GLOBAL EQUITY MARKETS' VOLATILITIES AND RETURNS SPILLOVERS:
AN UPDATE TO DIEBOLD AND YIMLAZ (2009)

by

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Abstract

Diebold and Yimlaz, in their paper, published in 2009 and titled *Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets,* provided a simple and intuitive measure of interdependence between markets by measuring the returns and volatilities spillovers of 19 countries' equity markets, an approximation of global equity markets.

The goal of this paper is to extend on the original paper from three perspectives. Firstly, the original paper's results shows markets interdependence results up to 2007, which does not capture the 2008 global financial crisis and its aftermath, and it is very interesting to see what happened during and after such unprecedented crisis, and to see what happened after other major and recent events such as the European sovereign debt crisis. Secondly, this study's dataset adds two key players in the global economy that are having increasing prominence: Saudi Arabia and India, increasing the number of equity markets studied to 22 countries. Thirdly, this paper uses an improved model that avoids identification schemes based on Cholesky factorization, where variance decompositions calculations depend on the ordering of the variables, by using Generalized VAR, an extension they suggested in 2009 and later used in 2012 for the same purpose of this paper but studying interdependence between different asset classes instead.

Keywords: Global Equity Markets; Volatility Spillover; Returns Spillover; Generalized VAR; Global Equity Markets Interdependence

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1: Introduction

1.1: Diebold and Yimlaz Study in 2009[1]

Diebold and Yimlaz attempted to measure financial markets interdependence by measuring historical patterns in volatilities and returns spillovers between global markets. Using a different approach to (VAR) models of Engle *et al.* (1990), in which they focus on variance decomposition, they measured volatilities and returns spillovers from and to each sampled country over time and created total volatility and return indices and showed how they behaved overtime. The results were very interesting as they showed how spillovers react to major world events and how volatilities spillovers and returns spillovers behave differently[2]. This paper also provides the results using their original methodology, which is also explained in Section 2.1.

1.2: Diebold and Yimlaz Study in 2012[3]

In 2012, Diebold and Yimlaz attempted a very similar analysis of interdependence by calculating volatilities and returns spillovers; however, the focus was on interdependence between asset classes in the U.S. instead. In this paper, they innovated on their original approach, which had the problem where the ordering of the variables being an influence on the variance decompositions calculations, by using Generalized VAR of Koop, Pesaran and Potter (1996) and Pesaran and Shin (1998)[4]. This paper shows the results of the 2009 paper using the Generalized VAR method they used in 2012 to compare the difference and, as we will see in more detail in Section 3, the results are very similar.[2]

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[1] Hereafter DY2009

[2] See Figure 1-4 in Diebold and Yimlaz (2009) for historical volatility and return patterns replications.

[3] Hereafter DY2012

[4] Also referred to as Generlized Impulse Response

1.3: Extending the Results to Today

DY2009 results end at November 2007, amid a financial crisis and the beginning of a recessionary period. Therefore, it is very enticing to extend DY2009's findings to today and see what happened to markets interdependence, specifically to returns and volatilities spillovers, after historically significant events such as the 2008 global financial crisis and the Eurozone crisis.

2: Methodology And Data

2.1: DY 2009 Methodology

In DY2009, the authors utilized the known VAR models of Engle *et al.* (1990). However, they focused on variance decomposition, also known as forecast error variance decomposition (FEVD), a well-established calculation that shows each variable's contribution to itself and the other variables[5]. Note that this methodology identifies using Cholesky factorisation, which provide results that are sensitive to the ordering of the variables selected for each country.[6] The methodology is as follows:

Consider a simple covariance stationary first-order simple two[7] variables VAR where:

$$\mathbf{x}_t = \mathbf{\Phi}\mathbf{x}_{t-1} + \boldsymbol{\varepsilon}_t,$$

And

$\mathbf{x}_t = (\mathbf{x}_{1t}, \mathbf{x}_{2t})$ and $\mathbf{\Phi}$ is a 2×2

X is a vector of volatility or returns

By covariance stationarity, a moving average representation exists and is given by

$$\mathbf{x}_t = \mathbf{\Theta}(L)\boldsymbol{\varepsilon}_t,$$

[5] Lütkepohl, H. (2007)

[6] The results were based on vector regression of the second order (using Schwarz criterion).

[7] Two is selected to simplify notation and illustration. The methodology utilizes N-variable VAR.

Where

$\mathbf{\Theta}(L) = (\mathbf{I} - \mathbf{\Phi} L)^{-1}$.

Then the expression is rewritten using Choleski Factorization

$\mathbf{x}_t = \mathbf{A}(L)\, \mathbf{u}_t,$

Where

$\mathbf{A}(L) = \mathbf{\Theta}(L)\mathbf{Q}_t^{-1}, \mathbf{u}_t = \boldsymbol{Q}_t \boldsymbol{\varepsilon}_t, \mathrm{E}(\mathbf{u}_t \mathbf{u}_t') = \mathbf{I}$, and $\mathbf{Q}_t^{-1}$

And $\mathbf{Q}_t^{-1}$ is the unique lower triangular Choleski factor matrix of e_t

Now 1-step forecast using Wiener-Kolmogorov linear least-squares forecast

$\mathbf{x}_{t+1,t} = \mathbf{\Phi}\mathbf{x}_t,$

With 1-step ahead error vector

$$\mathbf{e}_{t+1,t} = \mathbf{x}_{t+1} - \mathbf{x}_{t+1,t} = \mathbf{A}_0 \mathbf{u}_{t+1} = \begin{bmatrix} a_{0,11} & a_{0,12} \\ a_{0,21} & a_{0,22} \end{bmatrix} \begin{bmatrix} u_{1,t+1} \\ u_{2,t+1} \end{bmatrix},$$

And the covariance matrix

$$\mathrm{E}\left(\mathbf{e}_{t+1,t}\mathbf{e}'_{t+1,t}\right) = \mathbf{A}_0\mathbf{A}'_0.$$

The variance of 1 step ahead error in forecasting x_1 is $a_{0,11}^2 + a_{0,12}^2,$

$a^2{}_{0,11}$ are errors due to shocks x_1 to itself, $a^2{}_{0,12}$ are errors in x_1 that are due to shocks in x_2

The spill-over index then is calculated as $(a^2{}_{0,21} + a^2{}_{0,12}) / (a^2{}_{0,21} + a^2{}_{0,12} + a^2{}_{0,11} + a^2{}_{0,22})$

2.2: DY 2012 Methodology

Calculating variance decomposition requires orthogonal innovations, while VAR innovation are contemporaneously correlated. Using identification schemes based on Cholesky we get orthogonal shocks, but the variance decomposition will be affected by the ordering of the variables. To avoid that, the generalized VAR framework of Koop, Pesaran, and Potter (1996) and Pesaran and Shin (1998) can be utilized here since it produces variance decompositions that do not change with changing the order of variables. This methodology allow for correlated shocks, while accounting for them appropriately using historically observed distribution of errors. The methodology goes as follows:

Consider The KPPS forecast error variance decomposition formula with H-ahead forecast error variance decomposition by $\theta_{ij}^{g}(H)$, for H = 1,2,…, we get:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \qquad (1)$$

Σ is the variance matrix for the error vector ε, σ_{jj} is the standard deviation of the error term for the jth equation, and e_i is the selection vector, with one as the

ith element and zeros otherwise.

Note that: $\sum_{j=1}^{N} \theta_{ij}^{g}(H) \neq 1$ because the shocks are not orthogonalized.

Normalisation is then needed for each entry of the variance decomposition matrix by the row sum as:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}. \qquad (2)$$

Then the total spill-over index can be calculated as:

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \cdot 100. \qquad (3)$$

2.3: Global Markets Returns

The data in this study uses nominal local currency stock market indices values from May 1994 to September 2017. The data, as the original study, includes seven developed countries (US, UK, France, Germany, Hong Kong, Japan, Australia) and fourteen emerging market countries, twelve in the original study (Indonesia, South Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand, Argentina, Brazil, Chile, Mexico and Turkey) with Saudi Arabia and India added in this study. Market indices used to represent countries in this study matches that of the DY2009 study, except for the US, S&P 500 is used instead of the Dow Jones Industrial Average as it represents a larger percentage of the US equity market.

As in DY2009, this study uses weekly returns calculated as change in log price. However, instead of looking at changes from Friday to Friday, this study inspects changes from Wednesday to Wednesday, since using Wednesdays will provide the most data points. To adjust for inflation, the formula $(1 + i_t)/(1 + p_t)$ is used where *i* is the weekly nominal return and *p* is the inflation rate calculated from the IMF's International Financial Statistics divided by 4, meaning that we are assuming the same weekly inflation rate during the month.

2.4: Global Markets Volatilities

With the assumption that volatility is fixed within a week, as in DY2009, Garman and Klass (1980) and Alizadah *et al.* (2002) methodology of calculating volatility from high, low, open, and close values is used. The formula is as follows:

$$\tilde{\sigma}^2 = 0.511(H_t - L_t)^2 - 0.019[(C_t - O_t)(H_t + L_t - 2O_t) - 2(H_t - O_t)(L_t - O_t)] \\ - 0.383(C_t - O_t)^2,$$

H is the week's high, L is the week's low, O is ith Wednesday open and C is the ith +1 Wednesday close.

3: Results and Analysis

As in DY2009, analysis will be broken into two sections. First, Section 3.1 will provide a full-sample analysis where results are provided to reflect the whole period of the study (1994-2004). Then, Section 3.2 will provide a rolling window estimates that show spillovers behaviour over time.

3.1: Full-sample Analysis of Spillovers tables

3.1.1: Adjusting DY2009 for Comparison

Since this study extends DY2009, it is imperative to compare the results of both studies. However, DY2009 use Cholesky factorization in the paper they published in 2009 and we are using the generalized VAR method they used in the paper they published in 2012. Therefore, DY 2009 results are replicated to compare the results using both methods. After that we take the results that use the generalized VAR method to compare it with our results. Table 1 and 2 show DY2009 results using Cholesky full-sample results for volatility and returns spillovers coefficients. Table 3 and 4 show the comparative results using the generalized VAR method.

Table 1

Spillover Table, Global Stock Market Volatility 10/1/1992-23/11/2007 as in Diebol and Yimlaz (2009) (Using Choleski Factorization)

From

	US	UK	FRA	GER	HKG	JPN	AUS	IDN	KOR	MYS	PHL	SGP	TAI	THA	ARG	BRA	CHL	MEX	TUR	From others	Spillover Index
US	63.9	14.9	3.9	1.9	4.9	0.2	1.8	0.3	1.6	0.9	0.4	2.6	0.3	0.1	0.1	0	0.1	0.2	2	36	
UK	22.9	54.5	5	1.3	7.4	0.5	2.1	0.3	1	0.8	0.1	2.4	0.2	0.2	0.4	0.2	0.1	0.1	0.7	46	
FRA	24	32.8	27.3	0.2	5.4	0.2	2.8	0.4	0.3	1.2	0.4	2.4	0.2	0.3	0.6	0.3	0.1	0.1	0.9	73	
GER	26.9	29.5	13.6	13.7	4.8	0.2	3.9	0.2	0.2	1.3	0.8	2	0.2	0.4	0.6	0.3	0.1	0.2	1	86	
HKG	2	0.5	0.7	0	87.7	0.1	0.1	0.4	1.4	0.5	1.5	3.4	0.6	0.4	0	0.1	0	0.1	0.3	12	
JPN	2.7	3.3	0.4	0.7	1.6	82.9	0.1	0.1	0.9	1.1	0.1	1.6	0.3	0	0.6	0.3	0.3	0.2	2.8	17	
AUS	8.9	2.2	0.3	0.6	43.9	0.2	34.7	1.2	1.7	1.3	0.1	2.8	0.1	1	0.1	0.2	0.2	0.3	0.1	65	
IDN	2.8	0.9	0.3	1	6.1	0.3	0.6	71.4	6.9	2.3	2.5	2.8	0.7	0	0	0.3	0.2	0.2	0.9	29	
KOR	2.5	0.6	0.4	0.4	9.1	1	1	10.3	67.5	1.3	0.9	2.5	0.8	0.2	0.1	0.1	0.2	0.3	0.8	32	
MYS	1.3	0.6	0.3	0.6	7.2	1	0.9	0.8	1.7	70.7	3.1	6.1	0.3	0.5	0.9	0.6	0.1	1.5	1.9	29	
PHL	2.1	0.3	0.3	0.4	8.9	0.3	0.4	8.8	3	6.1	66.7	1.5	0.2	0.2	0.2	0.2	0.1	0.2	0.3	33	
SGP	12.5	4.1	0.6	0.1	12.2	0.8	0.8	7.6	7.2	2.8	1.5	45.8	0.5	0.1	0.7	0.7	0	0.7	1.2	54	
TAI	8.5	0.4	0.4	0.2	2.8	0.7	1.3	0.5	9.5	0.7	1.7	0.6	69	0.2	0.4	0.8	0.2	0.7	1.3	31	
THA	0.5	0.7	0.4	0.3	9	0.2	0.3	3.6	2.9	0.4	0.8	5.3	0.2	73.9	0.1	0.5	0.1	0.7	0.2	26	
ARG	3.5	1.5	1.6	0.4	2.7	0.5	1.2	0.3	0.1	2.1	0.2	0.8	0.4	0.3	81	0.9	0.8	0.6	1	19	
BRA	4.5	2.3	1.4	0.3	12.6	0.4	3.3	1	0.3	10	0.7	3.4	0.5	0.3	11.7	45.2	0.3	0.9	0.8	55	
CHL	3.5	0.7	0.7	0.3	2.7	0.1	3.6	1.1	0.2	1.8	0.3	1.8	0.3	0.4	3.6	5	73.7	0.2	0.1	26	
MEX	6.5	1.3	0.7	0.3	25	0.2	4.8	0.3	0.5	2.4	0.3	2.1	0.2	0.5	6.3	3	0.3	44.1	1.1	56	
TUR	2.8	1.7	0.8	0.7	3.9	0.3	1.2	0.3	1.1	2.7	0.5	0.9	4	0.1	0.7	0.3	0.2	1.1	76.8	23	
To others	138	98	32	10	170	7	30	38	41	40	16	45	10	5	27	14	3	8	17	750	
Including own	202	153	59	23	258	90	65	109	108	111	83	91	79	79	108	59	77	52	94	1900	39.50%

Volatility

Table 2

Spillover Table, Global Stock Market Returns, 10/1/1992-23/11/2007 as in Diebol and Yimlaz (2009) (Using Choleski Factorization)

From

To	US	UK	FRA	GER	HKG	JPN	AUS	IDN	KOR	MYS	PHL	SGP	TAI	THA	ARG	BRA	CHL	MEX	TUR	From Others	
US	93.6	1.6	1.5	0	0.3	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.3	0.2	0.1	0.1	0	0.5	0.3	6	
UK	40.3	55.7	0.7	0.4	0.1	0.5	0.1	0.2	0.2	0.3	0.2	0	0.1	0.1	0.1	0.1	0	0.4	0.5	44	
FRA	38.3	21.7	37.2	0.1	0	0.2	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.3	63	
GER	40.8	15.9	13	27.6	0.1	0.1	0.3	0.4	0.6	0.1	0.3	0.3	0	0.2	0	0.1	0	0.1	0.1	72	
HKG	15.3	8.7	1.7	1.4	69.9	0.3	0	0.1	0	0.3	0.1	0	0.2	0.9	0.3	0	0.1	0.3	0.4	30	
JPN	12.1	3.1	1.8	0.9	2.3	77.7	0.2	0.3	0.3	0.1	0.2	0.3	0.3	0.1	0.1	0	0	0.1	0.1	22	
AUS	23.2	6	1.3	0.2	6.4	2.3	56.8	0.1	0.4	0.2	0.2	0.2	0.4	0.5	0.1	0.3	0.1	0.6	0.7	43	
IDN	6	1.6	1.2	0.7	6.4	1.6	0.4	77	0.7	0.4	0.1	0.9	0.2	1	0.7	0.1	0.3	0.1	0.4	23	
KOR	8.3	2.6	1.3	0.7	5.6	3.7	1	1.2	72.8	0	0	0.1	0.1	1.3	0.2	0.2	0.1	0.1	0.7	27	
MYS	4.1	2.2	0.6	1.3	10.5	1.5	0.4	6.6	0.5	69.2	0.1	0.1	0.2	1.1	0.1	0.6	0.4	0.2	0.3	31	
PHL	11.1	1.6	0.3	0.2	8.1	0.4	0.9	7.2	0.1	2.9	62.9	0.3	0.4	1.5	1.6	0.1	0	0.1	0.2	37	
SGP	16.8	4.8	0.6	0.9	18.5	1.3	0.4	3.2	1.6	3.6	1.7	43.1	0.3	1.1	0.8	0.5	0.1	0.3	0.4	57	
TAI	6.4	1.3	1.2	1.8	5.3	2.8	0.4	0.4	2	1	1	0.9	73.6	0.4	0.8	0.3	0.1	0.3	0	26	
THA	6.3	2.4	1	0.7	7.8	0.2	0.8	7.6	4.6	4	2.3	2.2	0.3	58.2	0.5	0.2	0.1	0.4	0.3	42	
ARG	11.9	2.1	1.6	0.1	1.3	0.8	1.3	0.4	0.4	0.6	0.4	0.6	1.1	0.2	75.3	0.1	0.1	1.4	0.3	25	
BRA	14.1	1.3	1	0.7	1.3	1.4	1.6	0.5	0.5	0.7	1	0.8	0.1	0.7	7.1	65.8	0.1	0.6	0.7	34	
CHL	11.8	1.1	1	0	3.2	0.6	1.4	2.3	0.3	0.3	0.1	0.9	0.3	0.8	2.9	4	65.8	2.7	0.4	34	
MEX	22.2	3.5	1.2	0.4	3	0.3	1.2	0.2	0.3	0.9	1	0.1	0.3	0.5	5.4	1.6	0.3	56.9	0.6	43	
TUR	3	2.5	0.2	0.7	0.6	0.9	0.6	0.1	0.6	0.3	0.6	0.1	0.9	0.8	0.5	1.1	0.6	0.2	85.8	14	
Contribution to others	292	84	31	11	81	19	11	31	14	16	10	8	6	12	21	9	3	8	7	675	Spillover index
including own	386	140	68	39	151	97	68	108	86	85	73	51	79	70	97	75	68	65	92	1898	35.50%

Table3

Spillover Table, Global Stock Market Returns 10/1/1992-23/11/2007 as in Diebol and Yimlaz (2009) (Using Generalized Impulse Response)

From

	US	UK	FRA	GER	HKG	JPN	AUS	IDN	KOR	MYS	PHL	SGP	TAI	THA	ARG	BRA	CHL	MEX	TUR	From Others	
US	25.5	10.7	10.1	10.8	3.9	3	5.9	1.2	2.1	1	2.3	4.4	1.2	1.4	3	3.6	3.1	6.1	0.6	74	
UK	10	23.7	14	12.6	5.5	3	5.6	0.9	2.1	1.2	1.9	4.2	1.1	1.7	2.6	2.1	2.1	4.5	1.2	76	
FRA	9.3	13.8	23.4	15.9	4.4	3.4	4.9	1.1	2.2	1	1.5	3.6	1.3	1.4	3	2.2	2.3	4.5	0.9	77	
GER	9.8	12.3	15.8	23.1	4.9	3	4.8	1.4	2.3	1.3	1.7	4	1.8	1.6	2.4	2.4	2.1	4.4	0.9	77	
HKG	4.3	6.4	5.3	5.8	26.4	2.5	6.2	3.1	3.8	4	4.2	10.1	3	4.2	1.9	1.9	2.5	4	0.4	74	
JPN	5	5.3	6	5.6	3.7	38.9	6	2.5	4.5	2	1.2	4.6	3.2	1.3	1.6	3	1.4	3	0.8	61	
AUS	7.1	7.4	6.6	6.3	6.5	4.3	27.6	1.6	3.3	2.1	3	4.6	1.6	2.5	2.8	3.3	3.1	5.1	1.2	72	
IDN	2.5	2.6	1.9	2.6	5	2.6	2.6	37.6	3.3	6.1	6.9	7.4	1.6	7.1	1.8	2.1	3.4	2.5	0.7	62	
KOR	3.4	3.7	3.6	3.9	5.5	4.4	4.7	2.9	38.4	2	1.6	6.3	3.6	6.1	1.8	1.9	1.9	3	1.3	62	
MYS	1.7	2.4	1.7	2.6	7	2.1	3.1	6.5	2.6	38.4	5.6	9.6	2.5	7.1	1.6	0.5	2.1	2.7	0.2	62	
PHL	4	3.5	2.5	2.9	6.1	1.5	4.1	5.9	1.8	5.3	32.5	8.4	2.7	6.8	3.1	1.7	2.3	4.1	0.7	67	
SGP	4.7	5.1	4.1	4.6	9.7	3	4.3	4.4	4.2	6	5.7	24.7	3.3	6	2.6	1.3	2.4	3.4	0.6	75	
TAI	3	3	3.4	4.5	5.5	3.6	2.5	1.6	4.2	2.9	3.1	6.3	44	2.9	2	1.2	1.8	3.5	0.9	56	
THA	2.4	2.9	2.1	2.7	5.6	1.3	3.3	6.1	5.6	6.2	5.9	8.1	2.2	35.4	1.9	1.8	2.4	3	1.1	65	
ARG	4.8	4.5	4.9	4	2.9	1.9	4.2	1.1	2	1.6	2	3.8	1.9	1.7	38.1	6.9	4.2	8.6	0.9	62	
BRA	5.9	3.8	4.2	4.2	3.1	3	5.1	1.7	1.9	0.8	1.8	1.9	1	1.9	7	38.1	6	7.2	1.4	62	
CHL	4.8	3.6	3.6	3.3	4.1	1.7	4.5	3.1	2.1	2.1	2.3	4.2	1.7	2.9	4.3	6.4	37.3	6.5	1.5	63	
MEX	7.1	6	5.9	5.8	4.7	2.2	5.3	1.4	2.3	2.1	2.9	4	1.9	2.1	6.3	5.2	3.6	30.5	0.6	70	
TUR	2.1	3.6	2.7	3.3	1.6	1.5	2.4	0.6	1.9	0.5	1.3	1.7	1.9	1.7	1.7	2.6	2.1	1.3	65.5	34	Spillover index
Contribution	92	101	98	101	90	48	79	47	52	48	55	97	37	60	52	50	49	77	16	1251	
Including own	118	124	122	124	116	87	107	85	91	87	88	122	81	96	90	88	86	108	81	1901	0.658

Table 4

Spillover Table, Global Stock Market Volatility 10/1/1992-23/11/2007 as in Diebol and Yimlaz (2009) (Using Generalized Impulse Response)

From

	US	UK	FRA	GER	HKG	JPN	AUS	IDN	KOR	MYS	PHL	SGP	TAI	THA	ARG	BRA	CHL	MEX	TUR	From Others	Spill over Index
US	27.3	16.9	17.5	14	3.8	1	3.3	0.3	1.5	0.3	0.9	1.3	2.6	0.1	1.6	1.3	0.8	3.2	2.2	73	
UK	9.1	30.5	21.7	15.8	4.5	1.7	3.3	0.4	1.1	0.4	0.5	1.7	1.7	0.3	1.9	1.5	0.6	2	1.4	70	
FRA	9	20.5	30.1	20.5	3.5	1.2	1.8	0.3	0.6	0.3	0.5	1.3	1.5	0.3	2.3	2.3	0.3	2.2	1.7	70	
GER	10.2	19.9	24.2	27.3	3.1	1.2	1.3	0.3	0.7	0.4	0.6	1.2	1.4	0.3	2.1	1.9	0.2	1.9	1.9	73	
HKG	1.2	0.9	1.4	1.2	53.9	0.8	6.2	2.5	4.5	2.8	8.3	5.5	3.6	2.1	0.4	1.9	0.2	2.2	0.4	46	
JPN	2	4.2	3.6	3.6	2	66.2	1.5	0.4	1.9	2.7	0.3	1.2	1.8	0.4	2	2	0.1	1.3	2.8	34	
AUS	5.5	4.5	3.3	2.5	29.3	0.7	31.6	0.8	1.6	0.8	3	2.6	1.1	0.1	1.2	2.3	2.3	6	1	68	
IDN	1.8	1.6	1.2	1.9	4.9	0.5	1.8	50.7	6.8	3.7	10.4	7.6	0.9	2	0.3	1.2	0.9	0.8	1.1	49	
KOR	1.6	1.3	1.2	1.4	6.9	1.4	1.4	9	50	2.1	2.8	7.1	9.2	2.5	0.2	0.3	0	0.7	0.9	50	
MYS	1	0.9	0.5	0.8	6	1.2	2.7	1.4	2.4	61.6	3.9	1.6	1.2	0.9	2.3	5.7	0.4	3.2	2.1	38	
PHL	1.4	0.7	0.8	1.1	6.7	0.2	1.4	8.5	2.4	5.8	57.7	5.6	0.9	1.8	0.7	2.1	0.8	1	0.5	42	
SGP	5.1	5	4.5	4.3	6.6	1.4	3.5	5.7	5.6	2.9	3.3	31.6	3.9	4.6	2.3	3.6	1.8	2.9	1.5	68	
TAI	5.8	2.5	3.1	3	2.9	1.2	0.6	0.4	9.2	0.5	1.5	3.5	61.1	0.7	0.9	0.2	0.3	1.2	1.5	39	
THA	0.3	0.4	0.5	0.4	6.8	0.5	0.3	4.1	3.8	1.1	3.5	9.3	1.5	65.1	0.2	0.9	0.1	0.8	0.2	35	
ARG	2.1	2.4	3.6	3.1	2.2	0.9	2.6	0.3	0.4	2	0.2	1.5	0.9	0.3	54.7	8.3	1.9	10.5	2.1	45	
BRA	2.3	2.8	3.1	3	7.8	0.9	6	1.2	0.5	7.9	2.2	2.5	0.8	0.6	10.2	34.7	3.4	8.7	1.3	65	
CHL	2.3	1.8	1.1	0.8	2.2	0.1	4.8	1.6	0.1	1.8	1.1	3.4	0.1	0.1	4.4	7.3	61.1	5.2	0.7	39	
MEX	3.6	2.9	3.3	3	15	0.3	7.3	0.3	0.9	1.9	1.9	1.4	1	0.2	6.4	7.1	2.5	38.8	2.1	61	
TUR	2.1	2.8	3.3	3.9	3.7	0.4	2.1	0.9	2	2.9	1	1.4	4.9	0.3	1.6	1.7	0.7	3.2	61.4	39	
Contribution	67	92	98	84	118	16	52	38	46	40	46	60	39	18	41	51	17	57	25	1005	
Including own	94	122	128	112	172	82	83	89	96	102	104	91	100	83	96	86	78	96	87	1901	0.529

Tables 1-4 show “input-output” decomposition of spillovers across countries. For example, in Table 2 US is responsible for 40.3% of the errors forecasting 10-weeks ahead UK returns, and UK is responsible for 1.6% of the errors forecasting 10-weeks ahead US returns.[8]

DY2009 takeaway from Tables 1-2 is the spillover index. Showing 36% and 40% of forecast error in returns and volatility, respectively, the author stresses on the significance of spillovers and that they, unconditionally, both are of the similar magnitude. However, conditionally, they could portray significantly different dynamics in reaction to economic events.

However, using the generalized VAR method, our results show that DY2009 results are indeed biased towards giving higher coefficients based on its ordering. The most clear example is US having a total contribution of 386 in the original results' returns table and 118 in the updated results table. In addition, when the ordering problem is solved, spillover indices reach about 66% for returns and 53% for volatilities; showing that DY2009 might have underestimated the magnitude of spillovers and confirming their finding that returns and volatility spillovers, unconditionally, have similar magnitudes.

3.1.2: Comparing the Updated Results to the Adjusted DY2009

Tables 5-6 summarizes spillovers of volatility and results using this study's updated data and the generalized VAR method. The tables now include Saudi Arabia and India and cover the period from April 1994 to September 2017.

[8] Diebold Yimlaz (2009)

Table 5

Spillover Table, Global Stock Market Volatility 08/04/1994-15/09/2017 (using generalized impulse response)

From

	US	UK	FRA	GER	HKG	JPN	AUS	KOR	MYS	PHL	SGP	TAI	THA	ARG	BRA	CHL	MEX	TUR	KSA	IND	IDN	From Others	
US	20.4	11.9	12.6	11.9	3.3	2.9	12	2.4	0.4	1.3	1.9	3	0.6	1.3	2.1	6.9	0.4	1.1	1.3	1.1	1.1	80	
UK	11.9	17.5	12.8	11.2	4.2	2.1	17.2	2	0.4	1.3	1.8	3	0.5	1.1	2.3	6.1	0.4	1.2	0.9	0.8	1.3	83	
FRA	12.8	14.1	17.9	14.9	3.4	1.9	14	1.6	0.3	1.2	1.7	3	0.6	0.9	2.2	5.3	0.3	1.6	0.8	0.6	0.9	82	
GER	13.3	14.3	16.2	20.2	2	2	14	1.3	0.5	0.8	1.1	3.3	0.5	0.8	1.3	4.6	0.2	1.9	0.8	0.4	0.6	80	
HKG	7.7	7	6.3	4.4	19.5	3.3	6.6	3.8	1.1	6.1	9.4	2	1.3	1.2	3.3	8.4	0.9	0.4	0.8	1.8	4.9	81	
JPN	10.4	6.4	6.6	6.4	5.3	26.6	6.6	3.5	0.9	1.4	2.6	2.8	0.8	0.8	2.8	9.2	0.4	1	2.5	1.8	1.3	73	
AUS	12.1	17.3	12.7	11	4	2.1	18.2	1.9	0.3	1.3	1.7	3	0.5	1.1	2	6	0.4	1.4	1	0.9	1.3	82	
KOR	6.2	5.5	4	3.6	6.7	3.9	4.9	31	1.1	1.9	3.8	6	1.8	0.8	2.2	5.7	1.7	1.1	0.5	3	4.6	69	
MYS	2.9	0.6	0.9	1.5	6.8	1.7	0.5	1.9	64.3	3.8	3.7	3	2.5	0.5	0.2	1.2	0.1	0.8	0.1	0.3	2.8	36	
PHL	3.5	2.4	2.6	1.7	9.3	1.5	2.3	1.8	2.5	31.4	14.7	1.2	4.4	1.2	3.1	4.4	0.2	0.6	0.3	0.5	10.4	69	
SGP	5.6	4.3	4.1	2.8	12.2	2.4	4	2.8	1.7	11.5	24.5	1.1	2.5	0.8	1.6	5.6	0.9	0.4	0.6	1.6	9	76	
TAI	8	5.1	4.3	5.5	3.3	3.4	5.5	7.8	1	1.7	1.3	40.4	0.8	1.6	1	4.1	0.1	1.3	0.4	1.5	1.9	60	
THA	2.4	1.8	2	1	4.8	1	1.4	4.7	1.8	7.7	5.9	1.3	46.9	0.4	1.6	3.5	0.5	1.7	0.2	2.3	7.1	53	
ARG	7.4	4.1	4.1	3.8	2.7	2.1	4	0.7	4.6	1.4	1.3	2.5	0.4	43.8	6.3	6.5	0.4	1.6	0.9	0.5	0.8	56	
BRA	6.8	5	5.3	3.8	6	2.1	4.2	1.6	14.6	2.7	2	2.2	1.2	3.3	26.6	9.8	0.8	0.3	0.5	0.4	0.8	73	
CHL	8.9	7.6	6.8	5.4	6.4	3.2	7.5	2.5	1.6	2.6	2.6	1.8	1.4	1	7.9	25.7	0.8	0.5	1.3	1.5	2.7	74	
MEX	2.1	2.7	1.9	1.7	3	0.7	2.1	1	0.7	0.6	2.4	0.7	0.6	0.4	1.5	2.1	71.5	0.2	0.3	0.3	3.5	29	
TUR	2.7	1.3	2.2	2.2	1	1.9	1.4	2.5	0.8	1.2	0.5	7.8	2.2	1	0.6	1	0.1	67.6	0.6	1.2	0.5	32	
KSA	1.5	1.2	0.9	1	0.9	0.8	1.6	0.4	0.2	0.4	0.4	0.4	0.2	0.4	0.5	1.6	0.2	0.3	80.8	4.5	1.7	19	
IND	8.9	4.4	4.1	3.3	4.2	3.2	4.6	4.8	0.2	0.8	2.4	2	1.7	1	1.9	9.5	0.4	0.8	3.7	35.1	3.2	65	
IDN	2.5	3	2	1.5	6.9	1.4	2.8	4.8	1.5	12.1	12.2	1.7	4.5	0.3	0.7	3.8	0.1	0.4	1.2	2.2	34.5	66	
Contribution	138	120	112	99	96	44	117	54	36	62	73	52	29	20	45	105	9	19	18	27	60	1336	spillover index
Including own	158	138	130	119	116	70	135	85	100	93	98	92	76	64	72	131	81	86	99	62	95	2100	0.636

Table 6

Spillover Table, Global Stock Market Returns 08/04/1994-15/09/2017 (using the generalized impulse response)

From

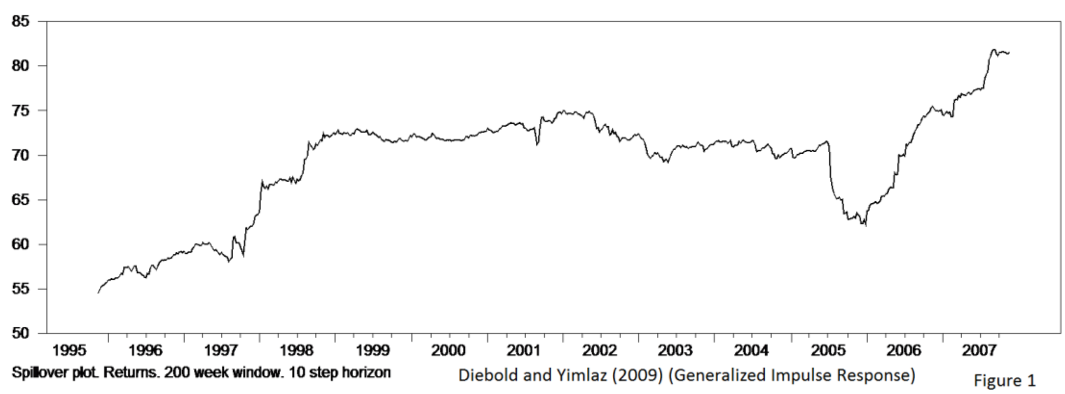
	US	UK	FRA	GER	HKG	JPN	AUS	KOR	MYS	PHL	SGP	TAI	THA	ARG	BRA	CHL	MEX	TUR	KSA	IND	IDN	From Others	
US	15.8	9	8.9	9	5.2	4.5	9.4	2.7	1.3	1.7	4.6	2.7	2.1	3.2	4.2	3.3	5.4	2.1	0.9	2.1	1.8	84	
UK	8.3	14.6	9.8	9.2	5.3	3.8	14.3	2.6	1.5	2.1	4.6	2.4	2.1	2.7	3	2.5	3.8	2.2	0.8	2.4	2	85	
FRA	8.8	10.4	15.6	12.4	5	4.4	10.6	2.5	1.1	1.7	4.3	2.5	1.8	2.9	3	2.4	4.1	2	0.8	2.1	1.7	84	
GER	8.8	9.7	12.3	15.6	4.7	4.5	10.1	2.8	1.4	1.8	4.2	2.9	2	2.8	3.1	2.5	4.1	2.1	0.8	2.2	1.9	84	
HKG	5.8	6.3	5.6	5.4	17.7	4.1	6.4	4.3	3	3	8.7	3.9	3.6	2.7	3.6	2.4	4.2	1.5	0.7	3.4	3.4	82	
JPN	6.5	5.9	6.4	6.5	5.3	22.8	6.4	4.3	2	2.7	5.2	3.7	2.7	2.3	3.1	2.6	3.7	1.3	1.1	2.8	2.5	77	
AUS	8.4	13.8	9.7	9.2	5.2	4	14.1	2.7	1.5	2.2	4.7	2.5	2.1	2.8	3	2.7	3.9	2.2	0.8	2.5	2.1	86	
KOR	4.5	4.5	4.1	4.6	6.2	4.9	5	26.1	2.4	3.1	5.3	4.8	5.5	2.3	2.6	1.8	3.4	1.5	0.7	3	3.6	74	
MYS	2.8	3.4	2.5	3.2	5.7	2.9	3.5	3.3	32.5	5.6	8.5	3.7	5.7	1.4	1	1.7	2.3	1.3	0.4	2.2	6.5	68	
PHL	3.6	4.1	3.3	3.3	4.9	3.1	4.4	3.3	4.9	25.8	6.9	3.1	6.3	3	2.5	2.9	3.6	1.2	0.3	2.8	6.7	74	
SGP	5.2	5.5	4.9	4.8	8.7	4	5.9	3.7	4.7	4.3	17.5	3.9	5.1	2.6	2.7	2.6	3.4	1.8	0.9	3.2	4.5	82	
TAI	4.8	4.5	4.5	5.2	6	4.5	4.8	5.1	3.2	2.9	6	27.3	3	2.4	2.5	2.3	3.1	1.3	0.8	3.5	2.4	73	
THA	3.7	3.7	2.8	3.3	5.2	3.1	3.8	5.4	4.5	5.5	7.3	3	25.5	2.7	2.5	2.7	3.3	1.9	0.6	2.5	6.9	75	
ARG	5.4	4.9	4.9	4.7	4.1	2.6	5.2	2.2	1	2.3	3.7	2.4	2.6	26.6	7.4	4.5	8.1	2.1	0.9	1.7	2.6	73	
BRA	6.4	5	4.6	4.8	4.9	3.2	5.2	2.4	0.8	2	3.7	2.2	2.3	6.7	24.1	6.1	8	2.9	0.6	2.1	2	76	
CHL	5.6	4.8	4.1	4.3	3.6	3.1	5.1	1.9	1.6	2.5	4.2	2.4	3	4.6	7.1	27	6.4	2.4	1.1	2.1	3.2	73	
MEX	7.3	5.6	5.6	5.5	5	3.4	5.9	2.8	1.4	2.3	4	2.3	2.5	6.2	7	4.9	21.2	2.2	0.5	2.4	2.1	79	
TUR	5	5.4	4.7	4.8	3.3	2.1	5.5	2	1.6	1.5	3.7	1.7	2.7	2.9	4.4	3.1	3.9	35.8	1	2.6	2.3	64	
KSA	3.8	3.4	3.2	3.4	2.3	2.7	3.9	1.4	0.7	0.7	3	1.5	1.4	2.5	1.5	2.2	1.4	1.6	56.2	1.8	1.4	44	
IND	4.2	4.8	4.1	4.3	5.7	3.7	5.4	3.4	2	3.3	5.5	3.8	2.9	1.9	3	2.4	3.7	2.2	0.9	29.3	3.5	71	
IDN	3.7	3.9	3.1	3.6	5	3.1	4.1	4	4.9	6.3	6.4	2.3	7	2.9	2.7	3.2	3.2	1.7	0.6	3	25.2	75	
Contribution	113	118	109	111	101	72	125	63	46	57	104	58	66	62	70	59	83	38	15	50	63	1584	Spillover Index
including own	128	133	125	127	119	95	139	89	78	83	122	85	92	88	94	86	104	73	72	80	88	1839	75.40%

The results shown in Table 4-6 are interesting and confirms the study's expectations and intuition. There are two key findings to be extracted from the tables. First, spillover indices has increased over time (Table 3 and 4 versus 5 and 6); which is consistent with the intuition of an increased integration of global financial markets due to advances in the financial markets and technology or as a consequence of major events such as the subprime mortgages crisis, which, as we will show in the next section, tends to sustain over time. The second takeaway confirms DY2009's finding that volatility and returns spillovers tend be of similar magnitude when considered unconditionally. However, over time, or conditionally, spillovers from volatility and returns could have radically different magnitudes, which is to be analysed in the next section using rolling windows estimates.

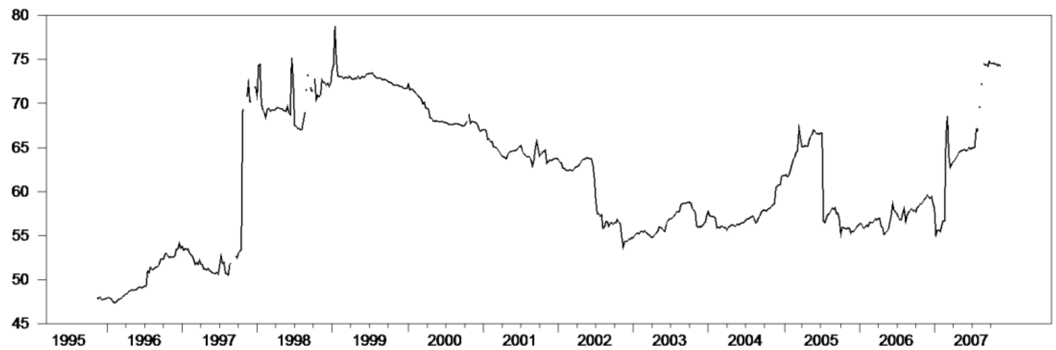
3.2: Analysis of Rolling-sample Spillovers Plots

3.2.1: Adjusting DY2009 for Comparison

Just as in Section 3.1.1, we will adjust DY2009's results and show their results under both methods, the generalized VAR method and the Choleski factorization method. Figure 1 - 4 show DY2009's results under both methods.

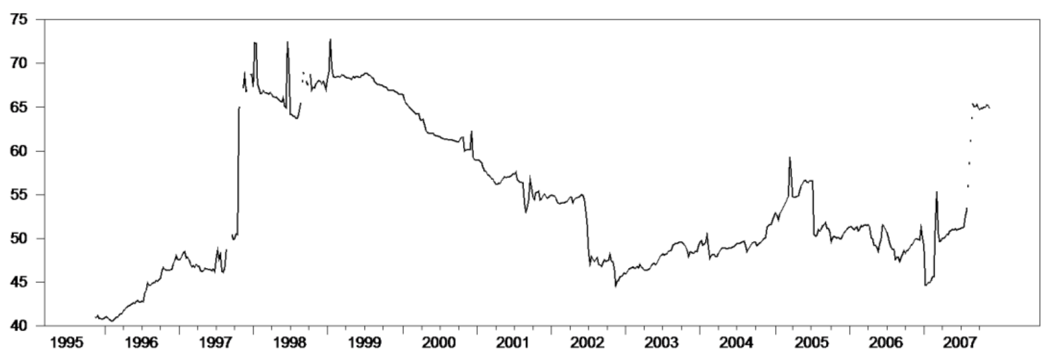


Diebold and Yimlaz (2009) (Generalized Impulse Response) Figure 1



Spillover plot. Volatility. 200 week window. 10 step horizon Diebold and Yimlaz (2009) (Generalized Impulse Response) Figure 2

Spillover plot. Returns. 200 week window. 10 step horizon Diebold and Yimlaz (2009) (Choleski Factorization) Figure 3

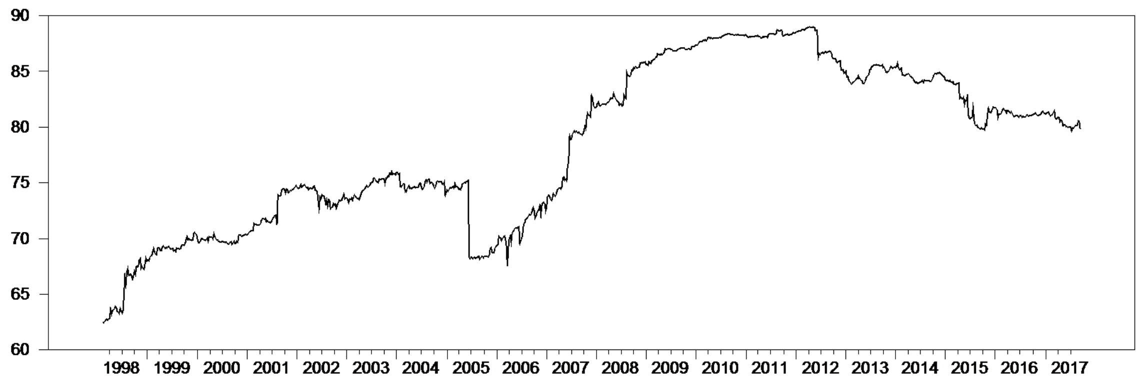


Spillover plot. Volatility. 200 week window. 10 step horizon Diebold and Yimlaz (2009) (Choleski Factorization) Figure 4

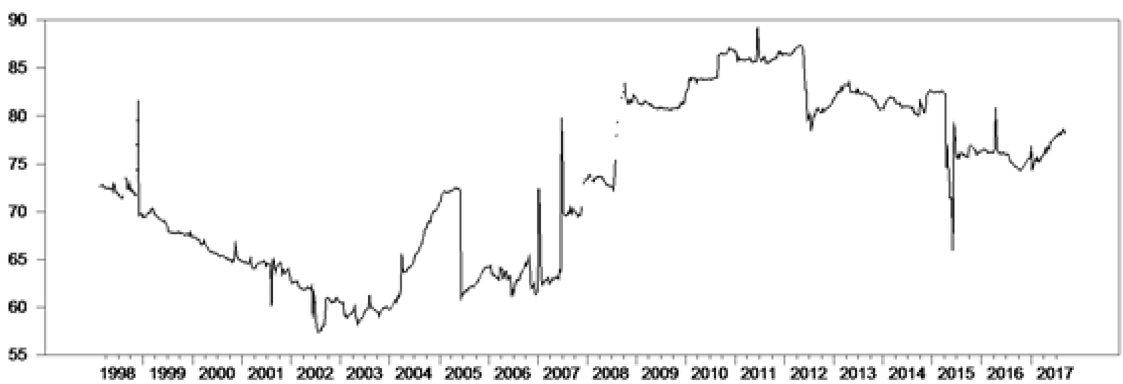
Looking at the figures, it is clear that the results under both results are very similar. In addition to the higher magnitude of the spillovers indices in the generalized VAR method graphs, there are only small notable differences in shape of the plots, more apparent in returns plots.

3.2.2: Comparing the Updated Results to the Adjusted DY2009

After showing DY2009 rolling window results using the generalized VAR method, it is now relevant to show our results using our data. Using the same window size, 200 weeks, we estimate the spillover index for returns and volatility over the sample period. Note that since this a 200 weeks rolling window and our data starts at 1994, our estimates will begin February 4, 1998. See Figure 5 and 6 below.



Spillover plot. Returns. 200 week window. 10 step horizon Ibrahim Fatani (2017) (Generalized Impulse Response) Figure 5



Spillover plot. Volatility. 200 week window. 10 step horizon Ibrahim Fatani (2017) (Generalized Impulse Response) Figure 6

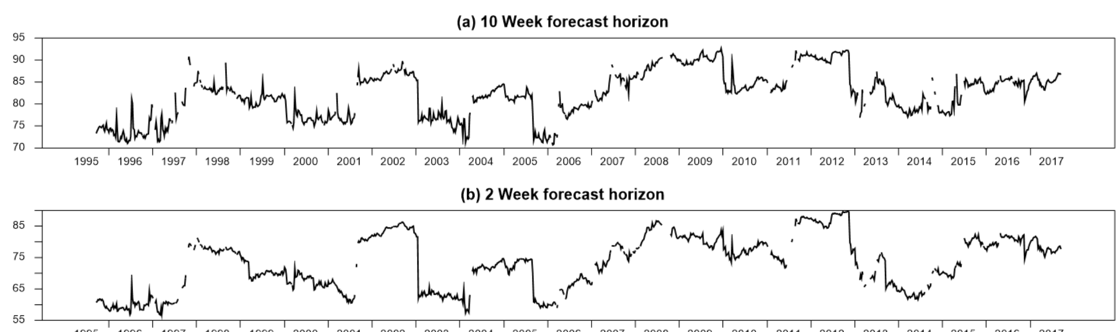
Figure 5 and 6 provide us with a lot of information. First, it is very interesting to see the aftermath of the subprime mortgages financial crises. It is clear that the financial crisis has caused a significant and sustained increase in the both spillovers indices to unprecedented high levels. In addition, it seems to be sustain further by another smaller shocks that coincides with the eurozone crisis and the 2015 Chinese stock market crash. It is also observed that both indices have not yet recovered from the financial crises, yet they are recovering.

In addition, Figure 5 and 6 show us a bigger picture of how volatility and returns index behave, unconditionally. relatively and they give us a stronger evidence of them being similar in magnitude and in movement. Another finding of DY2009 is supported in our results; returns spillovers move in trends and have small sensitivity to events that otherwise would have caused large spikes in the volatility index. The volatility index moves in a spike then trends fashion; however, the overall trend of the movement is similar to that of the returns spillovers.

3.3: Robustness

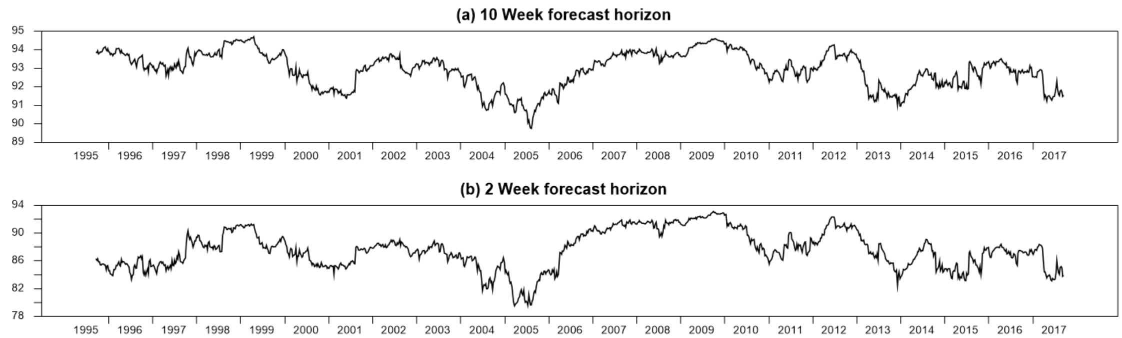
Following DY2009, this paper will also analyse the robustness of the model by changing the width of the rolling windows and length of the forecast horizon; however, this paper will ignore the third check DY2009 performed, which rechecks the results by randomizing the ordering of variables as it is irrelevant in our analysis due to our avoidance of the ordering sensitivity problem that is due to identification with Cholesky Factorization and our use of Generalized VAR.

The same adjustments were made to check for robustness as in DY2009, 75 weeks rolling window, instead of the original 200, with the original 10 weeks forecast horizon and with a lesser 2 weeks forecast horizon. Figure 7 and 8 provides our results for spill-over plot for volatilities and returns respectively.



Spillover plot, Global Market Volatility
75 Week Rolling Windows

Figure 7



Spillover plot, Global Market Returns
75 Week Rolling Windows

Figure 8

As the two figures show, volatility and returns spill-over results appear satisfyingly robust with the shorter window of 75 weeks and forecast horizon of 2 weeks.

4: Conclusion and Remarks for Future Analysis

DY2009 attempted to measure markets interdependence by measuring variance decompositions in a Vector Auto Regressive model. Their data included crisis and non-crisis episodes; however, their results ends right at the beginning of the subprime mortgages financial crisis, which elicits a need to extend the study to see the crisis' aftermath. Their key finding was capturing the importance of spillovers, as they represent a large percent of forecast errors, and how returns and volatility spillovers behave relative to each other conditionally and unconditionally over time. Their findings were that volatility spillovers exhibit an erratic movement in comparison to the smoother movements of returns spillovers and that both types have similar trends and magnitudes when considered over a long period, that is unconditionally.

Our findings reveal an interesting continuation of what happened to volatilities and returns spillovers after 2007 and after adjusting for the problem of ordering bias in the DY2009. The results are in line with what is expected and with DY2009. Volatilities and returns spillovers still behave in the same manner that is found in DY2009 when considered unconditionally.

In addition, our results show that spillovers of both types have increased. The increase can be explained as a consequence of developments in financial markets, in technology and in globalization, when considering the general trend of increasing spillovers, and as a consequence of major economic crises, when considering spikes in spillovers and how long they sustain.

An interesting extension to the study of volatility and returns spillovers is to consider different assets, such as real estates and bond markets, in each country and to include important commodities such as oil and gold. DY2012 considered different asset classes, but only considered volatilities spillovers within them in the United Stated, not from a global perspective. Many contributions has been made to study spillovers between stock markets and oil for developed countries[9] and many has been made for emerging markets[10], but none has considered a global perspective study that includes different asset classes.

[9] See Papapetrou, (2001), Agren (2006), Killian and Park (2009), Malik and Ewing (2009), Choi and Hammoudeh (2010), Vo (2009, 2011), Arouri et al. (2011, 2012), Ciner (2013), Degiannakis et al. (2013)

[10] See Basher and Sadorsky, 2006; Fowowe, 2013; Asteriou and Bashmakova, 2013; Lin et al., 2014; Bouri, 2015a, b; Noor and Dutta, 2017

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Software used for calculations Estima RATS

Data retrieved from Bloomberg and https://investing.com