Modelling Return and Volatility Spillovers in Global Foreign Exchange Markets

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Abstract

In this paper, we measure return and volatility spillovers in global foreign exchange (FX) markets using six most traded currency pairs in the world namely the \textit{aussie, cable, euro, gropher, loonie} and \textit{swissie}. We employ the Diebold and Yilmaz (2012) approach and consequently, we compute Total Spillover, Directional Spillover and Net Spillover indexes. We utilize daily data from January 01 1999 to December 31, 2014. We also carry out rolling sample analyses in order to capture secular and cyclical movements in global FX markets. We find evidence of interdependence among the major traded currency pairs based on the spillover indexes. In addition, return spillovers exhibit mild trends and bursts while volatility spillovers exhibit significant bursts but no trends. We also identify crisis episodes that seem to have influenced the recorded fluctuations in returns and volatilities of global FX markets. Our results are robust to the VAR lag structure, forecast horizon and rolling window width.

Keywords: FX market, Returns, Volatilities, Vector autoregression (VAR), Forecast error variance, Spillover index

JEL Classification: Q54, F31, G15
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1.0 Introduction

The wave of financial integration globally has continued to deepen owing to the rapid technological advances which have significantly enhanced the processing of financial services across borders. For instance, advances in computer hardware and software have dramatically reduced the costs of collecting and analyzing data, initiating and confirming transactions, clearing and settling payments, and monitoring financial flows (Herring, 1994). While the integration of domestic financial markets with the international financial markets facilitates trade among nations; the associated risks and uncertainties have remained a major concern. Schmukler (2004) outlines some of the areas of controversies in the literature particularly those relating to the risks associated with financial globalization. More prominently, when financial markets become more internationally integrated, the chances of spillover effect or contagion effect become more eminent. The global financial crisis seems to lend support to this argument. Earlier cases include the 1997–98 Asian and Russian crises, as well as those in Brazil 1999, Ecuador 2000, Argentina 2001, Turkey 2001, and Uruguay 2002 (see Schmukler, 2004). Agenor (2003) also documents the various benefits and costs of international financial integration and the paper also complements recent studies in arguing that financial integration must be carefully prepared and managed to ensure that the benefits outweigh the short-run risks. One way of minimizing short run risks is to provide information about the probable spillover effects between financial markets in order to guide both investors and policy makers in decision making.

Generally, the benefits of measuring these spillovers are three-fold. First, information about the intensity of these spillovers provides useful insights to portfolio investors on how to diversify their portfolio investments in order to minimize risks and by extension maximize returns. Second, policy makers require this information to identify and deal with any financial market that is more susceptible to higher risks and uncertainties. Thirdly, they can also serve as early warning signs for any untoward event in the financial markets.

In the literature, analysis of spillover effects is not new. The literature can be partitioned into two strands. On one hand are studies dealing with identical financial assets (see for
example in the last five years, Kenourgios et al., 2011; Syllignakis, 2011; Giovannetti and Velucchi, 2013; Jeon and Jang, 2014; Sugimoto et al., 2014; Tsai, 2014; and Aloui et al., 2015 focus on equity market only; while Antonakakis and Vergos, 2013; Claeys and Vašicˇek, 2014; and Fernández-Rodríguez et al. 2015 cover bond market only). On the other hand are studies that involve spillovers across different asset classes. For instance, there are studies dealing with bond and equity markets (see for example, Steeley, 2006; Dean et al., 2010; Zhang et al., 2013; and Cenedese and Mallucci, 2015); while studies like Browne and Cronin, 2012; Wahyudi and Sani, 2013; and Cronin, 2014 examine spillovers between equity and money markets. There is also evidence of spillover analyses among three different asset classes (see Flemming et al., 1998 and Nguyen and Nguyen, 2014 covering bond, equity and money markets and Kal et al. 2015 dealing with bond, currency and equity markets). Diebold and Yilmaz (2012) also consider four different financial markets involving bond, currency, equity and commodity markets while Liow (2015) extends the work of the latter to include real estate.

Our interest in the analysis of spillovers in foreign exchange market is strengthened by some striking features of the market. A foremost writer on currency trading, Boris Sclossberg highlights some of the attractions to the analysis of spillovers in currency market as follows. Forex market is the largest financial market in the world and it is the most liquid and fluid market in the world. It trades 24 hours a day from 5pm EST Sunday to 4pm EST Friday and it rarely has any gaps in price. Its sheer size and scope (from Asia to Europe to North America) makes the currency market the most accessible market in the world.\(^1\)

Motivated by these attractions, this study measures the return and volatility spillovers in global foreign exchange (FX) markets using most traded currency pairs in the world. Kavli and Kotzé (2014) and Ozer-Imer and Ozkan (2014) document the prominent studies dealing with currency markets. More noticeably, they highlight the currency markets captured in these studies as well as the methodological approaches employed. However, most of the studies are limited in terms of their scope such as the exchange rates analyzed, countries/regions covered, the shocks/ crisis episodes examined and the methodology employed. For example, Ozer-Imer and Ozkan (2014) examine the impact of global financial crisis on exchange rate spillovers while Boero et al. (2011) analyze the structure of exchange rates before and after the introduction of the euro. Also, McMillan et al. (2010) focus on three euro exchange rates; Kavli and Kotzé (2014) capture emerging market currencies; Bubák et al. (2011) deal with emerging European

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\(^1\) Find Boris Schlossberg article at: [http://www.investopedia.com/articles/forex/06/sevenfxfaqs.asp](http://www.investopedia.com/articles/forex/06/sevenfxfaqs.asp)
foreign exchange markets while Kitamura (2011) consider the spot rates of the Euro, Yen and Swiss franc.

Our study extends the exiting literature in the following ways: (i) we focus majorly on the most traded currency pairs in the world that account for more than 95% of all speculative trading in global Foreign exchange; (ii) we deal with both return and volatility spillovers among the currency pairs; (iii) we compute the various spillover indices using the Diebold and Yilmaz (2012) approach that allows us determine the extent of interdependencies among the currency pairs; and (iv) we capture the various secular and cyclical events that may have influenced the magnitude of return and volatility spillovers among the selected currency pairs using rolling sample analyses.

The currency pairs considered for the analysis are The Australian Dollar and US Dollar (AUD/USD) (nicknamed ‘aussie’), The British Pound and US Dollar (GBP/USD) (nicknamed ‘cable’), The Euro and US Dollar (EUR/USD) (nicknamed ‘euro’), The US Dollar and Canadian Dollar (USD/CAD) (nicknamed ‘loonie’), The US Dollar and Japanese Yen (USD/JPY) (nicknamed ‘gropher’), and The US Dollar and Swiss Franc (USD/CHF) (nicknamed ‘swissie’). These currency pairs, along with their various combinations (such as EUR/JPY, GBP/JPY and EUR/GBP) have continued to drive all speculative trading in global FX. Due to the volume of foreign exchanges of these currency pairs, they are more likely to be susceptible to higher risks and uncertainties than the less traded currencies.

As noted, we utilize the novel approach of Diebold and Yilmaz (DY hereafter) (2012) to quantify the spillovers. In addition to its less computational requirements, the different episodes characterizing the behaviour of spillovers over time can be traced using this approach. The underlying multivariate framework for the implementation of DY (2012) is the Vector Autoregressive (VAR) models and the variance decompositions form the basis for the computation of the spillovers. In actual fact, this approach was first proposed by DY (2009); however, the variance decompositions generated are sensitive to the ordering of the variables as they are based on Cholesky factorization. In order to circumvent this problem, DY (2012) exploit the generalized VAR framework of Koop, Pesaran, and Potter (1996) and Pesaran and Shin (1998), hereafter KPPS, which produces variance decompositions which are invariant to the ordering.

In terms of application, the use of the revised DY methodology in dealing with market spillovers is just emerging since the approach itself is still very much recent. In addition

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2 This statement is ascribed to Boris Schlossberg at: http://www.investopedia.com/articles/forex/06/sevenfxfaqs.asp
to the applications rendered by DY, the few notable studies that have adopted the methodology include Antonakakis (2012), Louzis (2012), Awartani and Maghyereh (2013), Conefrey and Cronin (2013), Duncan and Kabundi (2013), Sugimoto et al. (2013), Fernández-Rodríguez et al. (2015), and Nishimura et al. (2015).

In Section 2, we describe DY (2012) approach for the computation of return and volatility spillovers. Some preliminary analyses involving descriptive statistics and graphical illustrations are provided in Section 3. In Section 4, we present and discuss the Spillover tables while rolling window analyses are rendered in Section 5 to complement the spillover tables. Thereafter, some robustness checks are carried out in Section 6 and we conclude the paper in Section 7.

2.0 The Diebold – Yilmaz (2012) Approach

The underlying framework for the spillover analysis is the generalized vector autoregressive (VAR) model of KPSS which is invariant to variable ordering. Essentially, four different spillover types can be generated using the DY (2012) and they are Total Spillovers, Directional Spillovers, Net Spillovers and Net Pairwise Spillovers. In setting up the spillover indexes, a covariance stationary VAR (p) is considered (see pages 159-160 of DY, 2009 and pages 58-59 of DY, 2012).

\[ r_t = \Phi r_{t-1} + \varepsilon_t; \quad \varepsilon_t \sim (0, \Sigma) \]  

where \( r_t = (r_{1t}, r_{2t}, ..., r_{Nt})' \) is an \( N \times 1 \) vector of return/volatility series, \( \Phi \) is an \( N \times N \) matrix of parameters, \( \varepsilon_t \) is a vector of independently and identically distributed disturbances and \( \Sigma \) is the variance matrix for the error vector \( \varepsilon \). The moving average representation can be written as:

\[ r_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} \]

where \( A_i \) is assumed to obey the recursion \( A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p} \). \( A_0 \) is an identity matrix with an \( N \times N \) dimension and \( A_i = 0 \) for \( i < 0 \). Equation (2) forms the basis for the derivation of variance decompositions required to determine the spillover indexes. Before providing the representations for the various indexes, the following preliminary considerations are important:

1. Own variance shares are defined as the fractions of the H-step-ahead error variances in forecasting \( r_t \) that are due to shocks to \( r_s \) for \( i = 1, 2, ..., N \).

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See Diebold and Yilmaz (2012) for a detailed exposition of the methodology.
2. Cross variance shares or spillovers are defined as the fractions of the H-step-ahead error variances in forecasting $r_i$ that are due to shocks to $r_j$, for $i, j = 1, 2, \ldots, N$, such that $i \neq j$.

3. Based on the generalized VAR framework of KPPS, $H$-step-ahead forecast error variance decompositions denoted by $\theta^g_{ij}(H)$ is written as:

$$
\theta^g_{ij}(H) = \frac{\sigma^{-1}_{ij} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_j)}
$$

(3)

where $\sigma_{ij}$ is the standard deviation of $\epsilon$ for the $j$th equation and $e_i$ is the selection vector, with one as the $i$th element and zeros otherwise.

4. Since the sum of the contributions to the variance of the forecast error is not equal to one – that is $\sum_{j=1}^{N} \theta^g_{ij}(H) \neq 1$; DY (2012) normalized each entry of the variance decomposition matrix by the row sum in order to use the full information of the matrix. The normalized KPPS $H$-step-ahead forecast error variance decompositions represented by $\tilde{\theta}^g_{ij}(H)$ is expressed as:

$$
\tilde{\theta}^g_{ij}(H) = \frac{\theta^g_{ij}(H)}{\sum_{j=1}^{N} \theta^g_{ij}(H)}
$$

(4)

where $\sum_{j=1}^{N} \tilde{\theta}^g_{ij}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H) = N$ by construction.

Given these preliminaries, the total spillover index is written as:

$$
S^g(H) = \frac{\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H)} \times 100 = \frac{\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H)}{N} \times 100
$$

(5)

All the parameters in equation (5) have been previously defined. Essentially, equation (5) measures the contribution of spillovers of return/volatility shocks across the assets under consideration. In our case, the total spillover index captures the contribution of spillovers of return/volatility shocks across the six (6) global FX markets to the total forecast error variance.

Also, it is possible to assess quantitatively the direction of spillovers across the six global FX markets using the DY (2012) approach. These directional spillovers are classified into two namely ‘Directional Spillover To’ and ‘Directional Spillover From’. The former measures the directional spillovers whether return or volatility transmitted by
market $i$ to all other markets $j$ while the latter relates to return or volatility received by market $i$ from all other markets $j$. The index for the computation of ‘Directional Spillover To’ denoted by $S^g_i$ is given as:

$$S^g_i(H) = \frac{\sum_{j=1}^{N} \tilde{\theta}^g_{ji}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}^g_{ji}(H)} \times 100 = \frac{\sum_{j=1}^{N} \tilde{\theta}^g_{ji}(H)}{N} \times 100$$  \hspace{1cm} (6)$$

Also, the ‘Directional Spillover From’ denoted as $S^g_i$ is measured using the index given below:

$$S^g_i(H) = \frac{\sum_{i=1}^{N} \tilde{\theta}^g_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H)} \times 100 = \frac{\sum_{i=1}^{N} \tilde{\theta}^g_{ij}(H)}{N} \times 100$$  \hspace{1cm} (7)$$

Equally, the Net Spillovers can be obtained using the index expressed below:

$$S^g_i(H) = S^g_i(H) - S^g_i(H).$$  \hspace{1cm} (8)$$

Equation (8) gives the difference between the gross return/volatility shocks transmitted to and received from all other markers. In other words, information about each market’s contribution to the return/volatility of other markers can be obtained through the net spillovers.

In our analysis, we consider a second order 6-variable VARs with 10-step-ahead forecasts. Relevant diagnostics are also rendered to validate the robustness of our results.\(^4\)

### 3.0 Data and Preliminary Analyses

A statistical analysis of returns and volatilities of the considered currency pairs is rendered here in order to elicit their statistical properties. We adopt daily data over a sixteen year period from 01/01/1999 to 31/12/2014 which are freely downloadable from the database of Forex Forum Global View (www.global-view.com/forex-trading-tools/forex-history/). The returns of the series ($r_t$) are computed as the first

\(^4\) The program used to compute the spillovers is available on request.
difference of the natural logarithm of the level series \( P_t \); this is expressed in equation (1) below:

\[
r_t = 100^* \left[ \Delta \log(P_t) \right]
\]

Where \( r_t \) represents the calculated exchange rate returns, \( P_t \) is the level exchange rate, and \( \Delta \) is the first difference lag operator. Thus, positive/negative returns will represent depreciation/appreciation of the quoted currency relative to the base currency. Meanwhile, the volatility series is obtained from the estimation of GARCH(1,1) model

\[
\hat{\sigma}_t^2 = \omega + \alpha \hat{\sigma}_{t-1}^2 + \beta \hat{\sigma}_{t-1}^2
\]

The summary statistics for the two series are presented in Tables 1 and 2.

Table 1: Summary Statistics for log returns of six major currency pairs (full sample)

<table>
<thead>
<tr>
<th>Statistics</th>
<th>EUR/USD</th>
<th>USD/JPY</th>
<th>USD/CHF</th>
<th>GBP/USD</th>
<th>USD/CAD</th>
<th>AUD/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.000743</td>
<td>0.001268</td>
<td>-0.00776</td>
<td>-0.00152</td>
<td>-0.00669</td>
<td>0.00709</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.676302</td>
<td>3.831966</td>
<td>9.195039</td>
<td>8.724579</td>
<td>3.273668</td>
<td>5.632588</td>
</tr>
<tr>
<td>Minimum</td>
<td>-2.81808</td>
<td>-4.58288</td>
<td>-5.01157</td>
<td>-8.32348</td>
<td>-4.33465</td>
<td>-10.0619</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.627112</td>
<td>0.655254</td>
<td>0.684765</td>
<td>0.585388</td>
<td>0.553243</td>
<td>0.828405</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.006212</td>
<td>-0.14729</td>
<td>0.466701</td>
<td>-0.10768</td>
<td>0.142307</td>
<td>-0.85743</td>
</tr>
<tr>
<td>Observations</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
</tr>
</tbody>
</table>

Source: Compiled by the authors

Table 1 presents the descriptive statistics for the return series of all the currency pairs over the full sample period. The mean in the table represents the average returns of each currency pair over the considered time period. On average, three out of the six exchange rate pairs namely; EUR/USD, USD/JPY and AUD/USD have positive average returns which imply the EUR and the AUD depreciated against the USD while the JPY appreciated against the USD. On the other hand, the USD/CHF, GBP/USD and the USD/CAD all have negative average returns and this implies that the USD appreciated against the CHF and CAD while the GBP appreciated against the USD. The behaviour of the return series is further analysed using graphical illustrations (see Figure 1). Figure 1 depicts that USD appreciated against EUR, CHF, CAD and AUD consistently over the period under consideration while the trend appears mixed for GBP and JPY. This observation is also consistent with the computed descriptive statistics. The GBP depreciated against USD before the global financial crisis and thereafter became relatively stronger than the latter. However, the JPY/USD seems to follow an unsteady pattern although USD gained more appreciation against JPY over the period under consideration.
The maximum and minimum values including the skewness and kurtosis statistics of the currency pairs’ returns are also presented. The return series of all the currency pairs are skewed with the exemption of the EUR/USD which appears symmetrical around the mean with the skewness statistics of 0.006. However, while the USD/CHF and the USD/CAD are positively skewed, the USD/JPY, GBP/USD and AUD/USD are negatively skewed. The kurtosis statistics also reveal that the return series of all currency pairs are highly peaked or leptokurtic.

Table 2: Summary Statistics for the volatility of six major currency pairs (full sample)

<table>
<thead>
<tr>
<th>Volatility Series</th>
<th>EUR/USD_VOL</th>
<th>USD/JPY_VOL</th>
<th>USD/CHF_VOL</th>
<th>GBP/USD_VOL</th>
<th>USD/CAD_VOL</th>
<th>AUD/USD_VOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.98E-05</td>
<td>4.37E-05</td>
<td>4.79E-05</td>
<td>3.51E-05</td>
<td>3.02E-05</td>
<td>6.87E-05</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.000193</td>
<td>0.000242</td>
<td>0.000508</td>
<td>0.000607</td>
<td>0.000270</td>
<td>0.001295</td>
</tr>
<tr>
<td>Minimum</td>
<td>7.56E-06</td>
<td>1.39E-05</td>
<td>9.64E-06</td>
<td>8.23E-06</td>
<td>8.75E-06</td>
<td>1.42E-05</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>2.30E-05</td>
<td>2.44E-05</td>
<td>3.56E-05</td>
<td>3.99E-05</td>
<td>2.75E-05</td>
<td>0.000104</td>
</tr>
<tr>
<td>Skewness</td>
<td>2.198647</td>
<td>2.898515</td>
<td>5.221791</td>
<td>6.557676</td>
<td>4.066067</td>
<td>7.612949</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>10.41644</td>
<td>15.49616</td>
<td>46.62434</td>
<td>64.02680</td>
<td>25.65225</td>
<td>71.56589</td>
</tr>
<tr>
<td>Obs.</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
<td>4170</td>
</tr>
</tbody>
</table>

Source: Compiled by the authors

Table 2 shows the descriptive statistics for the volatility series of all the currency pairs under the whole sample period. Drawing from figure 2, all the six currency pairs are volatile (though some are more volatile than others) with evidence of volatility clustering, i.e., periods of high volatility are followed by periods of relatively low volatility. Also, virtually all these currency pairs exhibit notable spikes that coincide with the global financial crisis and the sovereign debt crisis expect for the GBP/USD_VOL (with notable spike around 2001 as a result of 9/11 terrorist attack in the US) and the USD_JPY_VOL with mixed behaviour. The average unpredictability nature of each currency pair is captured by the mean in table 2. The USD/CAD_VOL has the least mean value while the AUD/USD-VOL has the highest mean value. In terms of deviation from the mean, the EUR/USD_VOL has the least value followed by the USD/JPY_VOL, USD/CAD_VOL, USD_CHF_VOL, GBP/USD_VOL and AUD/USD_VOL in ascending order. Thus, the AUD/USD is more volatile than others judging by the standard deviation. In addition, all the volatility series are positively skewed and have fat tails.
Figure 1: Combined graph for currency pairs and their returns
Figure 2: Volatility graph for currency pairs
4.0 Analysis of Spillover Tables

The DY approach is usually partitioned into two namely the Spillover Tables and the Rolling Window Analyses. The former produces a single-fixed (scalar) value for each of the indices over the period of interest. This may be useful where the interest is to estimate the aggregate spillovers over a particular period of time. However, a deeper and intuitive result can be obtained where unprecedented events characterizing the behaviour of the spillovers are reflected in the analysis. This is the essence of the rolling window analyses. Thus, the latter complements the former as it unveils the cyclical and secular movements explaining the behaviour of the spillovers from one period to another.

Here, we analyze the spillover tables for both returns and volatilities of the global FX markets (see Tables 3 and 4 respectively). Table 3 presents the return spillovers computed for the whole sample based on a second order 6-variable VARs with 10-step-ahead forecasts. The off-diagonal column sums give the “contribution to others” while the off-diagonal row sums provide the “contribution from others”. Both are directional spillovers where “Directional spillovers to” is represented by “contribution to others” while “Directional spillovers from” is denoted by “contribution from others” in both tables. Thus, each element in each column, other than the main diagonal elements, captures individual market’s contribution to the forecast error variance of other markets. In the same vein, each element in each row, excluding the main diagonal elements, measures the amount of contributions of other markets to the forecast error variance of a particular market under consideration. Technically, “contribution to others” measures the total contribution of shocks to a particular market to the forecast error variance of other markets while “contribution from others” measures the total contribution of shocks to other markets to the forecast error variance of a particular market. In essence, the spillover table is analogous to the input-output table as it shows how shocks are absorbed and transmitted within the system under consideration.

The net spillovers are obtained by subtracting the “contribution from others” from “contributions to others” or vice versa. In other words, the net spillovers reflect the difference between the contribution a market gives to and receives from others. Using the former definition, a positive magnitude is an indication that the market under consideration has a greater influence in other markets than the influence it receives from them. This makes the market under consideration less vulnerable to external shocks. Conversely, a negative magnitude implies that the market under examination is more vulnerable to shocks to other markets. Furthermore, the total spillover index is presented in the lower right corner of the spillover table and it is computed by expressing the sum of “contributions to others” (or the sum of “contributions from others”) as a percentage of sum of “contributions including own”. This renders the
various directional spillovers into a single index; therefore, it effectively captures the total spillovers transmitted among the markets under consideration.

Let us now proceed to the interpretation of the spillover table for the return series (see Table 3).\(^5\) Starting with individual directional spillovers from others, the swissie records the highest contribution to the forecast error variance of the euro returns with about 26.7% followed by the cable with about 14%. Thus, shocks to the swissie are more likely to affect the behaviour of the euro returns than shocks to other major FX markets in the world. Interestingly and expectedly too, shocks to the euro have greater impact on the forecast error variance of the swissie returns than shocks to other FX markets considered. The euro explains about 29.7% of the forecast error variance of the swissie returns and distantly followed by the cable with 11.2%. Also, although relatively smaller compared to the euro and the swissie FX markets, the forecast error variance of the cable returns is more influenced by shocks to the euro with about 17.7% and closely followed by the swissie and the aussie with about 12.7% and 11.7% respectively. In the case of the loonie returns however, the contribution from other markets to its forecast error variance is dominated by the aussie with 20.3% and distantly followed by the euro with 10.2%. Like the loonie returns, the contribution of other markets to the forecast error variance of the aussie returns is largely captured by the loonie with about 17.9% and closely followed by the euro as well with about 14.2%. The gropher market however receives the lowest contribution from other markets with the swissie having the highest with about 10.7% and followed by the euro with about 4.7%. Thus, bidirectional spillovers seem more evident between the swissie and the euro as well as between the aussie and the loonie than any other FX market pairs. On the whole however, the euro returns receive the highest contribution from others with about 61% and followed closely by the swissie, cable and aussie returns with contributions of about 57%, 51% and 51% respectively while the loonie receives about 44%, the gropher records the lowest contributions from others. In other words, shocks to other markets account for greater percentage of the forecast error variances of the euro, swissie, cable and aussie markets than their own shocks while the forecast error variances of the loonie and gropher are substantially explained by their own shocks. Intuitively, the euro, swissie, cable and aussie are more vulnerable to return shocks of Global FX markets than other currency pairs in the world.

Quite similar to the gross directional spillovers from others, shocks to the euro have greater impact on other global FX markets than any other FX market. Following the euro in terms of influence in the global FX markets are the swissie, aussie, cable and loonie in that order while the impact of the gropher seems minimal. In essence, the global FX markets are also vulnerable to the return shocks of the euro, swissie, cable and aussie. In relation to the net spillovers, positive values are recorded for both the euro and swissie

\(^5\) For convenience, we adopt the nicknames of the selected currency pairs. Note that AUD/USD is the aussie, GBP/USD is the cable, EUR/USD is the euro, USD/CAD is the loonie, USD/JPY is the gropher and USD/CHF is the swissie.
although the former is higher (about 16%) than the latter (about 5%) while other currency pairs considered have negative net spillovers. This suggests that the euro and swissie give more than they receive in the global FX markets while others (the cable, aussie, loonie and gropher) give less than they receive. This finding further strengthens the significance of the euro and swissie returns in the global FX markets.

Looking at the total spillover index, the computed value is 46.9% which is an indication that slightly less than half of the total variance of the forecast errors during the sample is explained by shocks across the currency pairs, whereas the remaining 53.9% is explained by idiosyncratic shocks.
Table 3: Return Spillovers of Global FX Markets from May 1999 to Dec. 2014.

<table>
<thead>
<tr>
<th>FROM</th>
<th>EUR_USD</th>
<th>USD_JPY</th>
<th>USD_CHF</th>
<th>GBP_USD</th>
<th>USD_CAD</th>
<th>AUD_USD</th>
<th>Contribution from others</th>
<th>Net Spillover</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR_USD</td>
<td>38.8</td>
<td>2.3</td>
<td>26.7</td>
<td>14.0</td>
<td>7.1</td>
<td>11.2</td>
<td>61</td>
<td>16</td>
</tr>
<tr>
<td>USD_JPY</td>
<td>4.7</td>
<td>82.5</td>
<td>10.7</td>
<td>1.8</td>
<td>0.0</td>
<td>0.2</td>
<td>18</td>
<td>-9</td>
</tr>
<tr>
<td>USD_CHF</td>
<td>29.7</td>
<td>5.7</td>
<td><strong>43.3</strong></td>
<td>11.2</td>
<td>4.0</td>
<td>6.2</td>
<td>57</td>
<td>5</td>
</tr>
<tr>
<td>GBP_USD</td>
<td>17.7</td>
<td>1.2</td>
<td>12.7</td>
<td><strong>49.2</strong></td>
<td>7.6</td>
<td>11.7</td>
<td>51</td>
<td>-4</td>
</tr>
<tr>
<td>USD_CAD</td>
<td>10.2</td>
<td>0.2</td>
<td>5.3</td>
<td>8.4</td>
<td><strong>55.7</strong></td>
<td>20.3</td>
<td>44</td>
<td>-7</td>
</tr>
<tr>
<td>AUD_USD</td>
<td>14.2</td>
<td>0.1</td>
<td>7.1</td>
<td>11.6</td>
<td>17.9</td>
<td><strong>49.1</strong></td>
<td>51</td>
<td>-1</td>
</tr>
<tr>
<td>Contribution to others</td>
<td>77</td>
<td>9</td>
<td>62</td>
<td>47</td>
<td>37</td>
<td>50</td>
<td>282</td>
<td></td>
</tr>
<tr>
<td>Contribution including own</td>
<td>115</td>
<td>92</td>
<td>106</td>
<td>96</td>
<td>92</td>
<td>99</td>
<td>Spillover index: 46.9%</td>
<td></td>
</tr>
</tbody>
</table>

Source: Compiled by the authors

Table 4: Volatility Spillovers of Global FX Markets from May 1999 to Dec. 2014.

<table>
<thead>
<tr>
<th>FROM</th>
<th>EUR_USD</th>
<th>USD_JPY</th>
<th>USD_CHF</th>
<th>GBP_USD</th>
<th>USD_CAD</th>
<th>AUD_USD</th>
<th>Contribution from others</th>
<th>Net Spillover</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR_USD</td>
<td>67.7</td>
<td>4.4</td>
<td>9.6</td>
<td>4.1</td>
<td>6.1</td>
<td>8.0</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>USD_JPY</td>
<td>5.7</td>
<td><strong>77.6</strong></td>
<td>1.0</td>
<td>0.8</td>
<td>1.4</td>
<td>13.6</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>USD_CHF</td>
<td>13.8</td>
<td>1.2</td>
<td><strong>82.1</strong></td>
<td>0.9</td>
<td>1.5</td>
<td>0.5</td>
<td>18</td>
<td>-6</td>
</tr>
<tr>
<td>GBP_USD</td>
<td>1.3</td>
<td>0.3</td>
<td>0.1</td>
<td><strong>96.4</strong></td>
<td>1.0</td>
<td>0.9</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>USD_CAD</td>
<td>6.5</td>
<td>5.1</td>
<td>0.8</td>
<td>0.7</td>
<td><strong>64.9</strong></td>
<td>21.9</td>
<td>35</td>
<td>-18</td>
</tr>
<tr>
<td>AUD_USD</td>
<td>5.1</td>
<td>11.1</td>
<td>0.6</td>
<td>0.8</td>
<td>7.5</td>
<td><strong>74.8</strong></td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Contribution to others</td>
<td>32</td>
<td>22</td>
<td>12</td>
<td>7</td>
<td>17</td>
<td>45</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Contribution including own</td>
<td>100</td>
<td>100</td>
<td>94</td>
<td>104</td>
<td>82</td>
<td>120</td>
<td>Spillover index: 22.7%</td>
<td></td>
</tr>
</tbody>
</table>

Source: Compiled by the authors
Table 4 presents the volatility spillovers over the full sample period. The distribution of the spillovers slightly differs from the return spillovers reported in table 3. Unlike returns, the directional volatility spillovers from and to other markets are quite low and below the average for all the currency pairs. Therefore, a large amount of return spillovers may not necessarily imply a large amount of volatility spillovers. Nonetheless, on the basis of the reported volatility spillovers, the loonie seems to be most vulnerable to volatility shocks of other markets followed by the euro, aussie, gropher and swissie while the cable has the least vulnerability and less risky relative to others. The spillover index of about 22.7 percent for the volatility is also smaller than the returns. This suggests that the return volatility for the individual currency pairs is driven by exogenous factors which are not captured in the VAR system used. Related existing studies have suggested that the inclusion of oil price and stock into a diversified portfolio of FX will improve its risk-adjusted return performance (see Ulku and Demirici, 2012 and Salisu and Mobolaji, 2013 for a review). Notwithstanding, the spillover indexes of 22.7 percent and 46.9 percent for volatility and return spillovers respectively suggest some level of interdependence among the major currency pairs in the world. In the section that follows, we consider a more robust framework for the evaluation of spillovers in the global FX markets.

5.0 Rolling-Sample Analysis

Although, the spillover table and index with other relevant discussions examined above have given an overview of the “average” spillover behaviour in the global FX market, it is however inadequate in capturing “important secular and cyclical movements in spillovers” (Diebold and Yilmaz, 2012). In light of this, we propose a rolling window framework using 200-day sub-sample rolling windows in order to address these inadequacies and properly capture events or crises episodes that may have occurred during the period under consideration.

The resultant plots for total spillover indexes for both returns and volatilities are presented in figures 3 and 4 respectively. Both total spillovers start at a value above 35 percent with volatility spillover slightly higher than return spillover in the first window. The total return spillover plot reveals that spillover effects across the major currency pairs were quite high fluctuating between 30 percent and 70 percent with an exception in 2005 where it exceeded the 70 percent mark. However, the total volatility spillover mostly varied between 30 percent and 60 percent with an important exception in mid-2008 which was prominently characterized by the global financial crisis era. The total return and volatility spillovers steadily fell below 35 percent between late 1999 and early 2000 as the world celebrated the turn of the new millennium. In the first half of 2001, both currency return and volatility spillovers declined to almost 30 percent with the indexes increasing to about 50 percent and 40 percent respectively in the second half of 2001. These sudden changes could be attributed to the internet bubble and the
swearing in of a new U.S president during this period. However, the return and volatility spillover indexes plunged to about 37 percent and 32 percent which is traceable to the U.S terrorist attacks in the same year.

Following the introduction of the Euro (€) into circulation in January 2002, both total spillover indexes recorded a significant upward movement from early 2002 to the last quarter of the year. In 2003, there was a plunge from about 57 percent to 48 percent in the currency return spillover index while the volatility spillover declined from 54 percent to almost 35 percent following the Iraqi invasion and this later rose in the same year except for a sharp downward movement in the volatility spillover to 30 percent in the mid-2003. After the second half of 2003, currency return spillover effects increased to almost 70 percent while the corresponding volatility climbed to about 55 percent following the reversal in the Fed interest rate policy. The period between early 2004 and late 2006 revealed several up and down movements but of major significance is that of 2007 where there was a significant plunge in the currency spillover index traceable to the global turmoil in the financial market with the currency spillover index falling to less than 45 percent for returns and 35 percent for volatility. Furthermore, this was followed by a series of up and down movements between mid-2007 and second half of 2008 owing to the global financial crisis and various regime changes around the world (France, Great Britain and Russia).

However, both spillover plots reveal a gradual increase after late 2008 probably reflecting the continuous upward trend in oil prices in 2008. This was followed by substantial fluctuations for the rest of the period (i.e. between 2009 and 2014) particularly for the volatility spillovers. For instance, in 2011, the currency return spillover index plunged from 58 percent to 40 percent with the volatility also hitting the bottom in the second half of 2011 owing to the worsening economic crisis in Greece during that period, after which there was a surge between mid- 2011 and the first quarter of 2012 following the occurrence of major sporting events in Europe (Euro 2012 in Poland and Ukraine and the London 2012 Olympics). From a downward slope in 2013, the plots reveal an upward movement in the spillover index which is traceable to various world events such as the World Cup tournaments (hosted by Brazil) and incessant drop in oil prices. In sum, a cursory look at the two graphs depicts that return spillovers exhibit both trends and bursts over the period under consideration while volatility spillovers display significant bursts but no trends.
5.1 Directional Spillovers

Having discussed the total spillover plots in the global currency market, it is however necessary that we examine the direction of spillovers from and to others among the various currency pairs for both returns and volatilities. We start by examining the directional return spillovers presented in figures 5 and 6. Both directional return spillovers to and from others seem to follow similar patterns. The first group involves currency pairs that witnessed somewhat increasing trends from 1999 to 2007 followed by a sharp decline during the crisis period and thereafter, there was a smaller and unsteady increase in the spillovers. The euro, swissie, cable and gropher fall under this category. The second group appears to be the converse of the first group. The spillovers recorded significant increases during the crisis period with a somewhat downward trend afterwards. The loonie and aussie fall under this category. Regardless of the groupings, the two figures suggest substantial directional return spillovers among the
currency pairs. Like the total return spillovers, the directional return spillovers also exhibit both trends and bursts over the rolling window.

Looking at the direction volatility spillovers (see figures 7 and 8), we find a pattern that is similar to the total volatility spillovers. In other words, the directional volatility spillovers also display significant bursts like the total volatility spillovers. All the currency pairs recorded substantial volatility spillovers implying that they are all vulnerable to volatility shocks in the global FX markets.

5.2 Net Spillovers

Examining the net directional spillover effects enables us to detect net transmitters and receivers of spillovers and their contribution to total spillovers. Figures 9 and 10 present the respective net return and volatility spillovers for the currency pairs. As depicted in figure 9, the net spillovers for the grophers and loonie were almost predominantly negative implying that they were mainly net receivers of return spillovers between 1999 and 2014. While the euro and swissie were majorly net spillover transmitters over the entire rolling window, the behaviour of the cable and aussie was mixed. One of the notable distinctions between the latter two is that the cable was a net receiver after the global financial crisis while the aussie was a net spillover transmitter during the same period. In other words, the cable became more vulnerable than the aussie after the global financial crisis. More noticeably, the euro appears to be the highest contributor to return spillovers in the global FX markets followed by the swissie. This further reinforces the results of the spillover table for returns where only the euro and swissie have positive net spillovers on average. However for net volatility spillovers, figure 10 shows that the euro was substantially a net spillover transmitter while the grophers was largely a net spillover receiver. In fact, the only notable positive net spillover for the grophers was recorded during the global financial crisis (2007-2009) and 2011-2012 coinciding with the natural disaster in Japan where 9 earthquakes struck northeast of the country. The net volatility spillovers for the other currency pairs hovered around zero for most parts of the rolling window. However, virtually all of them displayed significant net volatility spillovers during and after the global financial crisis. Some individual specific crisis episodes also evident include the 1999-2000 internet boom (Dotcom bubble); the 2001 terrorist attack in the US; and 2011 global currency crisis being the fall out of the European debt crisis on the euro. In summary, the rolling window analyses unveil substantial return and volatility spillovers for some periods than the others due to some secular and cyclical events as highlighted. These variations are usually not readily visible in the spillover tables. This explains why it is important to complement the spillover indexes with rolling window analyses.
Figure 5: Directional Spillovers to the Individual Return Series
Figure 6: Directional Spillovers from the Individual Return Series
Figure 7: Directional Spillovers to the Individual Volatility Series
Figure 8: Directional Spillovers from the Individual Volatility Series
Figure 9: Net Spillovers for the Individual Return Series

Net Spillovers for REUR_USD

Net Spillovers for RUSD_JPY

Net Spillovers for RUSD_CHF

Net Spillovers for RGBP_USD

Net Spillovers for RUSD_CAD

Net Spillovers for RAUD_USD
Figure 10: Net Spillovers for the Individual Volatility Series
6.0 Robustness Checks

We also render some robustness checks in order to ascertain the reliability of our results. Essentially, we consider the sensitivity of the spillover indexes for both returns and volatilities to VAR lag structure, forecast horizon and rolling window width. Consequently, we consider three scenarios as follows: (i) VAR orders of 2-6; (ii) 5- to 20-day forecast horizons; and (iii) 100- to 250-day rolling window widths. The resulting graphs are presented in figures 11 to 13. As depicted in all these figures, our results for both returns and volatilities are robust to all the considered scenarios. In other words, the calculated spillover indexes for the return and volatility series of the global FX markets are not sensitive to VAR lag structure, forecast horizon and rolling window widths. Figure 11 deals with VAR lag structure, figure 12 relates to forecast horizon while figure 12 captures rolling window width.

Figure 11: Sensitivity of return & volatility spillover indexes to VAR lag structure

![Total Return Spillovers for VAR Orders of 2-6](image1)

![Total Volatility Spillovers for VAR Orders of 2-6](image2)
Figure 12: Sensitivity of return & volatility spillover indexes to forecast horizon

**Total Return Spillovers for Different Forecast Horizons**

![Figure 12: Total Return Spillovers for Different Forecast Horizons](image1)

Figure 13: Sensitivity of return & volatility spillover indexes to rolling-window width

**Total Volatility Spillovers for Different Forecast Horizons**

![Figure 13: Total Volatility Spillovers for Different Forecast Horizons](image2)

**Total Return Spillovers for Different Rolling-Window Widths**

![Figure 13: Total Return Spillovers for Different Rolling-Window Widths](image3)
7.0 Concluding Remarks

This study measures the degree of interdependence in global FX markets using six most traded currency pairs in the world that account for over 95 percent of global forex trading. It employs the novel approach of DY (2012) that facilitates the computation of relevant spillover indexes such as the gross spillover index, directional spillover index and net spillover index. It also complements these single-fixed spillover indexes with rolling-window analyses which seem to be more reliable and realistic. The striking findings of the study can be classified into four. First, we find evidence of cross-market spillovers among the selected currency pairs. Similarly, with the exception of the gropher, the directional spillovers are quite high indicating strong interdependence in the returns of the major traded currency pairs. Intuitively, an unprecedented change in the return of one currency pair is more likely to affect the returns of other major currency pairs. Among these currency pairs however, the euro, swissie, aussie and cable appear to exert more influence on the behaviour of returns of the global FX markets than other major currency pairs. Second, we find relatively lower volatility spillovers compared to the return spillovers over the period under consideration. Nonetheless, on the basis of the reported volatility spillovers, the loonie seems to be most vulnerable to volatility shocks of other markets followed by the euro, aussie, gropher and swissie while the cable has the least vulnerability and less risky relative to others. Third, on the basis of the rolling window analyses, return spillovers exhibit both trends and bursts while volatility spillovers exhibit only bursts although the latter series seems to exhibit more bursts than the former. Fourth, we identify different episodes (both crisis and non-crisis) that characterize the observed fluctuations in returns and volatilities of global FX markets. Overall, our results are robust to the VAR lag structure, forecast horizon and rolling window width.
References


