İSTANBUL BİLGİ UNIVERSITY

Institute of Social Sciences

The effect of Global Crisis on the Volatility Spillovers among Crude Oil Prices, Stock Market Index and Exchange Rates

Kerem ŞURĞUN

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Abstract

This research investigates the dynamic relations between crude oil, stock market returns and exchange returns from USD to EURO and tries to determine whether those variables treat differently before and after global crisis. Diebold and Yilmaz model is used to focus on variance decompositions that are derived from vector autoregressive (VAR) models. We use daily returns of the variables as data comprehensing the period from January, 2000 to November, 2015 and the period is divided into two sub periods to explore whether volatility spillovers among these variables change due to global crisis. Given information of any variables can help investors and portfolio makers to think that they should reduce the dependence between other variables which they don't have enough information. Finally, it is suggested that applying the Diebold and Yilmaz approach to the research improves the accuracy of relation of volatilities among variables and benefits to evaluate changes dynamically.

Keywords: Volatility Spillover, Stock Market Index, Exchange Rates, Crude Oil Prices, Diebold&Yilmaz Model, Global Crisis, Spillover Effect, Variance Decomposition

Özet

Bu araştırmada ham petrol, hisse senedi piyasası getirileri ve Dolar ile Euro arasındaki kur paritesi arasındaki dinamik ilişki incelenmiştir. Çalışmanın amacı, ekonomik kriz öncesi ve sonrası bu değişkenlerin farklı davranıp davranmadığını ekonometrik yöntemle ölçmektir. Çalışmada, Diebol ve Yilmaz modeli kullanılmış olup, vektör otoregresif modellerden elde edilen sapmaların ayrışımları üzerine yoğunlaşılmıştır. 2000 yılının Ocak ayından, 2015 yılının Kasım ayına kadar olan günlük getiri oranları veri olarak kullanılmış olup, ayrıca bu dönem iki farklı döneme daha ayrılmış ve oynaklığın yayılma etkisinin küresel kriz öncesi ve sonrası değişip değişmediği araştırılmıştır. Herhangi bir değişkenin bilgisi elde edinildiğinde, yatırımcılar ve portfolyo uzmanları, bilgisinine sahip olmadıkları değişkenlerin birbirine bağımlılığını azaltmak üzere bu tür çalışmalardan yararlanabilirler. Son olarak, Diebol ve Yilmaz modeli çalışmamızda, değişkenlerin arasındaki oynaklığın yayılması etkisisi daha kesin yöntemlerle ölçmüş ve bu değişkenlerin dinamik olarak değişimlerinin incelenmesi konusunda katkıda bulunmuştur.

Anahtar kelimeler: Yayılma etkisi, Oynaklık yayılma etkisi, Hisse senedi piyasası, Döviz kuru oranları, USD/EURO, Diebold&Yilmaz Modeli, Küresel finansal kriz, sapmaların ayrışımları, Ham petrol fiyatları

To my beloved mother, father and friends

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I. INTRODUCTION

In the last fifteen years, the world faced with many changes and improvements in financial and economical terms. Stock market has been widely recognized by many countries and technological improvements allowed international investors to understand the dynamics of stock market. Many countries have increased their foreign trade volume and many economical definitions emerged for countries like BRICS, MENA or MIST due to increasing production and purchasing volumes from eachother. Owing to this, exchange rate has become more significant than ever and mainly change of USD prices have been started to be followed more and more by consumers, traders and producers. On the other hand, countries experienced the global crisis which has had a ripple effect around the world. It started to show it's effects in the middle of 2007 and the stock markets have fallen around the world, financial institutions have been destructed, governments tried to create rescue packages in order to decrease the effect of the crisis and increasing trade volume has started to decrease gradually. If we come to oil market which is most significant commodity for economies, it's price reached a record peak during global crisis and on the contrary oil market price has experienced a drop of almost 75 percent than the price of during global crisis. Those affairs are happening and they continue to affect the World economy.

In the recent years, relationship among oil price returns, exchange rate returns and stock index returns has been an important topic for researchers since these markets have widely effect on the global economy. According to Nandha and

Paff (2008), a rise in oil price will decrease the stock index price which it can be clue that there is significant relation between oil and stock index returns. On the one hand, Ferraro, Rogoff and Rossi (2015) predicts that exchange rates can be forecasted by oil prices. Moreover, Umer, Sevil and Kamisli (2015) found that there is a relation between exchange rates and stock prices and strenght of the comovement between them depends on the economical shocks like global crisis.

Crude oil as a commodity is traded in U.S dollar and changes in exchange rates affect crude oil supply, demand and price. There has been continuously historic records for international oil price since 2002 and it started to decrease again in the end of 2014.

US dollar has decreased by a large amount against the Euro before the crisis, it increased again after global crisis and it still follows the the way of increase against Euro towards the end of 2015.

There is not any detailed work done by researchers to analyze whether there is an impact of global crisis on volatility spillover effect of oil prices, exchange rate USD to EURO and stock market prices. The volatility spillover tests whether there is mutual effect of return volatilities to eachother in different markets. While other econometrical approaches measure if return volatility is affected by its own historical volatitilities, spillover effect measures if volatility of other variables can affect it. In this paper, key concern is how volatilities of exchange rate, stock returns and oil prices are transferred to eachother and how big this effect is. We examine in this study the volatility

spillover between oil prices, stock prices and exhange rates (USD/EURO) over the period of January 4, 2000 to November 30, 2015 and we divided the data into two time periods on August 8, 2007 which is defined as the beginning date of global crisis by major economy agencies. Our target is to find if there is change in size of transmissions between these variables before and global crisis. We used Diebold and Yilmaz model which is really beneficial to measure dynamic spillover effects. Based on this approach, we create spillover index by using daily oil price data, daily exchange rate ratio of USD to EURO and daily S&P 500 price data.

Extension of this paper can be done through dividing the period into three sub periods and it provides more details for the period starting and ending in the time of the global crisis.

We structure the rest of the paper as follows, Section 2 provides the literature review, Section 3 describes the data and descriptive statistics, Section 4 tells about the methodology, Section 5 explains empiricial findings and section 5 provides the concluding remarks.

II. LITERATURE REVIEW

A number of researchers and economists have analyzed the relationship between oil prices, exchange rates and stock prices. They use mainly bi variate GARCH models but only some of them realize that Diebold and Yilmaz approach provides them to measure volatility spillovers dynamically. Generally, researchers analyze relations between couples like oil and exchange rate, or oil and stock market etc.

Fratzscher, Schneider and Robays (2014) investigate relationship between oil prices, the US dollar and asset prices. They find that there is bidirectional relation between the US dollar and oil prices since the early 2000s and both oil prices and US dollar are influenced with changes in risk and return of equity market while oil prices are not before 2001. As methodologically, their approach is trying to define multi-directional, contemporaneous causality between oil prices which is supposed as financial asset and asset prices by using heteroskedasticity. In their method, variance decomposition indicates that a small part of variation in oil prices and Exchange rates can be explained by schocks to other assets. They used one – day – ahead forecast error variance decompositions as the same is implied in this thesis. As a result, they found that there is strong negative correlation between oil prices and exchange rates since the early 2000s and global financial crisis creates a sharp rise in the correlation with risk and uncertainity.

Ebrahimi and Nooshinshokri (2013) investigate relation between oil price shocks and real effective exchange rates and also other macroeconomic variables. Their estimations based on SVAR model and they are using Blanchard-Qua approach. They apply variance decompositions for positive and negative formation of oil prices. They try to explain how it differs as positive or negative for changes in variables sourced from volatility of other variables. They found that response of the real effective exchange rate to a shock in increasing oil prices in the long term is positive while to a shock in negative oil price is negative and significant. It shows that when there is reduction in oil revenues, government implements export-oriented policies.

Chun Wei and Hsuan Chen (2014) analyzes how volatility of oil prices are affected by oil futures returns, exchange rate returns between the US dollar and Euro and the S&P 500 returns in their article. They use daily data from January 4, 2000 to September 30, 2009. They apply multivariate GARCH-BEKK model and it shows significant fluctations in oil market while those changes have a significant effect on exchange rates and stock prices. They also found that there is a strong relationship between oil prices, its' past volatility and volatility of exchange rates. Overally, their findings show that strong dependincies between those variables allow investors to take advantage of the exchange rates, oil prices and stock market index.

Lee, Liao, Ya Huang and Tzu Huang investigate the dynamic relationship between Brent oil prices and stock markets for oil-exporting and oil-importing countries seperately in their paper. They define Diebold and Yılmaz method as a new approach for spillover effect and they use this method instead of GARCH method. Their data insists of the observations from January 5, 1994 to December 28, 2012 for Canada, Brazil and Mexico as oil exporter countries and USA, Netherland and Germany as oil importer countries. They try to find which country is affecting other markets most and which is most affected by others. As dynamic spillover effect, they find major events which is affecting the oil and stock markets during their time period and split them before event and after event. Then, they examine those major events impact on dynamic return and volatility spillover between oil market and stock market. Dynamic spillovers change during the major events significantly. As a conclusion, oil market spillover on oil exporting countries

is more than oil-importing countries in terms of volatility. Net volatility spillovers from Brent oil to countries are net spillovers sent.

There is one another research done by Aloui and Aissa (2016) indicating the relationship between oil, stock prices and exchange rates. They apply vine copula based GARCH method. They use a data insisting of 10 years Daily return observations and they found a significant and symmetric relation among those variables. Copula approach introduced by Belford and Cooke (2001,2002) provides them to measure multivariate distrubutions of returns while other methods can only explain bivariate dependicies. They divide their study into six-sub periods to test whether crude oil data contain one or more structural break by defininf major events which affected the crude oil market. Dependence between oil and exchange rates is in lower level just after global crisis and their relation is negative, but dependence between oil and stock market is positive which means that an increase in the price of oil is related with the increase of stock market prices. They found that after financial crisis, all conditional and unconditional pairs become significantly dependents and multivariate dependence between series is highly affected by the financial crisis.

On the other hand, there are some researches analyzing the relation between oil and exchange rates and found insignificant relation. One of the good example of it has been published by Zhang, Fan, Tsai and Wei (2008) with the name as Spillover effect of US dollar exchange rate on oil prices. Their finding doesn't show that there is relation between variables, however they find that their spillover effect is unimportant and US dollar exchange rate

doesn't provide any significant change in the oil market. According to them, there is quite significant influence of US dollar exchange rate on the international crude oil market only in long term. They use TGARCH model of Zakoian (1994) to discuss this topic.

Chen and Chen (2007) test the relationship between real oil prices and exchange rate of G7 countries by using panel cointegration approach and found that there is significant relation between oil prices and exchange rates in the long term.

One another research analyzes the oil price volatility and real exchange rate relation for the case of Thailand that is written by Jiranyakul (2015). They use monthly data of oil price and real effective exchange rate in Thailand during July 1997 to December 2013. As Thailand has switched from fixed to floating exchange regime, it caused fluctations in nominal exchange rate and they try to find effects of exchange rate on oil prices. Their approach consists of bivariate GARCH model and Granger causality test. They found that real oil price volatility doesn't cause real effective exchange rate.

There are not many articles researching the effect of global crisis for stock, oil and exchange rates based on volatility spillover but there are some researches like Global Crisis effects on volatility spillover between China and Hongkong stock markets that is written by Zhang and Jaffry (2015). They use mainly ARCH and GARCH models and found that there is an increasing bi directional volatility spillover effect after global crisis.

Compared to other studies, this study is trying to explain the effect of global crisis on oil, stock and exchange rate markets by using volatility spillover approach and trying to find if there is difference for volaility transmission from those markets to eachother before and after crisis. Our research is quite new and includes daily data from 2000 to end of 2015.

III. DATA AND DESCRIPTIVE STATISTICS

This research aims to analyze the volatility spillover effect before and after 2008 Global Crisis among exchange rate of USD to EUR, oil prices and stock prices. Daily closing prices of S&P 500 are used as stock prices, spot price FOB (dollars per barrel) as oil prices and SDRs per currency unit USD to EUR same range for all data from January 4, 2000 to November 30, 2015. If there is no data for specific dates for each of the variable, then data in the same date has been removed from the list. Exchange rate information is taken as SDRs per currency unit from International Monetary Fund organization's data in local currency units. Crude oil prices information is extracted from Federal Reserve Bank of St. Louis sourced from US Energy Information Administration as spot prices in dollars per barrel and stock prices are taken from Bloomberg and CBOE.

We selected those data carefully since there is no study for the same date range which is analyzing effects of exchange rates, oil prices and stock prices to eachother. Stock prices were extremely high during the beginning of 2000s and while oil prices not but both of them follow a rising trend during global crisis. Oil prices fluctuated during the period. On the other hand, exchange

rates follow a similar trend until global crisis and it decresed until global crisis has finished but it increased sharply again towards end of the 2015.

In our sample, the logarithmic return of daily exchange rate, logarithmic return of daily crude oil prices and logarithmic return of daily closing prices are used from 4 January 2000 to 30 November 2015. Totally 3924 observations were used to analyze in this whole period. Indices can be found in the following table. (Table. 1).

Table. 1 Selected data variables, with their symbols used in the paper

	Data	Index	Symbol
1.	Exchange rates SDRs per unit	USD/EURO	EXC
2.	Crude Oil prices	Spot Price (Dollars per barrel in USD)	OIL
3.	Stock Prices	Standart & Poor's (S&P 500)	STOCK

We have divided the sample into two time ranges in order to observe if there are different results before and after global crisis 2008. The pre crisis period includes dates from 4 January 2000 to 08 August 2007 with 1868 obervations while the post crisis period includes dates from 09 August 2007 to 30 November 2015 with 2056 observations. 09 August 2007 is selected as the beginning date of global crisis since BNP Paripas announced cessation in three hedge funds in US Mortgage debt and following this, seizure in the banking system began in this date. (Elliott, L, 2011)

In the next section, descriptive statistics of the logarithmic return of daily exchange rate, logarithmic return of daily crude oil prices and logarithmic

return of daily closing prices have been shown in Table. 2, Table. 3 and Table. 4 for whole period, pre crisis period and post crisis period respectively.

Table. 2 Summary statistics on returns for the whole period

	EXCHANGE	OIL	STOCK
Full sample period: 4 January 2000 through 30 November 2015			
Mean	-6.69E-06	0.000117	0.000101
Median	-0.000144	0.000795	0.000538
Maximum	0.047355	0.191438	0.109572
Minimum	-0.042041	-0.170918	-0.094695
Std. Dev.	0.006592	0.024898	0.012795
Skewness	0.059773	-0.122783	-0.165376
Kurtosis	5.681,8560	8.062,9500	10.894,6000
Jarque-Bera	1.178.286,000	4.200.931,000	10.207,970
Probability	0.000000	0.000000	0.000000
Observations	3924	3924	3924

Table. 3 Summary statistics on returns for the pre-crisis period

	EXCHANGE	OIL	STOCK
Sample period: 4 January 2000 through 08 August 2007			
Mean	-0.000156	0.000556	3.63E-05
Median	-0.000140	0.001491	0.000461
Maximum	0.022521	0.124425	0.055732
Minimum	-0.042041	-0.170918	-0.060045
Std. Dev.	0.006376	0.024550	0.011169
Skewness	-0.228602	-0.586043	0.104468
Kurtosis	4.585.465,0	6.978.316,0	5.751.559,0
Jarque-Bera	2.119.195,0	1.338.794,0	5.926.798,0
Probability	0.000000	0.000000	0.000000
Observations	1868	1868	1868

Table. 4 Summary statistics on returns for the post-crisis period

	EXCHANGE	OIL	STOCK
Sample period: 9 August 2007 through 30 November 2015			
Mean	0.000129	-0.000282	0.000160
Median	-0.000144	4.82E-05	0.000661
Maximum	0.047355	0.191438	0.109572
Minimum	-0.040377	-0.128267	-0.094695
Std. Dev.	0.006780	0.025210	0.014113
Skewness	0.270629	0.268308	-0.286970
Kurtosis	6.392.014,0	8.995.316,0	1.200.839,0
Jarque-Bera	1.010.757,0	3.103.855,0	6.980.162,0
Probability	0.000000	0.000000	0.000000
Observations	2056	2056	2056

When we analyze the full period, oil data has the highest average return value and exchange rate has a negative daily mean returns. Standart deviation is the lowest for exchange rate compared to others and it can be said that oil data is most variable value. The highest sharp ratio belongs to stock data, followed by oil and exchange rate.

If we compare pre and post periods of the crisis, exchange rate still has a negative Daily mean returns before the crisis, while it turns out to positive after crisis. On the other hand, oil data has negative mean value after the crisis. In terms of volatility as reflected by the standart deviations, as expected all variables have greater volatilities after the crisis. Standart deviation of the oil has more increased than others. Daily mean returns after the crisis period are higher than the returns during the whole sample period except oil data. At the same time, standart deviations are higher compared the whole sample period.

As it can be seen in Table.2, Table.3, and Table.4, kurtosises are greater than 3 except stock data for post-crisis. It means that distrubutions are leptokurtic. Skewnesses are positive and negative in different periods for the observations and have not 0 value for any data. Normality of data is strongly rejected by the Jarque Bera Test statistics. As a result, whole, pre and post periods have not normal distribution.

In the following section, correlations among the logarithmic return of daily exchange rate, logarithmic return of daily crude oil prices and logarithmic return of daily closing prices have been shown in Table.5, Table.6 and Table.7 for the whole period, pre-crisis period and post-crisis period respectively.

Table. 5 Correlations for the whole period

Full period: 4 January 2000 through 30 November 2015			
	EXC	**OIL**	**STOCK**
EXC	1.000.000	-0.120555	-0.079461
OIL	-0.120555	1.000.000	0.196974
STOCK	-0.079461	0.196974	1.000.000

Table. 6 Correlations for the pre-crisis period

4 January 2000 through 08 August 2007			
	EXC	**OIL**	**STOCK**
EXC	1.000.000	-0.036813	0.038625
OIL	-0.036813	1.000.000	-0.032698
STOCK	0.038625	-0.032698	1.000.000

Table. 7 Correlations for the post-crisis period

09 August 2007 through 30 November 2015			
	EXC	**OIL**	**STOCK**
EXC	1.000.000	-0.189677	-0.159984
OIL	-0.189677	1.000.000	0.359713
STOCK	-0.159984	0.359713	1.000.000

Among our variables, correlations coefficient are greater for the oil and stock couple for whole period and post-crisis period. Exchange rate has a negative relation with oil and stock for all periods except it is positive only in pre-crisis period with stock data. It can be told that if exchange rate return value increases, oil and stock returns decrease. Correlation coefficients in post-crisis period are greater than pre-crisis period which means that they are affected by eachother morely after global crisis.

As it is reported in the tables above (Table. 5, Table. 6, Table. 7) there is a strong relation between oil and stock positively and their dependence increase after crisis. Crisis affects all variables in a way that their relations are increasing.

IV. METHODOLOGY

To measure volatility spillovers and return, vector autoregressive (VAR) model is used which is implied by Diebold and Yilmaz in their thesis published on 2009. They focus on variance decompositions that provide aggregate spillover across markets and create a single spillover measure from all information.

If we start with basic Stochastic Volatility model that is introduced by Taylor (1982, 1986), it will be easier to filter volatilities which is required to estimate variance decompositions and calculate the spillover index

Stochastic volatility model is

$$r_t = \exp(h_t / 2)\, \varepsilon_t , \qquad (1)$$

$$h_t = \upsilon + \phi\, (h_{t-1} - \upsilon) + \sigma\, \eta_t \qquad (2)$$

where εt and ηt are i.i.d N(0,1) , rt is the return and ht is the logarithm of the variance on day t. Equations (1) and (2) assumes that log variance vector h follows a stationary model of order 1 (AR1) with a common mean υ, a parameter ϕ (0,1) and a Gaussian noise ηt. The conditional distributions of the returns rt, given ht is Gaussian with the time varying variance. (Martino and Aas and Lindqvist and Rue, 2008). The non-linear dependence of rt, on ht in equation 1 prohibits application of Kalman filter. Alternatively, sequential Efficient Importance Sampling (EIS) is performed to evaluate likelihood function of basic SV model. EIS, introduced by Richard and Zhang (2007), generates accurate Monte Carlo estimates of likelihood functions for a wide range of SV models. (Liesenfeld and Richard, 2003 and 2006)

First of all, stationarity of the price and return series of 3 variables are tested in order to estimate the VAR model. Augmented Dicket Fuller (ADF) tests are performed at the level of price and return series. Table below provides ADF test statistics.

Table. 8 Augmented Dickey-Fuller test for stationarity

ADF Test Statistics			
Null Hypothesis: Unit root (individual unit root process)			
Price Series		**Return Series**	
Series	Prob.	Series	Prob.
USD EURO	0,6088	USD EURO	0,0001
OIL	0,3981	OIL	0,0001
STOCK	0,9239	STOCK	0,0001

The results show that all the stock price indices include a unit root that we cannot reject the null hypothesis of the presence of a unit root (non-stationarity) at level. However, if logarithmic return of series are taken, results show that all the return series are stationarity which means we can reject the null hypothesis.

The lag orders of the variables are determined by Akaike Information Criterion (AIC) in order to estimate the VAR model. 2 is selected as VAR order of series for all market estimations. Based on the selected lag order, model is formulated as

$$h_t^i = \alpha + \sum_{j=1}^{n} \beta_j h_{t-1}^j + \sum_{j=1}^{n} \vartheta_j h_{t-2}^j + \varepsilon_t \qquad (3)$$

where h_t^i represents the return volatility for variable i, h_t^j is the return volatility of variable j representing each of the remaning selected variables except variable i.

Diebold and Yilmaz (2009) assumes a covariance stationarity first-order, two variable VAR model

$$z_t = \varphi z_{t-1} + \varepsilon_t \quad (4)$$

where $z_t = (z_{1,t}, z_{2,t})'$ and φ is a 2 x 2 matrix of parameters. Below equation gives moving average representation of the VAR,

$$z_t = \Theta(L)\varepsilon_t \quad (5)$$

where $\Theta(L) = (I - \Theta \mathrm{L})^{-1}$. If we rewrite the equation based on Cholesky decomposition,

$$\mathrm{T}(L) = \Theta(\mathrm{L})\mathrm{C}_t^{-1}$$

$$u_t = C_t\, \varepsilon_t$$

where $\mathrm{E}(u_t\, u') = I$ and C_t^{-1} is the unique lower triangular Cholesky factor of the variance matrix of ε_t , then the equation can be simplified to

$$z_t = \mathrm{T}(L)u_t \quad (6)$$

Optimal one-step ahead forecast is

$$z_{t+1,t} = \varphi\, z_t \quad (7)$$

with the related one-step-ahead forecast error vector

$$e_{t+1,t} = z_{t+1} - z_{t+1,t} = T_0 \quad u_{t+1} = \begin{bmatrix} t_{0,11} & t_{0,12} \\ t_{0,21} & t_{0,22} \end{bmatrix} \begin{bmatrix} u_{1,t+1} \\ u_{2,t+1} \end{bmatrix}$$

(8)

that has the covariance matrix of the form

$$\mathrm{E}(e_{t+1,t}\, u'_{t+1,t}) = T_0\, T'_0 \tag{9}$$

In a two variable VAR system, there can be two different spillovers, one is from variable 1 to variable 2 with a contribution of $t^2_{0,21}$ and the other from variable 2 to variable 1 with a contribution of $t^2_{0,12}$. Total spillover can be calculated as $t^2_{0,21} + t^2_{0,12}$. So that, the spillover index is the ratio of the total spillover to total forecast error variation which is equal to

trace $(T_0\, T'_0)$. Then the ratio is,

$$S = \frac{t^2_{0,21} + t^2_{0,12}}{\text{trace}\ (T_0\, T'_0)}\ x\ 100 \tag{10}$$

The generalized version of the spillover index in a system with N variables is

$$S = \frac{\sum^{N}_{i,j=1} (i \neq j) t^2_{0,ij}}{\text{trace}\ (T_0\, T'_0)}\ x\ 100 \tag{11}$$

Variance decompositions for t+1, t+5, t+10 and t+15 before the 2008 year and after it are estimated in this thesis. It will help us to see the change in spillover index which can be sourced from the global crisis on 2008.

V. EMPIRICAL RESULTS

As it is mentioned in the methodology part, method belonging to Diebold and Yilmaz (2009) is used in this thesis to examine the relationship between exchange rate, oil price and stock prices in terms of volatilities with global crisis effect. In the next section, analysis of those three data's volatility spillovers will be provided. In our analysis, we are decomposing the spillover index into all of the forecast error variance components for variable i coming from countries to variable j, for all i and j.

Volatilility spillovers are determined over the whole period January 2000 – November 2015, the pre-crisis period, January 2000 – August 2007 and post crisis period, September 2007 – November 2015. After that, rolling window estimation is used to indicate time variation in spillovers. Total volatility spillover indexes are reported in Table. 9. Other ''Spillover tables'' for different time periods will be shown in Table. 10 and Table. 11 accordingly. The off-diagonal row sum is the directional volatility spillover of variable i from variable j (stated as '' Contribution from others '') and the off-diagonal column is the directional contribution of variable i to variable j (stated as '' Contribution to others ''). Totals are giving the the numerator of the spillover index, the column sums or row sums are giving the denominator of the spillover index.

The total volatility spillovers are being showed in the Table. 9. It can be easily understood that there is an increasing spillover among the variables as time

goes by. If we compare periods, spillovers increase in a huge amount after crisis. Spillover is at the highest level in the post-crisis period.

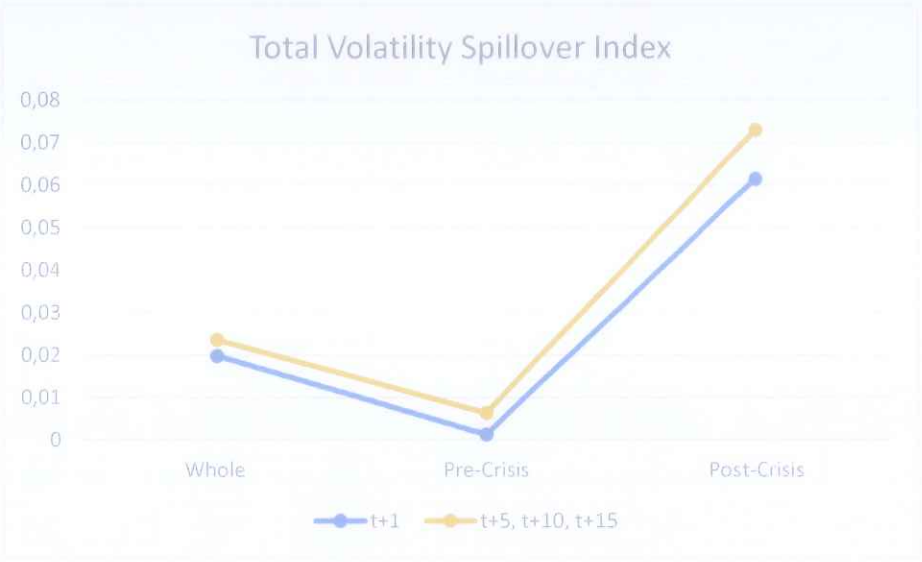
Table. 9 Total Volatility Spillover Index

Total Volatility Spillover Index			
Time	**Whole**	**Pre-Crisis**	**Post-Crisis**
t+1	0,019797	0,00127	0,061426
t+5	0,023591	0,006349	0,0728828
t+10	0,023591	0,006349	0,0728829
t+15	0,023591	0,006349	0,0728829

Note: The numbers are the total volatility spillover indexes.

Below figure shows that total volatility spillover index increases in the post-crisis period. In the pre-crisis period, total spillover index is changes between %0,12 and %0,63 but it sharply increased after crisis to %6,1 and %7,2. If we examine only whole period and don't divide the time into two periods, spillover index changes between %1,9 and %2,3 which is higher than the values in pre-crisis period but lower than the values in post-crisis period. Accordingly, it can be summarized as variables are more correlated in the post-crisis period and shock transmission of variables are stronger. If only the whole sample is taken into account volatility spillover index numbers can be misleading about the period after the crisis since whole sample period is much lower than the post-crisis index. Therefore, splitting the sample based on the crisis period provides more information in terms of the spillover rather than analyzing the whole sample period.

Figure. 1 Total Volatility Spillover Graphic



We will also comment on the spillovers from each variable to others for volatility series but we will only focus on the pre and post-crisis periods since volatility spillover indexes reveal that whole sample period analysis may be misleading.

Table. 10 shows the results of volatility spillovers series in the pre-crisis period. According to the table stock prices have the highest stock return volatility spillover to others. Highest spillover from stock prices to the others is mainly to USD/EURO prices. Crude oil prices have less return volatility spillover at time t+1 and it stays the same for t+5, t+10 and t+15. Stock prices are the highest contributor and least contributed. Furthermore exchange rate receives the highest spillover from the other variables. But at the same time exchange rates have the highest net spillover.

Table. 10 Volatility Spillovers for pre-crisis period

	Time	USD/ EURO PRICES	CRUDE OIL PRICES	S&P 500 STOCK PRICES	CONTRIBUTION FROM OTHERS
USD/ EURO PRICES	t + 1	100,000000	-	-	-
	t + 5	98,789130	0,014490	1,196383	1,210873
	t + 10	98,789110	0,014491	1,196404	1,210895
	t + 15	98,789110	0,014491	1,196404	1,210895
CRUDE OIL PRICES	t + 1	0,156933	99,843070	-	0,156933
	t + 5	0,266952	99,631970	0,101078	0,368030
	t + 10	0,266963	99,631940	0,101097	0,368060
	t + 15	0,266963	99,631940	0,101097	0,368060
S&P 500 STOCK PRICES	t + 1	0,139838	0,084309	99,775850	0,224147
	t + 5	0,237434	0,088247	99,674320	0,325681
	t + 10	0,237435	0,088249	99,674320	0,325684
	t + 15	0,237435	0,088249	99,674320	0,325684
CONTRIBUTION TO OTHERS	t + 1	0,296771	0,084309	-	
	t + 5	0,504386	0,102737	1,297461	
	t + 10	0,504398	0,102740	1,297501	
	t + 15	0,504398	0,102740	1,297501	
CONTRIBUTION INCLUDING OWN	t + 1	100,296771	99,927379	99,775850	
	t + 5	99,293516	99,734707	100,971781	
	t + 10	99,293508	99,734680	100,971821	
	t + 15	99,293508	99,734680	100,971821	
NET SPILLOVER	t + 1	0,296771	0,241242	0,224147	
	t + 5	1,715259	0,470767	1,623142	
	t + 10	1,715293	0,470800	1,623185	
	t + 15	1,715293	0,470800	1,623185	

The volatility series for the post-crisis period can be found in Table. 11 below

Table. 11 Volatility Spillovers for post-crisis period

	Time	USD/ EURO PRICES	CRUDE OIL PRICES	S&P 500 STOCK PRICES	CONTRIBUTION FROM OTHERS
USD/ EURO PRICES	t + 1	100,000000	-	-	-
	t + 5	97,992930	1,177988	0,829078	2,007066
	t + 10	97,992930	1,177989	0,829080	2,007069
	t + 15	97,992930	1,177989	0,829080	2,007069
CRUDE OIL PRICES	t + 1	3,467684	96,532320	-	3,467684
	t + 5	3,432439	95,336500	1,231056	4,663495
	t + 10	3,432438	95,336480	1,231077	4,663515
	t + 15	3,432438	95,336480	1,231077	4,663515
S&P 500 STOCK PRICES	t + 1	3,188734	11,771390	85,039880	14,960124
	t + 5	3,133099	12,061190	84,805710	15,194289
	t + 10	3,133091	12,061180	84,805730	15,194271
	t + 15	3,133091	12,061180	84,805730	15,194271
CONTRIBUTION TO OTHERS	t + 1	6,656418	11,771390	-	
	t + 5	6,565538	13,239178	2,060134	
	t + 10	6,565529	13,239169	2,060157	
	t + 15	6,565529	13,239169	2,060157	
CONTRIBUTION INCLUDING OWN	t + 1	106,656418	108,303710	85,039880	
	t + 5	104,558468	108,575678	86,865844	
	t + 10	104,558459	108,575649	86,865887	
	t + 15	104,558459	108,575649	86,865887	
NET SPILLOVER	t + 1	6,656418	15,239074	14,960124	
	t + 5	8,572604	17,902673	17,254423	
	t + 10	8,572598	17,902684	17,254428	
	t + 15	8,572598	17,902684	17,254428	

As reported in Table. 11, there is change in terms of the results in the contribution to others field and here crude oil prices is the variable which has higher contribution to others and exchange rates and stock prices follow it accordingly. In terms of the contribution from others results reveal that in the post-crisis period stock prices receive the highest spillover from other variables which shows that the stock market became more fragile and more prone to other variables. Netspillover values increased heavily when we

compare with pre-crisis period. However, crude oil prices have the highest net spillover and exchange rates have the lowest while it was in the first rank during pre-crisis period. Exchange rates are the least contributed from others and stock prices are the highest, while it was vice versa during pre-crisis period. Most influenced variable is the exchange rate during pre-crisis period but it changes after crisis and stock prices become the most influenced by others. We can conclude that crisis affected variables and it changed the spillover dynamics between variables.

VI. CONCLUDING REMARKS

This paper examines the dynamic linkages among exchange rates, oil prices and stock prices and their reactions to global financial crisis. Diebold and Yilmaz (2012) is used to determine volatility spillovers among the variables and this methodology contributed the research in terms of the intensity and magnitude of volatility spillovers, both in static way and in dynamic way since it quantities the results. The data covers the daily returns from January, 2000 to November, 2015 and also period is divided into two sub periods, namely the pre-crisis period (4 January 2000 – 08 August 2007) and the post-crisis period (09 August 2007 – 30 November 2015)

Other researches have been documented in literature review part. Many articles have been written to understand relation among oil prices, stock prices and exchange rates but generally they examine the relations bi-directionally and pairwise. Some found that there is positive relations between variables

and some other found negative for the short term but positive in the long term. Our research reveals the global crisis effect on variables in a dynamic way.

As we see in correlation tables, relation becomes stronger during the post-crisis period which mean that their effect to eachother and dependency increase after crisis and the strongest relation is between oil and stock market. Augmented Dickey-Fuller results indicate that the variables are stationary after logarithmic returns of series are taken.

We have only focused on volatility spillovers for the pre and post crisis periods because indexes reveal that if whole sample period analysis is taken into to analysis, it may be misleading. When we take the contribution from others consideration into, results show that stock market index receive highest spillover from other variables and it means that stock market becomes more fragile and prone to other variables. Global crisis affects the netspillover values and they increase a lot during post-crisis period. Crude oil prices become the the first in terms of net spillover and exchange rate become the last although it has the highest during pre-crisis period. If we come to the most influenced variable, it was exchange rates during pre-crisis period but stock prices took the place of it after crisis.

Finally, these results reveal that global crisis affected variables and it created a great change for volatility spillover dynamics among the variables. The investigation of the dynamic linkages among oil prices, stock market index and exchange rates can be extended by adding a sub period which starts on 2007 and ends on 2009 to measure volatility spillover effect during crisis

time. This research offers investors to diversificate their portfolios by taking the relation among these variables into consideration.

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