worst financial turmoil (2007-2009) since the great depression of (1929 – 1939), and the Greece debt crisis, December 2009.

(6). European sovereign debt crisis in 2009.

(7). The fall in Crude oil prices in 2014.

(8). Russia financial crisis (2014 – 2017) according to the Centre for Eastern Studies (OSW), the leading causes of the Russian crisis are the tensions between Russia and the west; which led to sanction war, and the dramatic fall in oil prices.

(9). First signs of Brexit worries on June 23, 2016, whereby the British pound plunged to its lowest level since 1985.

The graphical illustrations above Figures (1 & 2) highlight important economic events during the years of the sample (2005 – 2016). The analysis orchestrated here, visually signalise the effect of volatility spillover across intra-foreign exchange markets. The magnitude and extent of the spillover effect of both returns (Figure 1) and volatility (Figure 2) significantly marked by the crisis episodes of (2007 – 09). In particular, the series of European sovereign debt crisis (2009 – 2014) and China stock market crash (2015), among others. This means, interestingly, besides volatility spillover, the contribution of return spillover is unexpectedly significant enough to show some commonality with volatility spillover in terms of responding to economic events.

Figure 1. Spillover Plot: Global Foreign Exchange Market Returns (2005 – 2016)

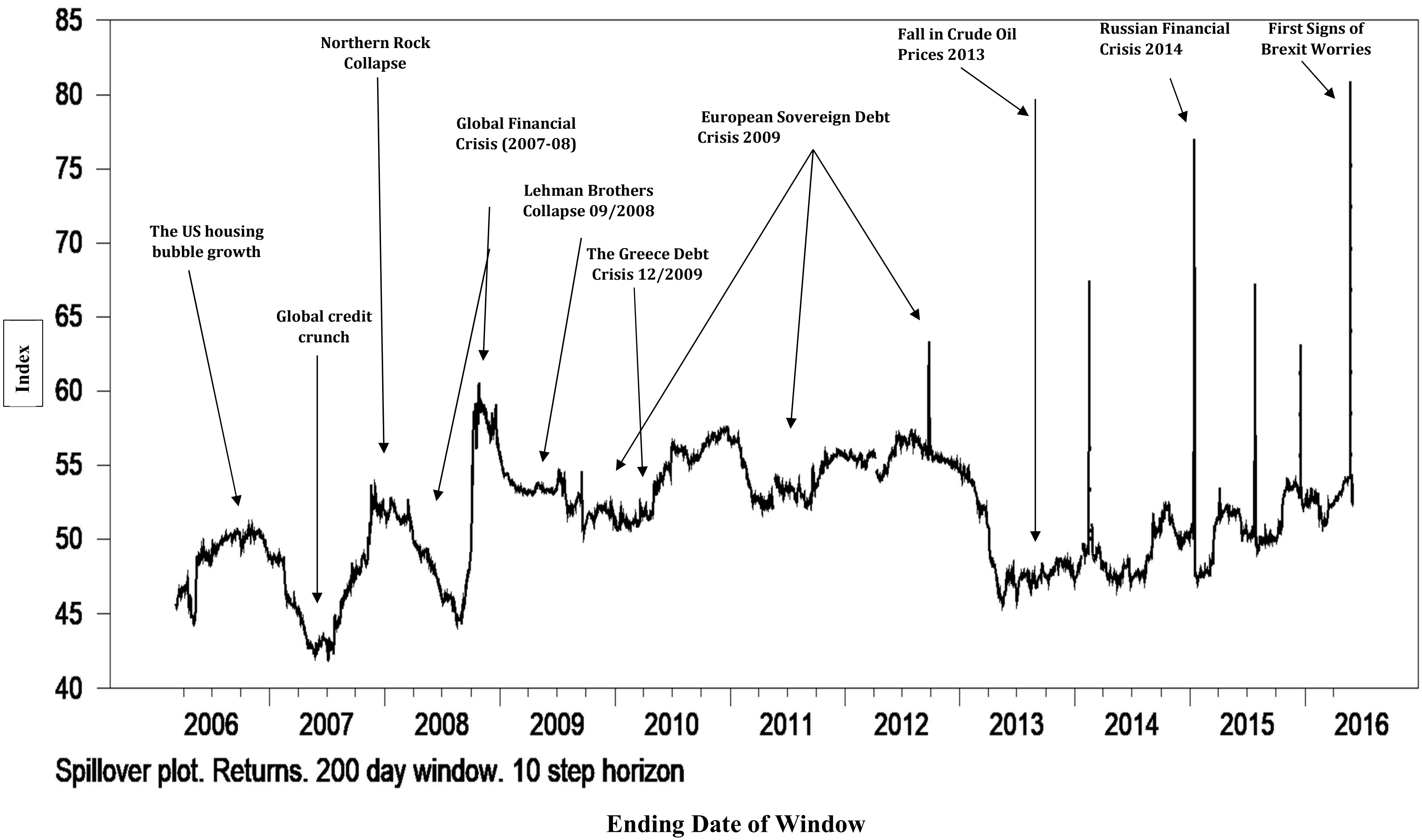
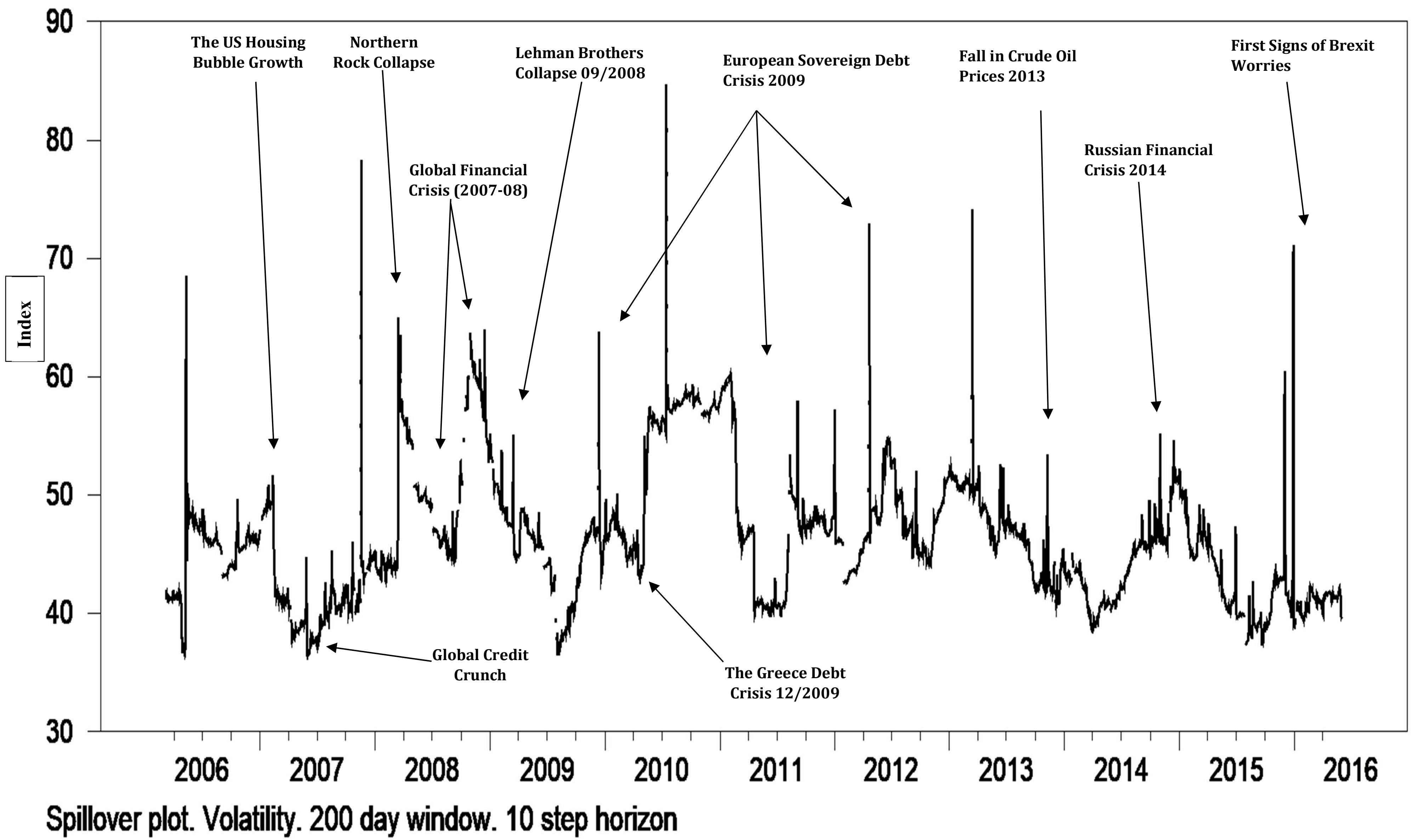


Figure 2. Spillover Plot: Global Foreign Exchange Market Volatility (2005 – 2016)




Ending Date of Window

Further, we also observe bursts in total return and volatility spillovers which materialised twice in Figure 1 and four times in Figure 2. The total return's spillover began to decrease slightly after its strong response to the (2007 – 09) financial turmoil as well as the European sovereign debt crisis in 2009 until the China stock market crash in (2015), whereby it shows a dramatic increase.

On the contrary, volatility spillover fluctuates with explicit outbursts virtually with every single economic event highlighted during the years of the full sample (2005 – 2016). Put it differently, the volatility spillover plot (Figure 2), depicts the phenomenon of the globally systemically important financial institutions from a series of historical defaults involved too big to fail nature. To check the robustness of the result regarding rolling window width, forecast horizon, and VAR ordering; we perform spillover plots (Figure 3) using 84-day rolling window width. We also use two different variance decomposition forecast horizons; a 70-day forecast horizon in Figure 3 (a) and 14-day in Figure 3 (b). The results are robust even when employing maximum and minimum volatility spillover across a diversity of alternative VAR ordering using 200-day rolling windows, see (Figures 3 and 4).

### 5.4. Robustness Analysis

Based on the extent of the above results, the maximum and minimum spillover Figure 4, shows the variability of the volatility spillovers' magnitude in global foreign exchange markets, which appears to be relatively higher than return spillover. Notwithstanding, we find the behaviour of return spillover in the global currency markets (Figure 1) substantially responding to major economic events. Since we find "contribution to others" mainly dominated by developed countries, in particular, the British pound (GBP), Euro (EUR), and the Australian dollar (AUD); this means developing countries act as net receivers to return and volatility spillovers.

**Figure 3. Spillover Plot: Global Foreign Exchange Market (2005 – 2016) - 70 and 14 Day Forecast Horizons**

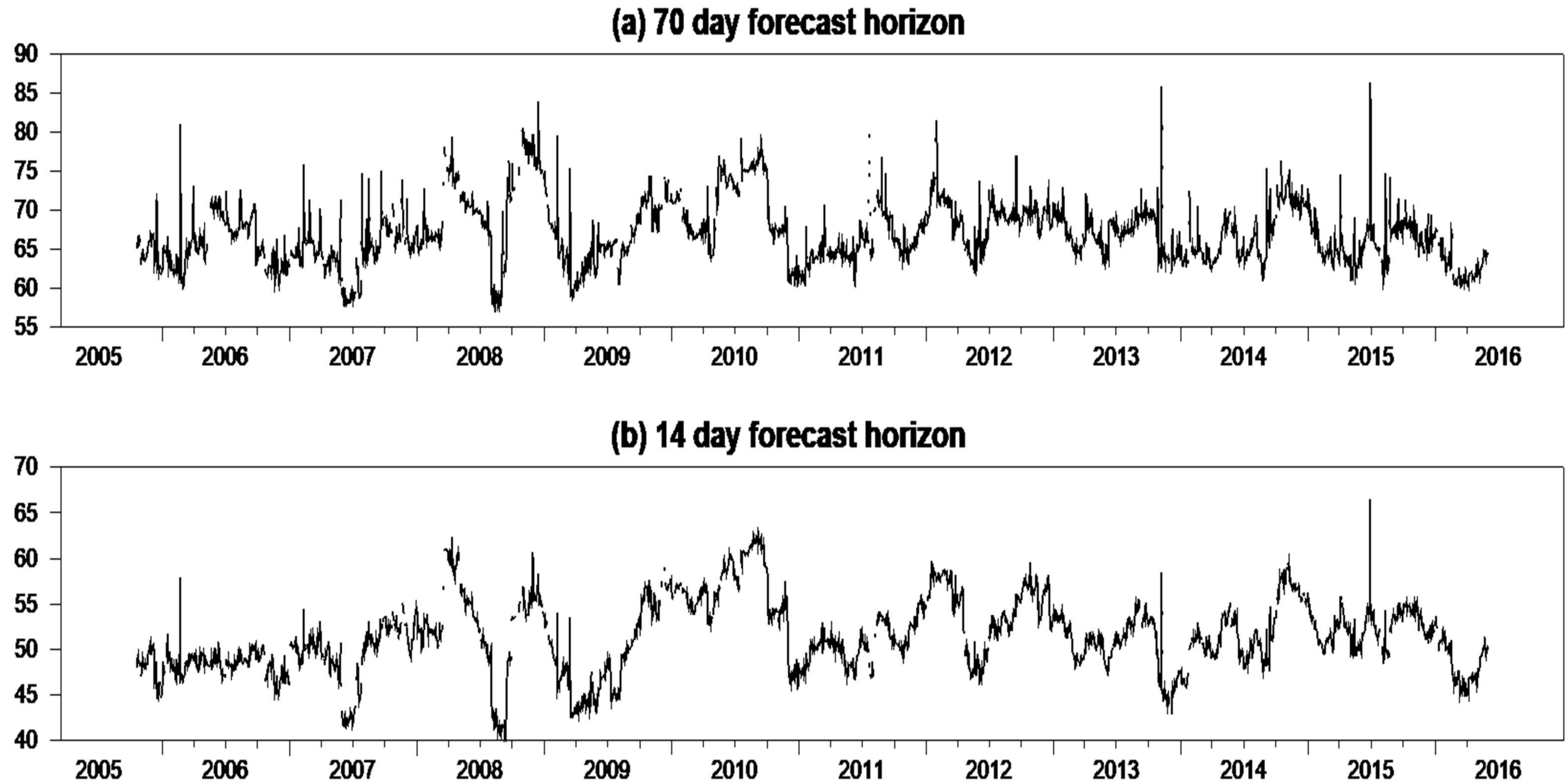



Figure 3 Spillover plot, Global FX Market Volatility
100 day Rolling Window

Figure 4. Maximum and Minimum Spillovers: Global Foreign Exchange Market (2005 – 2016)

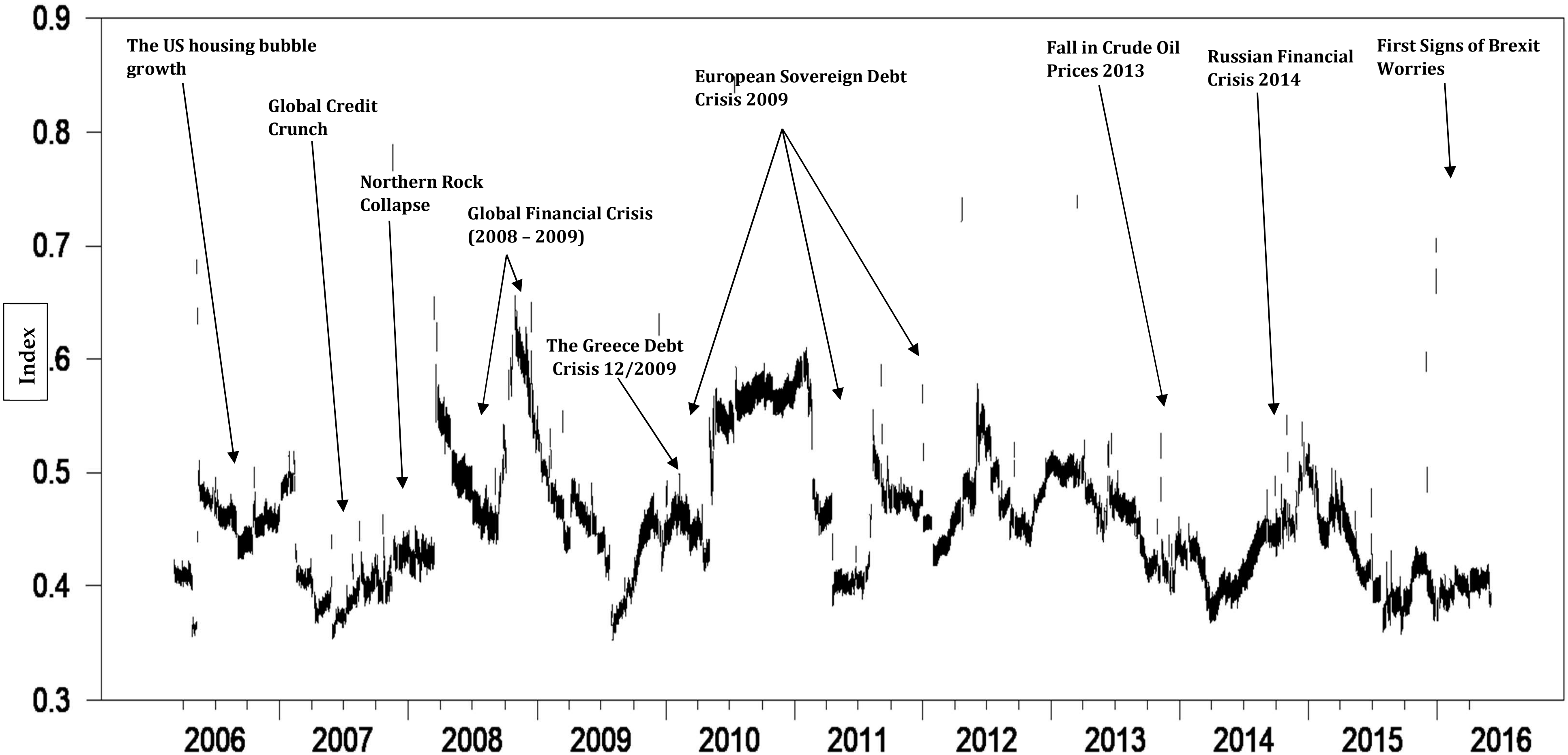



Figure 4. Maximum and minimum spillovers
Randomly Chosen Orderings

Ending Date of Window

Further, according to the Bank for International Settlements' (BIS) report (2013), the USD, EUR, GBP, AUD, CAD, JPY and CHF are the most traded globally, account for almost 90 per cent of the global foreign exchange turnover. This means, a substantial amount of return and volatility spillovers transmitted across the world during the years of the full sample (2005 – 2016); are coming from developed countries. The findings are robust even when employing maximum and minimum volatility spillover across a diversity of alternative VAR ordering using 200-day rolling windows.

Interestingly, the results highlight the significance of the global foreign exchange markets' spillover channels during crisis periods in several dimensions. One is the cyclical bursts in spillover that occurs as a consequence of significant economic events. These include, the credit crunch of July 2007, Lehman Brothers collapsed in September 2008, the financial turmoil which created havoc during (2007 – 09), the European sovereign debt crisis (2009 – 14) and the fall in Crude oil prices in 2013.

Two, it highlights the potential magnitudes of the spillover effect. In particular, from the default of systemically important financial institutions across the global financial system; which spread jitters from the outset of the U.S. subprime mortgage crisis. Three, the size of the shocks which led to bursts in spillover (see, Figs. 1, 2, 3 and 4) suggest strong cross-market interconnectedness. This reflects the definition of contagion presented by Forbes and Rigobon (2002) as a significant increase in cross-market linkages after a shock to one country or group of countries. Four, the results also provide significant insights, particularly to the financial regulators from the perspectives of understanding the effect of spillover from the default of systemically important financial institutions. Finally, they also introduce for investors the issue of cross-market linkages and economic interdependence during crises periods whereby volatility spillover increases substantially.

## 6. Time-varying volatility spillovers

In this section, we present the results of the time-varying volatility spillover among developed and developing countries; using autoregressive conditional heteroskedasticity (ARCH). Time-varying volatility helps investigate sources of significant shifts in the volatility during the years of our sample (2005 – 2016). This is because the ARCH models designed to capture persistence in time-varying volatility based on squared returns (Poon, 2005). The Arch model has a unique structure, where 'autoregressive' means high volatility tends to persist, 'conditional' refers to time-varying or specific point on time, and 'heteroskedasticity' refers to non-constant volatility (Poon, 2005). Before applying the Arch (1) model, we first generate the squared residuals using regression, which contains only an intercept. Table (5) shows the regression result of the squared residuals. This is because the squared residuals ensure that the conditional variance is positive and consequently, the leverage effects cannot be captured by the Arch model (Engle, 2001b).

Table 5: Regression results (squared residuals)

| Variable | Adjusted $t^*$ | p-value |
|---|---|---|
| Ehat2 | 8.12 | 0.000 |
| No obs: 2.871; | R – squared: 0.022; Adj R-squared: 0.022; | MSE: 1.3e-07 |

Second, we test the data for the presence of Arch effects using the Box-Pierce large multiplier (LM), which provides the most appropriate results (Alexander, 2001). Table (6) displays the result of the large multiplier's (LM) test for the presence of Arch effects in the data.

Table 6: LM test result for autoregressive conditional heteroskedasticity (ARCH)

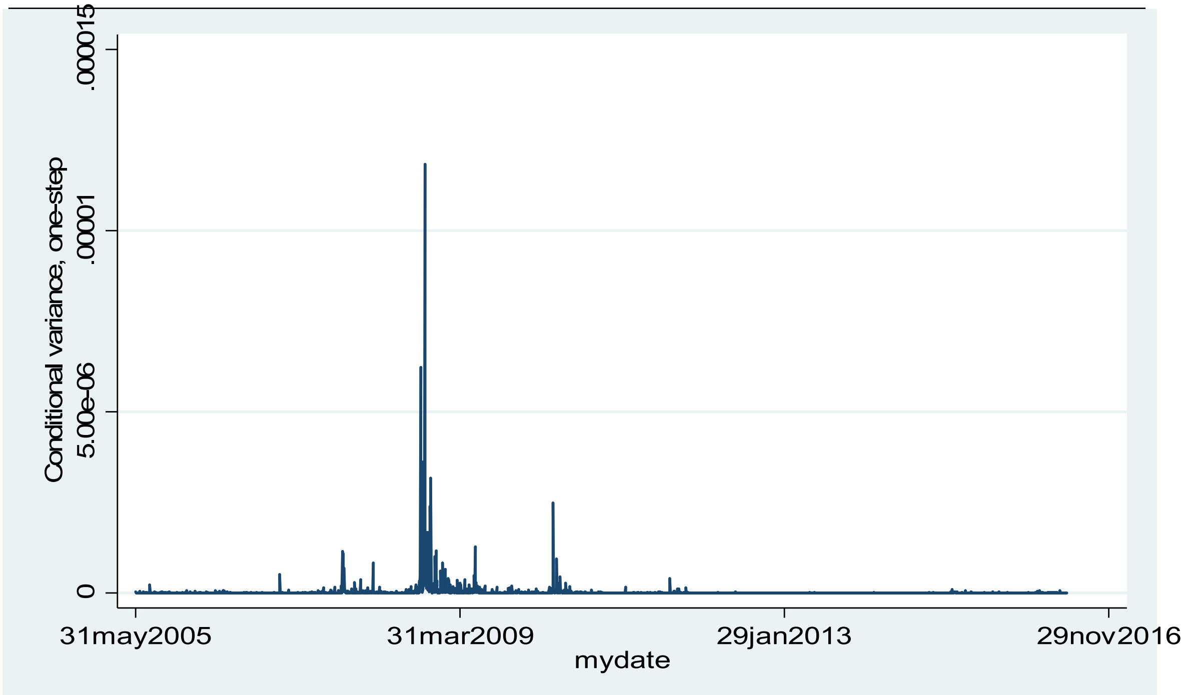
| lags(p) | chi2 | df | Prob > chi2 |
|---|---|---|---|
| 1 | 64.443 | 1 | 0.0000 |

H0: no ARCH effects vs. H1: ARCH(p) disturbance

The LM results show the null and alternative hypotheses, the statistic and its distribution and the p-value; which indicates the presence of Arch (p) model disturbance in the data. Thus, we estimate the Arch (1) model and generate the forecast error variance; which is essentially an in-sample prediction model based on the estimated variance function, see Eq. (19) for more details. Table (7) shows the result of the conditional variance of the estimated Arch (1) model. The conditional variance in the Arch model is allowed to change over time as a function of past error leaving the unconditional variance constant (Bollerslev, 1986). Then we proceed by plotting the forecast error variance against the years of our sample (2005 – 2016). Figure (5) shows the result of the Arch (1) model, which implies that the volatility spillovers from developed countries to the developing countries seem to be specifically strong in 2008.

Thus, the result indicates that the foreign exchange market's channel between developed and developing countries exhibit time-varying persistence in its conditional volatilities over the crisis period. This result is consistent with the spillover index findings of both static analysis (Table 4) and the dynamic analysis (Figures 2 & 4). It also shows that all the currencies in the sample from both (developed and developing) countries are characterised by clustering volatility. Our finding indicates that the global foreign exchange market experiences somewhat relatively sedate volatility spillovers from 2005 to 2007. Then, the foreign exchange market's volatility spillovers become much more volatile in 2008-2009. These results are consistent with the dynamic analysis of the spillover indices (Fig 2), which captured the 2008/09 financial crisis.

Table 7: Arch (1) conditional variance for global foreign exchange market (2005 - 2016)




| | | |
|---|---|---|
| 496. | 2.80e-09 | 2.80e-09 |
| 497. | 2.24e-09 | 2.24e-09 |
| 498. | 2.99e-09 | 2.99e-09 |
| 499. | 2.56e-09 | 2.56e-09 |
| 500. | 4.02e-09 | 4.02e-09 |

Figure 5: Result of global foreign exchange market time-varying volatility over (2005 – 2016), using Arch (1) model.

Note: This figure shows the persistence in time-varying volatility between developed and developing countries over 2005 – 2016. The underlying currencies across developed and developing countries, including the most traded globally, are described in the data section.

## 7. Net spillovers and net pairwise volatility spillovers

This section presents the results of the net spillover and the net pairwise spillover between developed and developing countries over the years of our sample (2005 – 2016). The key features of the net volatility spillover show the difference between the gross volatility shocks that are transmitted to and those received from all other markets (Diebold and Yilmaz, 2012). Therefore, the net pairwise volatility spillover (Eq.14) between country i and j is the difference between the gross volatility shocks transmitted from a country i to country j including the transmission from j to i (Diebold and Yilmaz, 2012). As shown in Eq. (12), the net volatility spillover offers important information about the amount of volatility in net terms, that each country contributes to other countries. Therefore, the main focus point of this section is to calculate the net volatility and the net pairwise volatility spillovers between developed and developing countries. Due to a large number of countries (23) in our sample, only 16 currencies selected, which we present in Figs. (6-to-9).

During the years of our sample (2005 -2016), there were two major events of net volatility spillovers through the global foreign exchange market, in particular during the 2008/09 financial crisis; and the European sovereign debt crisis in 2009/13. However, before the recent financial crisis and the European sovereign debt crisis, the net volatility spillovers between developed and developing countries was relatively low. But things changed drastically after 2007, where the net volatility spillover from the EUR to the Malaysian ringgit Fig. (8) jumped to 20% in the third quarters of 2008 and 40% in the third quarters of 2009. These results are consistent with the time-varying volatility results; which imply that the foreign exchange market experiences low volatility from 2005 to 2007. The pound sterling (GBP) and the Euro (EUR) Figs. (6-9) both acts as giving and receiving of the net volatility transmissions, with almost similar magnitudes across the global foreign exchange market. This finding supports the static analysis of the spillover index (Table 4) that the pound sterling (GBP) and the Euro (EUR) are the main contributors of volatility spillovers.

The Indonesian rupiah (IDR) also receives a significant amount of volatility spillovers from the Euro (EUR) Fig. (7), especially during the recent financial crisis and the European sovereign debt crisis in 2009/13. On the other hand, the Euro (EUR) receives a large amount of volatility spillover from the Malaysian ringgit (Fig. 9), which indicates that developed countries act as receivers and transmitters of volatility spillovers. The Argentine peso (ARS) contributes as well as receives a significant amount of volatility from the Malaysian ringgit (MYR), Fig. (9). The net volatility spillover from the pound sterling (GBP) to the Euro (EUR) Fig. (9) seems relatively low while receiving a significant amount of volatility spillovers from the Euro (EUR). The fact that the pound sterling (GBP) contributes as well as receives a large amount of volatility spillovers from the Euro (EUR) shows the increased link between developed countries in the global foreign exchange market.

**Figure 6: Net Volatility Spillovers, GBP INR EUR IDR**

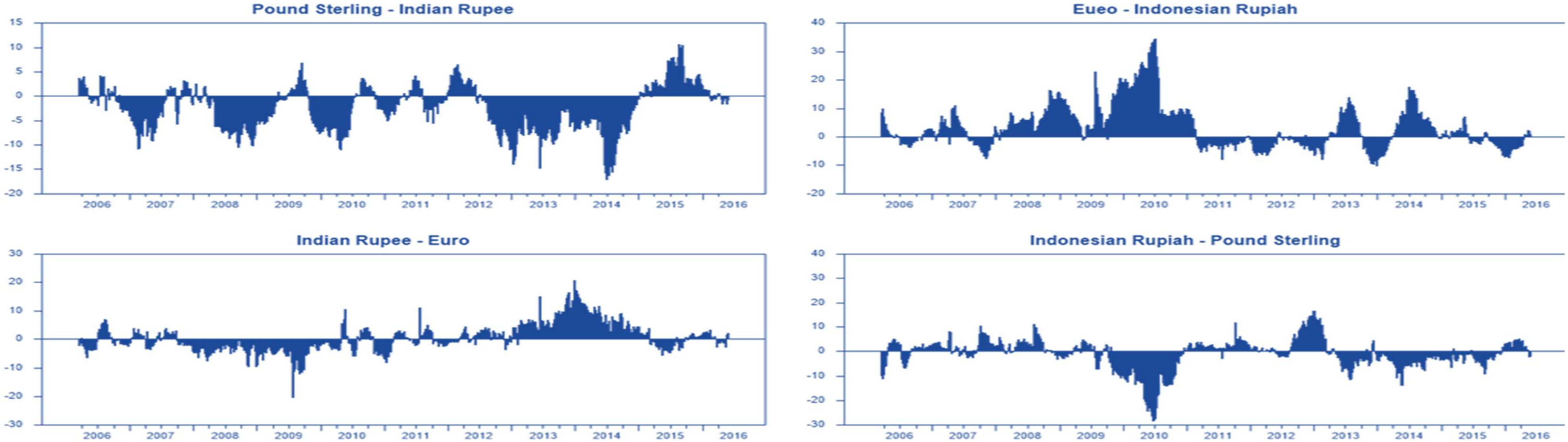



**Figure 7: Net Pairwise Volatility Spillovers,GBP INR EUR IDR**

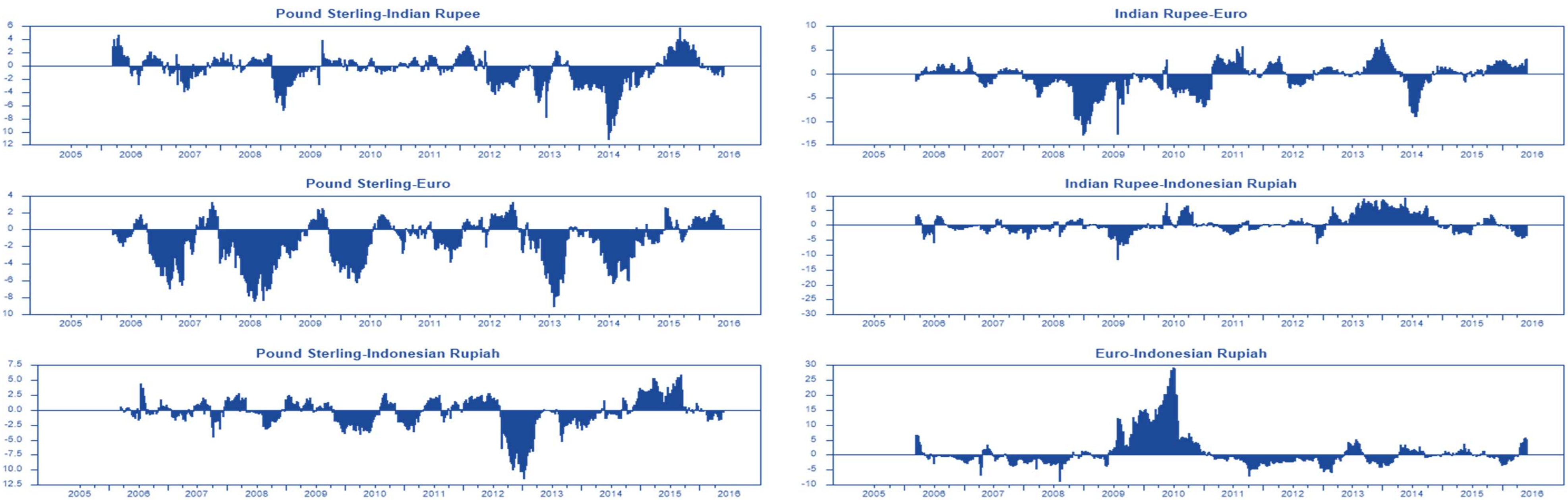


**Figure 8: Net Volatility Spillovers, GBP ARS EUR MYR**

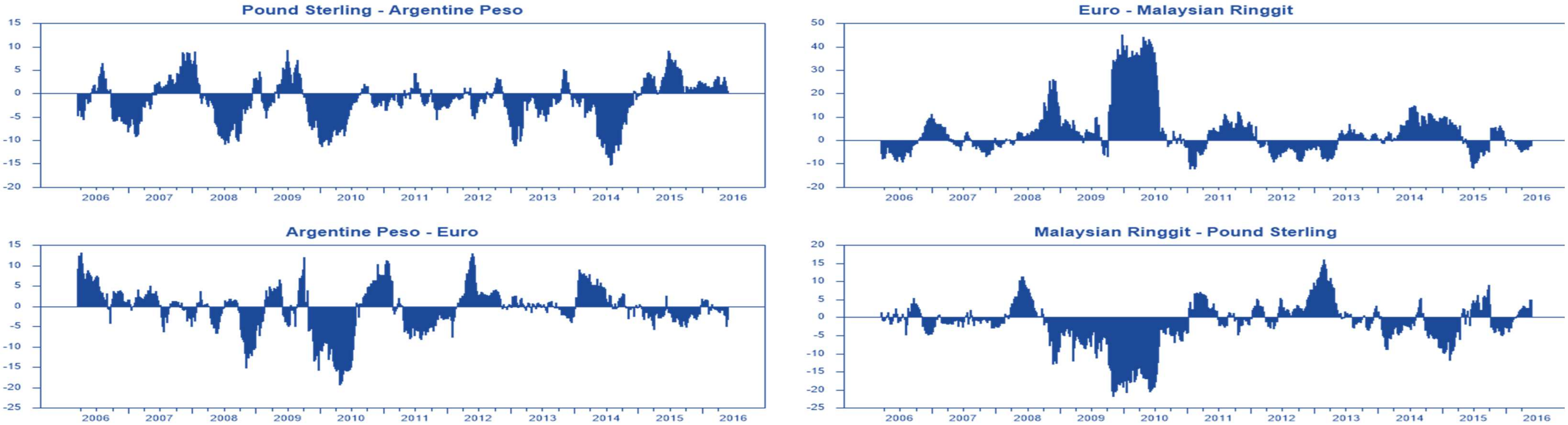
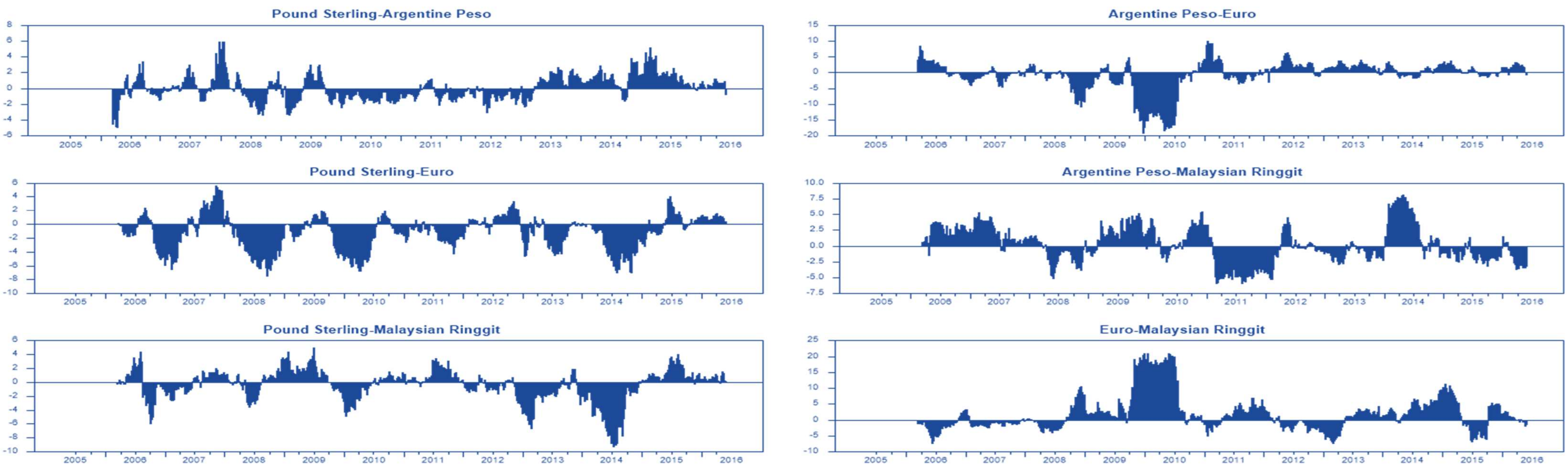



**Figure 9: Net Pairwise Volatility Spillovers,GBP ARS EUR MYR**



## 8. Conclusion

The critical question was whether the effects of return and volatility spillovers are bidirectional between developed and developing countries. Thus, in this paper, we examined the impact of return and volatility spillovers on global foreign exchange markets across developed and developing countries. Quoted against the U.S. dollar, the data sample comprises twenty-three global currencies across developed and developing countries. Seven out of which are the most actively traded globally, including the British Pound (GBP), Euro (EUR), Australian Dollar (AUD), Swiss Franc (CHF), Icelandic Krona (ISK), Czech Republic Koruna (CZK), Hong Kong Dollar (HKD). We discussed the effect of return and volatility spillovers between developed and developing countries, using the generalised vector autoregressive (VAR) methodology. Thus, we provide the empirical results of the spillover index, in the form of static analysis of 'the spillover tables', as well as a dynamic analysis in the form of 'spillover plots'. We also discussed the time-varying volatility spillover among developed and developing countries; using autoregressive conditional heteroskedasticity (ARCH).

During the years of the sample investigation (2005 – 2016), several exciting economic events reveal the magnitude and extent of the volatility spillover's effect across global foreign exchange markets. In particular, from the perspective of the recent financial markets' interconnectedness. Nevertheless, the findings do not disclose evidence of bidirectional spillover between developed and developing countries. However, we find non-negligible evidence of unidirectional spillovers (Table 4) from developed to developing countries. We also find that developed countries act as a receiver and transmitter of volatility, dominated by the British pound (GBP), Australian dollar (AUD), and the Euro (EUR), whereas developing countries are a net receiver of volatility.

Furthermore, the empirical results conclusively show that the magnitude and extent of the return and volatility spillovers are significantly large within the European region (Eurozone and non-Eurozone currencies). In particular, during crisis episodes, whereby the volatility spillover replicates remarkable bursts.

This phenomenon is in line with the findings presented by Glick and Rose (1998); and Yarovaya et al. (2015) that the currency crises tend to be regional. From a policy point of view, this paper documents significant macroeconomic implications. Firstly, the extent of global foreign exchange markets' volatility channel, highlights the significance of contagion and systemic risk, particularly from the globally systemically important financial institutions. Secondly, the substantial return spillover between developed countries, especially within the European region (Eurozone and non-Eurozone currencies) further quantify the importance of cross-market linkages and the recent financial innovations. In addition, it opens avenues for a better understanding of the potential crisis of a highly interlinked nature, mirrored in the historical economic events.

Overall, this paper contributes to the literature of intra-foreign exchange markets' channel, from the perspective of developed and developing countries. Here, the empirical results show that the spillover channels between developed and developing countries are insignificant. However, this raises the question of how the recent financial turmoil (which affected both developed and developing countries) propagated across the global economies.

## 9. Study limitations and future research

Examining the spillover effects between developed and developing countries over 2005 – 2016 is not a key limitation; since we are mainly interested in the time pre-and-post the 2008 financial crisis. Thus, in this paper, we investigate the effect of return and volatility spillovers during bad times; between developed and developing countries, i.e. crises period. A functional area for future research is to examine the magnitude and extent of return and volatility spillovers during good times between developed and developing countries. Since, after the years of our study period (2005 -2016), new exciting economic events happened. Our findings show that volatility spillover is significantly associated with financial crises and economic events. From the viewpoint of policymakers, the high level of financial interconnectedness within the European countries is of extreme concern.

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