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THE EFFECT OF 2008 CRISIS ON THE VOLATILITY SPILLOVERS
AMONG SIX MAJOR MARKETS

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MAY, 2015

The Effect of 2008 Crisis on the Volatility Spillover Among Six Major Markets

2008 Krizininm 6 Başlıca Market Arasındaki Yayılma Endeksine Etkisi

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Tezin Onaylandığı Tarih : 03.06.2015

Toplam Sayfa Sayısı: 30

Anahtar Kelimeler (Türkçe)

- 1) Spillover Effect
- 2) Volatility Spillover
- 3) 2008 Financial Crisis
- 4) Global Portfolio Diversification
- 5) Stock Market Return

Anahtar Kelimeler (İngilizce)

- 1) Yayılma Etkisi
- 2) Oynaklık yayılma Etkisi
- 3) 2008 Finansal Krizi
- 4) Global Portföy Çeşitlendirmesi
- 5) HisseSenedi Piyasa Getirisi

Abstract

The scope of this paper is to determine whether global stock markets treat differently under conditions of economic crisis by measuring volatility spillovers among six major markets, namely the US, the UK, Germany, Spain, Turkey and Greece. We examine the volatility spillover effects of the 2008 US financial crisis to these six major markets using daily stock returns from January 2003 to December 2014, analyzing before, during and after the 2008 financial crisis. By dividing the study periods into the pre-crisis, during crisis and post-crisis periods, this enables us to explore whether the volatility spillovers between these countries change due to the crisis. We use Diebold and Yilmaz model and focus on variance decompositions that are derived from vector autoregressive (VAR) models. This model allows us to combine spillover effects between global markets. The empirical findings support the general view of other researchers as mentioned in the literature section and suggest that stock markets tend to show increased volatility spillovers during the crisis period, thus resulting in lesser benefit of diversification that can be gained by investors trading in these markets.

Keywords: Spillover Effect, Volatility Spillover, The 2008 Financial Crisis, Global Portfolio Diversification, Stock Market Return

Özet

Bu çalışmanın amacı; ekonomik kriz koşulları altında global hisse senedi piyasalarının farklı davranıp davranmadığını Amerika, İngiltere, Almanya, İspanya, Türkiye ve Yunanistan olarak adlandırılan altı büyük ülke arasındaki oynaklığın yayılma etkisini ölçerek tanımlamaktır. Biz 2008 Amerika finansal krizinin bu altı büyük ülkeye olan oynaklık yayılma etkilerini, Ocak 2003'ten Aralık 2014'e kadar olan günlük hisse senedi getirilerini kullanarak, 2008 finansal krizi öncesi, kriz süresince ve kriz sonrası analizini ederek inceliyoruz. Çalışma periodunu kriz öncesi, kriz süresince ve kriz sonrası olarak bölmek, bu ülkeler arasındaki oynaklık yayılma etkilerinin krizden kaynaklı değişip değişmediğini bulmamızı sağlamaktadır. Biz Diebold&Yilmaz modelini kullanıyoruz ve vektör otoregresif modellerden elde edilmiş olan sapmaların ayrışımalarına yoğunlaşıyoruz. Bu model bize global piyasalar arasındaki oynaklık yayılma etkilerini birleştirmeye izin verir. Ampirik bulgular literatür bölümünde de bahsedildiği gibi diğer araştırmacıların genel görüşlerini destekliyor ve ileri sürüyor ki hisse senedi piyasaları kriz dönemi süresince artan bir oynaklık yayılma etkileri eğilimi gösteriyor. Dolayısıyla bunun sonucunda da bu piyasalara katılan yatırımcılar çeşitlendirme etkisinin faydasını daha az kazanabilir.

Anahtar Kelimeler: Yayılma Etkisi, Oynaklık Yayılma Etkisi, 2008 Finansal Krizi, Global Portföy Çeşitlendirmesi, Hisse Senedi Piyasa Getirisi

Acknowledgements

I would like to express my sincere appreciation to my supervisor, Asst. Prof. Serda Selin Öztürk who always supported me throughout my thesis with her patience. I am also grateful for her deep kindness, encouragement and assistance from the beginning to the end of my research. I am thankful for her friendly supervision such that she provided me to end up my study and graduate experience successfully.

Very special thanks to my close friend and venerable manager for their supports, toleration, encouragement and understanding during my graduate study.

Finally, I would like to thank to my family for their endless support through all my life. Their great encouragement and willingness have always helped me to overcome all difficulties in every step of my life.

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I. Introduction

There has been a growing financial integration and innumerable volatility transmission channels in the global market so much so that a crisis which arises locally may turn into a global dimension. During the 1990s, several crises such as “Tequila effect” (in 1994), “Asian flu” (in 1997), “Russian cold” (in 1998), and “Brazilian fever” (in 1999) occurred in emerging market economies. These crises firstly originated as country-specific shocks, but then spread to other emerging and developed countries.

Recently, the subprime mortgage crisis burst out in August 2007 in the US has often been referred to as the worst financial crisis ever since the Great Depression of 1930s. The financial markets and economy of the US has not only been impressed by this financial crisis, but it has also expanded to the other emerging and developed countries’ financial markets worldwide. As a result of this 2008 financial crisis, there were collapses of the financial institutions, failure of major businesses, stock market crashes and liquidity problems in the credit markets, insolvency threats to investment banks, decline in household wealth, stock wealth and consumption in the USA.

Volatility spillover implies to the spread of market disturbances from one stock to another, a process observed through movements in stock prices. Returns in the market are characterized by high volatility. That is, returns appear volatile to both downside and upside risks. According to the portfolio theory proposed by Markowitz (1952), investors should increase their investment proficiency by analyzing their portfolios with regard to the greatest return at the lowest possible risk. Correlations between investment objects are the key of an effective investment allocation in this theory. That’s why, it is no doubt that an accurate characterization of volatility spillovers and risk diversification have high importance for financial hedging, portfolio management and asset allocation. Stock markets of two countries can be highly correlated due to strong financial, economic ties and similarities in macroeconomic policy implementations between the countries and this correlation can increase greatly at the distressed periods like crises. However, investing in highly correlated (integrated) stock markets on the global dimension enables limited diversification benefits to the investors obviously.

This paper is related to the line of literature on stock market inter-linkages and integration. If there is a stock market inter-linkages, then global or local shocks in economic, financial,

political, fundamental areas would be transmitted from one to another market and most often in the form of volatility spillovers. Hence, in this study, we examine the volatility spillover processes between different countries' markets over the period from January 2003 to December 2014 which includes the 2008 global crisis. The objective of this paper is to investigate the transmission of the US financial crisis to financial markets in the UK, Germany, Spain, Greece and Turkey, analyzing before, during and after the 2008 deep financial crisis period. For our analysis, we use Diebold and Yilmaz (2009) model. According to this model, we constitute a spillover index using daily stock market data from the above mentioned six different economies in order to estimate the level of information transmission in these stock markets. Subsequently, we reach the dynamic co-movements which generates the transmission process between and among markets by analyzing the spillover effects in these stock markets. To that end, the results of this paper will provide information on whether the cross-market linkages between these markets change over time due to the crisis by dividing the study periods into pre-crisis, during crisis and post-crisis periods. The paper claims that a well-diversified portfolio is substantially linked to accurate comprehending of how closely international stock market returns are correlated notably at the turmoil periods for global investors.

The remainder of the paper is organized as follows: The next section (Section 2) provides an overview of related literature. In the next section that follows (Section 3), we explain our data and summary statistics. Then we present our methodology in Section 4. We evaluate our findings in the section titled "Empirical Results" part (Section 5). In the last section of the paper (Section 6), we summarize our findings.

II. Literature Review

Over the last two decades, a number of researchers and economists have analyzed various aspects of the international co-movements of stock returns due to the increasing integration within and across regional financial markets. Some of them have investigated just spillover effects between selected countries or sectors (Baele, 2005). On the other hand, some of them have analyzed spillover effects under crisis conditions (Anbar et al., 2011; Sugimoto et al., 2014).

Tsai (2014) examines the spillover effect in five leading stock markets (i.e., the US, the UK, Germany, Japan and France) using Diebold and Yilmaz (2012) methodology which is based on VAR model. He uses monthly index return data of the above stock markets from January 1990 to May 2013. He finds that, information transmission increases substantially between these

stock markets after 1998. He also finds that Germany and the US are the major stock markets such that they sustain the information to others and the US significantly influences other countries even in crisis periods.

Trenca and Dezsi (2013) investigate the interdependence, integration, contagion and spillover effects as possible linkages between 22 European emerging and developed stock markets from January 2001 to March 2012 (i.e., Netherlands, Greece, Austria, Belgium, Romania, Hungary, France, Croatia, Germany, the UK, Italy, Spain, Ireland, Denmark, Latvia, Sweden, Estonia, Lithuania, Portugal, Czech Republic, Bulgaria and Poland). They employ various multivariate GARCH models, namely the CCC (Constant Conditional Correlation), the DCC (Dynamic Conditional Correlation) and the BEKK (Baba-Engle-Kraft-Kroner). Their results suggest that developed markets are integrated only spillover effects with no contagion effect and the other emerging markets present medium degree of dependence. Also, they find contagion and spillover effects during the 2008 Financial Crisis in all the European markets, even if they are not integrated by strong dependence which implies that direct linkages carry over the shocks.

Atukeren et al. (2012) analyze the spillovers between business confidence and stock returns for the four economically distressed Southern European countries, namely Italy, Greece, Spain and Portugal for the period from January 1988 to December 2010. They employ Hong's (2001) version of Cheung and Ng's (1996) causality-in-mean and causality-in-variance tests by using monthly data. Their results show that each stock market and business confidence relationship have its own specific properties such that they react differently to the current macroeconomic environment and expectations about the future developments.

Grobys (2010) investigates volatility spillover effects in Great Britain, Germany, France and Sweden covering daily data from 26.11.1990-05.10.2000 to 06.10.2000-28.05.2010. In this study Vector-Auto Regression (VAR) models are used and the results show that the correlations and the volatility spillover effects between these European stock markets have increased over time such that the volatility spillover impact of the German stock market to the Swedish stock market have increased by 73.87% compared to the decade before.

Stock market returns and volatility spillover between politically foe emerging countries in the past ten years, namely Israel-Jordan, India-Pakistan, Greece-Turkey and the US which has been friendly to these six countries is analyzed in the paper written by Choudhry (2004). Daily stock returns of these seven countries from January 1, 1991 to June 30, 2001 and a nonlinear

GARCH-t model are used in this paper. Results show that there is a bidirectional mean and volatility spillover between two countries on unfriendly terms and the mean and volatility spillover originates from a larger friendly country (the US) to these foes smaller emerging markets, but not much the other way around.

On the other hand, some researchers have intensified the spillover effects between international financial markets under crisis condition. Hwang (2014) analyzes the transmission of the 2008 global financial crisis to four Latin American stock markets (i.e., Argentina, Brazil, Chile and Mexico) from January 2006 to December 2010. He uses daily data in DCC-GARCH model and analyzes before, during and after the 2008 financial crisis effects to these countries. Results show that there is a strong financial contagion and critical changes in mean and volatility of these Latin American markets due to the 2008 financial crisis.

Meric et al. (2012) examine the contemporaneous co-movements and time-series lead/lag linkages between the U.S., Latin American (i.e., Argentina, Brazil, Mexico), European (i.e., Austria, France, Germany, Holland, Norway, Spain, Sweden, Switzerland, the UK) and Australasian (i.e., Australia, China, Hong Kong, India, Indonesia, Israel, Japan, South Korea, Malaysia, New Zealand, Singapore, Taiwan) stock markets during the October 8, 2007 - July 26, 2010 period. They use weekly return data in time-varying correlation analysis, principal component analysis (PCA) and Granger-Causality (G-C) statistical techniques. They find that correlation between global stock markets has increased and the benefit of global portfolio diversification has decreased due to the 2008 stock market crash and the US stock market has influenced on the other European and Australian stock markets.

Samarakoon (2011) focuses on the transmission of shocks between the US, emerging and frontier markets in order to explain the interdependence from contagion of the 2008 US financial crisis. This article uses daily market indices for 62 markets involving of 22 emerging markets and 40 frontier markets during the 01.04.2000 to 03.09.2009 period. Two shock models based on the VAR framework representing partially overlapping and non-overlapping emerging and frontier markets are used. The empirical results show that there is an important bi-directional, asymmetric interdependence and contagion in emerging markets. Also interdependence is led more by US as contagion is led more by emerging markets and frontier markets displays interdependence and contagion to US shocks.

Chakrabarti (2011) views the presence and the changing nature of volatility contagion in the Asia-Pacific region, namely Australia, New Zealand, India, China, Japan, Hong Kong,

Jakarta and Malaysia around the financial crisis of 2007-2008. Daily stock index data is used for the period of June 2006 – December 2010 by separating this period into three sub-periods (i.e., pre-crisis, crisis and post-crisis period). She finds out Asia-Pacific region is a profitable place for investment which implies that the presence of volatility spillover can reduce volatility of risk-adjusted return, but cannot affect the mean risk-adjusted return by using multivariate GARCH approach.

Gklezakou and Mylonakis (2010) employ the interdependence among the price indices of 10 international stock markets, namely the USA, Belgium, France, Germany, Greece, Italy, the Netherlands, Spain, the UK and Japan under conditions of economic crisis. They use the daily closing price of the above indices from January 1, 2000 to February 20, 2009 by separating this period into three sub-periods (i.e., pre-crisis, crisis and post-crisis period) in correlation coefficient analysis and Granger-Causality tests. They find that these markets have been more closely connected and the USA and Germany have a dominant influence on the other stock indices during the crisis.

Majid and Kassim (2009) labor the integration and co-movements of the US, Indonesia, Malaysia, the UK and Japan stock markets under the condition of the 2007 US financial crisis. They use daily closing data of these five stock markets from February 15, 2006 to December 31, 2008 by dividing the period into two sub-periods (i.e., pre-crisis and during crisis period). They also use time series techniques of co-integration, impulse response functions (IRFs) and variance decompositions (VDCs) in their methodology. Their findings provide that there is a great degree of integration between the markets during the crisis period such that investors who participate in these markets have lesser benefits of diversification.

Besides the 2008 US global financial crisis, Arshanapalli et al. (1995) investigate the links and dynamic interactions between the US and six major Asian stock markets, namely Japan, Thailand, Hong-Kong, Singapore, Philippines and Malaysia before and after October 1987 stock market crash. They use daily closing stock market indices over the January 1986 to May 1992 period by dividing the period into two sets (i.e., pre-crash and post-crash). Using Johansen's multivariate co-integration tests and performing multivariate error-correction analysis, they find that co-integrating structure between these markets has extremely increased since October 1987 and the US influences on other markets is greater during the post-crash period.

Diebold and Yilmaz (2012) analyze the total and directional volatility spillovers. They have developed their own method to see daily volatility spillovers over U.S. stock, bond, foreign exchange and commodity markets from January 1999 to January 2010 period. They find that there are volatility fluctuations in all four markets, but this cross-market volatility spillover is restricted until the 2008 financial crisis.

Furthermore the interdependence of asset returns and volatility is examined by Diebold and Yilmaz (2009). They also analyze the return and volatility spillovers separately. They find out that return spillovers present an increasing trend but no burst though volatility spillovers display no trend but clear bursts by using VAR models.

Compared to the studies discussed earlier, we are particularly interested in the transmission of the US financial crisis to financial markets in the UK, Germany, Spain, Greece and Turkey, analyzing before, during and after the 2008 deep financial crisis period. Our study covers the most recent period of January 2003 to December 2014 using daily data. We find strong evidence of a contagion effect on these six stock markets during the 2008 financial crisis period and these stock markets are substantially affected by the US market using Diebold and Yilmaz (2009) model.

III. Data and Descriptive Statistics

This research aims to study the volatility spillover effects before, during and after the 2008 crisis among 6 international stock markets. We use daily closing price data of six selected stock markets, namely the USA, UK, Germany, Spain, Greece and Turkey, covering the period from January 3, 2003 to December 30, 2014. All the indices are denominated in local currency units, extracted from the Wall Street Journal Market Data Center.

We select these 6 specific markets since 2008 global financial crisis broke out in the USA and it affected almost the whole world markets. The United Kingdom and Germany are undoubtedly the leading economies in Europe. Spain and Greece are the most important countries which are affected mostly by the 2008 global crisis in the Mediterranean area. Turkey also is a developing country which is less affected by the 2008 crisis in this region.

The sample contains the logarithmic daily closing prices of the following indices from 3 January 2003 to 30 December 2014 (Table.1). 2761 observations were analyzed in this whole period from 3 January 2003 to 30 December 2014.

Table.1 Selected stock markets, along with the used stock indices

	Country Stock Index	Symbol
1.	USA Standard&Poor's (S&P 500)	S&P
2.	UK The Financial Times Stock Exchange (FTSE 100)	FTSE
3.	Germany Deutscher Aktienindex (DAX 30)	DAX
4.	Spain Índice Bursátil Español (IBEX 35)	IBEX
5.	Turkey Borsa İstanbul (BIST 100)	BIST
6.	Greece The Athens Stock Exchange	ATHEX

Furthermore, we have divided the sample into three sub-samples in order to empirically determine and analyze how these 6 selected countries were affected before and after by the 2008 global crisis. The pre-crisis period covers 3 January 2003 through 31 October 2007 (1111 observations). While during the crisis period, 1 November 2007 – 27 February 2009 (303 observations), all the markets boomed. The post-crisis period extends from 3 March 2009 to 30 December 2014 (1347 observations).

Table.2, Table.3, Table.4 and Table.5 provide the descriptive statistics of the daily stock return of the 6 selected countries over the entire period, the pre-crisis period, 2008 global financial crisis period and the post-crisis period, respectively. The stock returns are calculated as the change in log prices from day t to day $t+1$.

Table.2 Summary statistics on stock returns for the whole period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Full sample period: 3 January 2003 through 30 December 2014						
Mean	0,0002	- 0,0003	0,0000	0,0006	0,0000	0,0002
Median	0,0008	0,0004	0,0007	0,0011	0,0004	0,0008
Maximum	0,1080	0,0964	0,1348	0,1213	0,0938	0,1096
Minimum	- 0,0734	- 0,1367	- 0,0959	- 0,1334	- 0,0927	- 0,0947
Std. Dev.	0,0140	0,0185	0,0147	0,0187	0,0117	0,0123
Skewness	- 0,0822	- 0,2873	0,0944	- 0,2849	- 0,1844	- 0,5345
Kurtosis	8,0309	6,3833	9,6161	7,6188	11,2544	13,4532
Jarque-Bera	2.914,781	1.354,821	5.039,769	2.491,568	7.854,041	12.702,090
Probability	0	0	0	0	0	0
Observations	2761	2761	2761	2761	2761	2761

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

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

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Pre-crisis period: 3 January 2003 through 31 October 2007						
Mean	0,0006	0,0008	0,0006	0,0013	0,0003	0,0004
Median	0,0012	0,0011	0,0011	0,0016	0,0007	0,0008
Maximum	0,0664	0,0614	0,0405	0,1096	0,0590	0,0348
Minimum	- 0,0634	- 0,0611	- 0,0424	- 0,1334	- 0,0492	- 0,0360
Std. Dev.	0,0120	0,0109	0,0095	0,0196	0,0089	0,0080
Skewness	- 0,2004	- 0,2174	- 0,4091	- 0,3806	- 0,1315	- 0,1606
Kurtosis	6,1496	5,9078	5,2311	7,9543	7,3417	4,7297
Jarque-Bera	466,658	400,176	261,432	1.163,044	875,800	143,278
Probability	0	0	0	0	0	0
Observations	1111	1111	1111	1111	1111	1111

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Table.4 Summary statistics on stock returns for the crisis period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Crisis period: 1 November 2007 through 27 February 2009						
Mean	- 0,0030	- 0,0041	- 0,0028	- 0,0032	- 0,0026	- 0,0030
Median	- 0,0021	- 0,0037	- 0,0031	- 0,0039	- 0,0018	- 0,0009
Maximum	0,1080	0,0833	0,1012	0,1213	0,0938	0,1096
Minimum	- 0,0734	- 0,1021	- 0,0959	- 0,0901	- 0,0927	- 0,0947
Std. Dev.	0,0214	0,0228	0,0225	0,0261	0,0216	0,0242
Skewness	0,2757	- 0,2631	0,1508	0,2669	0,0453	- 0,2564
Kurtosis	7,5924	5,2196	6,5442	5,3125	6,8435	6,2396
Jarque-Bera	270,101	65,693	159,737	71,115	186,611	135,822
Probability	0	0	0	0	0	0
Observations	303	303	303	303	303	303

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Table.5 Summary statistics on stock returns for the post-crisis period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Post-Crisis period: 3 March 2009 through 30 December 2014						
Mean	0,0006	- 0,0002	0,0002	0,0009	0,0004	0,0008
Median	0,0009	0,0001	0,0006	0,0013	0,0005	0,0009
Maximum	0,0590	0,0964	0,1348	0,0690	0,0503	0,0684
Minimum	- 0,0599	- 0,1367	- 0,0687	- 0,1106	- 0,0478	- 0,0690
Std. Dev.	0,0133	0,0220	0,0158	0,0155	0,0105	0,0111
Skewness	- 0,0580	- 0,1664	0,3111	- 0,4318	0,0194	- 0,0892
Kurtosis	5,3888	4,8439	7,9953	6,6669	5,2658	7,6716
Jarque-Bera	321,013	197,041	1.422,194	796,508	288,210	1.226,639
Probability	0	0	0	0	0	0
Observations	1347	1347	1347	1347	1347	1347

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Among the 6 specific countries' stock indices listed, all the countries' markets except for Greece have positive daily mean returns during the full sample period. The average returns range from -0,000252 (Greece) to 0,000636 % (Turkey). Standard deviations range from 0,011747 (the UK) to 0,018654 % (Turkey). Although Turkey has a highest mean value, in terms of relative risk-return trade, the highest Sharpe Ratio is for the USA, followed by Germany and the UK.

It is interesting and not surprising to note that in the pre-crisis period, all stock markets give positive average daily returns, while in the crisis period, all of the markets have negative mean returns, suggesting that environment during the crisis brought down the returns associated to a higher risk. Specifically, in the pre-crisis period, Turkish market recorded the highest average daily returns at 0,001341 %, followed by Greece 0,000783 %, Spain 0,000583 %, Germany 0,000563 %, the USA 0,00039 % and the UK 0,000338 %, while in the crisis period, the UK market has the lowest average daily losses at -0,002611 %, followed by Spain -0,002819 %, the USA -0,002988 %, Germany -0,003013 %, Turkey -0,003151 % and Greece -0,004088%. In terms of volatility as reflected by the standard deviations, as expected, all the stock markets have greater volatilities during the crisis period than the pre-crisis period. Standard deviations range from 0,007989 (the USA) to 0,019599 % (Turkey) in the pre-crisis period, while this range changes such that Germany has the lowest volatility at 0,021426 % and Turkey has the highest volatility at 0,026069 % during the crisis period. Daily average returns during the post-crisis period are higher than the returns during the whole sample period. At the same time, the

standard deviations are also lower except for Greece and Spain. The means are all positive at the post-crisis period, except for Greece which has a higher standard deviation.

As reported in the above tables (Table.2, Table.3, Table.4 and Table.5), the rate of stock returns in the entire sample period and three sub-sample period are not likely drawn from a normal distribution because of the non-normal skewness and kurtosis measures. Also, normality of stock return series is strongly rejected by the Jarque-Bera test statistics.

Table.6, Table.7, Table.8 and Table.9 provide the correlations among the daily stock return of the 6 selected countries over the entire period, the pre-crisis period, 2008 global financial crisis period and the post-crisis period, respectively.

Table.6 Stock return correlation coefficients for the whole period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Full sample period: 3 January 2003 through 30 December 2014						
DAX	1,000	-	-	-	-	-
ATHEX	0,469	1,000	-	-	-	-
IBEX	0,822	0,498	1,000	-	-	-
BIST	0,449	0,366	0,438	1,000	-	-
FTSE	0,856	0,458	0,797	0,477	1,000	-
S&P	0,617	0,280	0,568	0,301	0,586	1,000

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Table.7 Stock return correlation coefficients for the pre-crisis period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Pre-crisis period: 3 January 2003 through 31 October 2007						
DAX	1,000	-	-	-	-	-
ATHEX	0,467	1,000	-	-	-	-
IBEX	0,815	0,483	1,000	-	-	-
BIST	0,280	0,356	0,322	1,000	-	-
FTSE	0,775	0,466	0,807	0,326	1,000	-
S&P	0,543	0,214	0,471	0,156	0,458	1,000

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Table.8 Stock return correlation coefficients for the crisis period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Crisis period: 1 November 2007 through 27 February 2009						
DAX	1,000	-	-	-	-	-
ATHEX	0,707	1,000	-	-	-	-
IBEX	0,916	0,683	1,000	-	-	-
BIST	0,659	0,664	0,655	1,000	-	-
FTSE	0,919	0,691	0,892	0,672	1,000	-
S&P	0,599	0,362	0,580	0,382	0,555	1,000

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Table.9 Stock return correlation coefficients for the post-crisis period

	DAX	ATHEX	IBEX	BIST	FTSE	S&P
Post-Crisis period: 3 March 2009 through 30 December 2014						
DAX	1,000	-	-	-	-	-
ATHEX	0,404	1,000	-	-	-	-
IBEX	0,796	0,443	1,000	-	-	-
BIST	0,487	0,304	0,436	1,000	-	-
FTSE	0,875	0,379	0,756	0,489	1,000	-
S&P	0,693	0,278	0,611	0,373	0,679	1,000

Notes: DAX, ATHEX, IBEX, BIST, FTSE and S&P are the stock indices in Germany, Greece, Spain, Turkey, the UK and the USA, respectively.

Among the 6 specific countries' stock return correlation coefficients, Germany, Spain and the UK have the strongest relations with each other in the whole period and the three sub-periods. Also the USA has strongest relation with Germany in each time period. The lowest correlation is between Greece and the USA in each time period, except for the pre-crisis period. As it is expected, correlation coefficients are increased substantially during a volatile period (2008 financial crisis period). After the crisis period, the correlations are decreasing, except for Germany-USA and Spain-USA.

As reported in the above tables (Table.6, Table.7, Table.8 and Table.9), all the economies worldwide are affected strongly by the global crisis. This is an expected magnitude that such influential crises do not allow the differentiations of the international economies. The increase

in the correlation coefficients also suggests that the benefits of diversification for portfolio management are limited within these markets during the crisis.

IV. Methodology

To measure the volatility spillovers, we adopt the model developed by Diebold and Yilmaz (2009). The Diebold-Yilmaz approach uses a measure based on forecast error variance decompositions that are derived from vector autoregressive (VAR) models. This methodology allows us to put together spillover effects across countries which provides valuable information into a single spillover measure.

Before estimating the variance decompositions and calculating the spillover index, to filter volatilities, we firstly start by estimating basic Stochastic Volatility (SV) model which is introduced by Taylor (1982, 1986) given as

$$r_t = \exp\left(\frac{\lambda_t}{2}\right)\varepsilon_t, \quad (1)$$

$$\lambda_t = \gamma + \delta\lambda_{t-1} + v\eta_t, \quad (2)$$

where r_t and λ_t indicate return and volatility, respectively, at time $t: 1 \rightarrow T$. The random variables ε_t and η_t are standard normal, $N(0,1)$. Equations (1) and (2) characterize a Gaussian non-linear dynamic state space model. The non-linear dependence of r_t on λ_t in (1) prohibits application of the Kalman Filter. As an alternative, we perform sequential Efficient Importance Sampling (EIS) to evaluate the likelihood function of the basic SV model. EIS, introduced by Richard and Zhang (2007), generates highly accurate Monte-Carlo estimates of likelihood functions for a wide range of SV models (Liesenfeld and Richard, 2003 and 2006).

Firstly, we start by testing the stationarity of the price and return series of 6 countries' in order to estimate the VAR model. We perform Augmented Dickey-Fuller (ADF) tests at the level of price and return series. Table.10 provides the ADF test statistics that examine the presence of unit roots for all the stock indices and returns.

Table.10 Unit root test results of selected stock markets' price and return series

ADF Test Statistics			
Null Hypothesis: Unit root (individual unit root process)			
Price Series		Return Series	
Countries	Prob.	Countries	Prob.
GERMANY	0,7572	GERMANY	0,0001
GREECE	0,8968	GREECE	0,0001
SPAIN	0,2459	SPAIN	0,0001
TURKEY	0,7423	TURKEY	0,0001
UK	0,2518	UK	0,0001
US	0,9529	US	0,0000

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-stationary) at level. But when we take the logarithmic return of the stock price indices, the results show that all the return series data are stationary. That's why, we can say that all price data of selected countries are integrated of order one, I(1). On the other hand, the reported results suggest that all the stock return indices are stationary such that we can reject the null hypothesis.

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

$$\lambda_t^i = \alpha + \sum_{j=1, j \neq i}^n \beta_j \lambda_{t-1}^j + \sum_{j=1, j \neq i}^n \delta_j \lambda_{t-2}^j + \varepsilon_t, \quad (3)$$

where λ_t^i represents the stock return volatility for country i, λ^j is the stock return volatility of country j representing each of the remaining selected countries except country i.

Afterwards, the discussion of Diebold and Yilmaz (2009) assumes a covariance stationary first-order, two-variable VAR model

$$y_t = \Phi y_{t-1} + \varepsilon_t, \quad (4)$$

where $y_t = (y_{1,t}, y_{2,t})'$ and Φ is a 2X2 matrix of parameters. The moving average representation of the VAR is given by

$$y_t = \theta(L)\varepsilon_t, \quad (5)$$

where $\theta(L) = (I - \theta L)^{-1}$. Re-writing the equation based on the Cholesky decomposition defining $K(L) = \theta(L)B_t^{-1}$, $u_t = B_t\varepsilon_t$, where $E(u_t u_t') = I$ and B_t^{-1} is the unique lower-triangular Cholesky factor of the covariance matrix of ε_t , the equation simplifies to

$$y_t = K(L)u_t. \quad (6)$$

Now, let the optimal one-step-ahead forecast be

$$y_{t+1,t} = \Phi y_t, \quad (7)$$

with the corresponding one-step-ahead forecast error vector

$$e_{t+1,t} = y_{t+1} - y_{t+1,t} = K_0 u_{t+1} = \begin{bmatrix} k_{0,11} & k_{0,12} \\ k_{0,21} & k_{0,22} \end{bmatrix} \begin{bmatrix} u_{1,t+1} \\ u_{2,t+1} \end{bmatrix}, \quad (8)$$

which has the covariance matrix of the form

$$E(e_{t+1,t} e_{t+1,t}') = K_0 K_0'. \quad (9)$$

In a two-variable VAR system, there are two possible spillovers, one from variable 1 to variable 2 with a contribution of $k_{0,21}^2$ and the other from variable 2 to variable 1 with a contribution of $k_{0,12}^2$. Hence, the total spillover is $k_{0,12}^2 + k_{0,21}^2$. Therefore, the total spillover index is just the ratio of the total spillover to total forecast error variation, which is equal to $\text{trace}(K_0 K_0')$, expressed as the following percentage

$$S = \frac{k_{0,12}^2 + k_{0,21}^2}{\text{trace}(K_0 K_0')} \times 100. \quad (10)$$

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

$$S = \frac{\sum_{i \neq j}^N k_{0,ij}^2}{\text{trace}(K_0 K_0')} \times 100. \quad (11)$$

We estimate the variance decompositions for t+1, t+5, t+10, and t+15 at the pre-crisis, crisis and post-crisis periods. This helps us observe the change in the spillover index which is arising from the current global 2008 financial crisis over time.

V. Empirical Results

As we mentioned the previous part, we use the method proposed by Diebold and Yilmaz (2009) in order to investigate the interrelationship between and among markets in terms of

volatilities with 2008 crisis effects. In this part, we provide a full-sample analysis of six different countries' volatility spillovers. As a part of our analysis, we suggest 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*.

We start by determining volatility spillovers over the pre-crisis period, January 2003 - October 2007, the crisis period, November 2007 - February 2009, and post-crisis period, March 2009 – December 2014. Then, we will trace time variation in spillovers via rolling window estimation. We report spillover indexes for volatilities in the lower right corners of Table.11. Before analyzing them, let us explain the rest of the three “Spillover Tables”. The direction of volatility spillovers across the six markets is presented off-diagonally in Table.12, Table.13 and Table.14. The off-diagonal row sum is the directional volatility spillover of country *i* from country *j* (labeled “Contribution from others”), and the off-diagonal column sum is the directional contribution of country *i* to country *j* (labeled “Contribution to others”). While totaled across countries give the numerator of the spillover index, the column sums or row sums (including diagonals) give the denominator of the spillover index.

The significant summary result can be found in Table.11. Spillover indexes indicate that there is an increasing spillover among these six countries as time goes by. According to the results, the volatility spillovers suddenly almost double during the crisis period. After the crisis, the volatility spillovers come back nearly to their pre-crisis period values decreasingly.

Table.11 Total Volatility Spillover Index

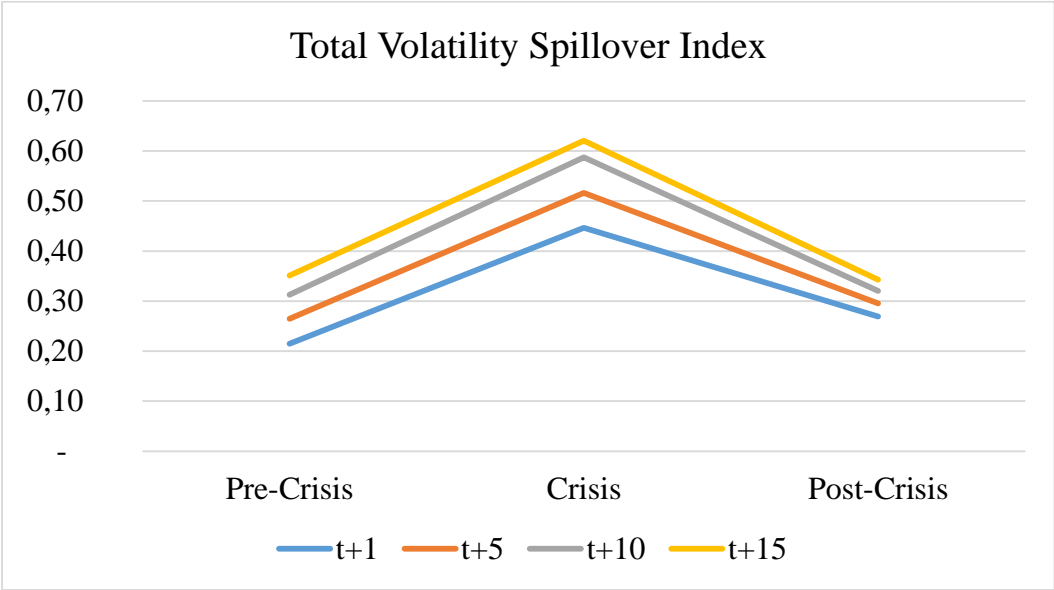
Time	Pre-Crisis	Crisis	Post-Crisis
t+1	0,21	0,45	0,27
t+5	0,26	0,52	0,30
t+10	0,31	0,59	0,32
t+15	0,35	0,62	0,34

Note: The numbers are the total volatility spillover indexes.

As we expected and literature suggested the results from total volatility spillover table suggests that the spillover is at its highest level in the crisis period. The spillover level before and after the crisis periods are similar which indicates that these are the normal level of spillover between these countries. In general, these results suggest that during the crisis period portfolio allocation between these markets provides not much gain for the investors. However, in the other periods gains through portfolio allocation in these countries' stock markets is possible.

Figure.1 also shows that the spillover index has been increasing since pre-crisis period. Originally, the spillover indices of the six markets are almost 29% on the average, but they instantly increase to more than almost 25% with the effects of the 2008 global financial crisis. After the crisis period, the spillover indices of these markets are decreasing, but still there is an increasing trend over time. Therefore, the six stock markets are highly correlated during the crisis and the shock transmission in these markets is extremely strong.

Figure.1 Total Volatility Spillover Plot



The other part of the analysis covers the pre-crisis, crisis and post-crisis period spillovers from each country to others for volatility series.

Table.12 represents the results of volatility series in the pre-crisis period.

Table.12 Volatility Spillovers for Stock Market Returns at pre-crisis period

Countries	Time	GERMANY	GREECE	SPAIN	TURKEY	UK	USA	Contribution from others
GERMANY	t+1	100,00	-	-	-	-	-	-
	t+5	97,32	0,07	0,08	0,02	2,31	0,20	2,68
	t+10	95,97	0,14	0,32	0,19	2,41	0,97	4,03
	t+15	94,36	0,21	0,59	0,37	2,53	1,93	5,64
GREECE	t+1	7,63	92,37	-	-	-	-	7,63
	t+5	8,78	90,29	0,37	0,30	0,22	0,03	9,71
	t+10	10,98	87,59	0,45	0,19	0,72	0,07	12,41
	t+15	12,80	85,32	0,53	0,17	1,09	0,10	14,68
SPAIN	t+1	41,43	2,18	56,38	-	-	-	43,62
	t+5	48,04	0,96	45,99	0,18	2,93	1,90	54,01
	t+10	48,93	0,83	41,12	0,13	4,53	4,46	58,88
	t+15	48,56	0,78	37,62	0,10	5,83	7,11	62,38
TURKEY	t+1	0,47	3,96	0,62	94,95	-	-	5,05
	t+5	1,79	2,99	4,61	88,62	1,95	0,05	11,38
	t+10	6,09	2,57	4,07	79,44	7,67	0,16	20,56
	t+15	10,32	2,23	3,67	71,77	11,86	0,15	28,23
UK	t+1	37,10	1,50	10,58	0,58	50,24	-	49,76
	t+5	38,94	1,14	7,46	0,16	51,59	0,71	48,41
	t+10	39,15	0,90	8,38	0,31	47,35	3,91	52,65
	t+15	38,42	0,74	8,99	0,46	43,85	7,54	56,15
USA	t+1	17,34	0,41	1,60	0,39	0,41	79,84	20,16
	t+5	22,27	0,36	4,41	0,16	4,20	68,61	31,39
	t+10	24,86	0,54	4,65	0,14	7,40	62,42	37,58
	t+15	26,19	0,68	4,81	0,17	9,73	58,42	41,58
Contribution to others	t+1	103,97	8,05	12,80	0,97	0,41	-	
	t+5	119,81	5,51	16,94	0,82	11,61	2,89	
	t+10	130,02	4,97	17,87	0,96	22,72	9,57	
	t+15	136,29	4,63	18,59	1,28	31,04	16,83	
Contribution including own	t+1	203,97	100,43	69,18	95,92	50,66	79,84	
	t+5	217,13	95,81	62,93	89,45	63,20	71,50	
	t+10	225,98	92,56	58,99	80,40	70,07	71,99	
	t+15	230,66	89,95	56,21	73,04	74,89	75,25	
Net Spillover	t+1	103,97	15,68	56,41	6,02	50,17	20,16	
	t+5	122,49	15,22	70,95	12,20	60,02	34,28	
	t+10	134,05	17,38	76,74	21,52	75,37	47,16	
	t+15	141,93	19,32	80,96	29,51	87,19	58,41	

Note: The numbers are the variance decompositions for the volatilities at time t+1, t+5, t+10 and t+15.

According to the Table.12, we see that Germany is responsible for the highest stock return volatility spillover to others. Highest spillover from Germany to the others is mainly to Spain and the UK. Meanwhile, the UK and the US have less stock return volatility spillover at time t+1, but it is seen that their volatility spillover rapidly increases at time t+10 and t+15. Obviously, Germany is the highest contributor and the least contributed. Therefore, it has the highest net spillover.

The results of volatility series in the crisis period can be found in Table.13

Table.13 Volatility Spillovers for Stock Market Returns at crisis period

Countries	Time	GERMANY	GREECE	SPAIN	TURKEY	UK	USA	Contribution from others
GERMANY	t+1	100,00	-	-	-	-	-	-
	t+5	87,45	0,82	2,96	0,04	0,87	7,86	12,55
	t+10	75,21	0,57	6,46	0,24	0,76	16,76	24,79
	t+15	67,19	0,76	9,32	0,78	1,01	20,94	32,81
GREECE	t+1	32,26	67,74	-	-	-	-	32,26
	t+5	33,94	56,63	6,81	1,19	0,55	0,89	43,37
	t+10	34,64	39,93	19,76	1,31	2,05	2,31	60,07
	t+15	31,43	29,07	25,88	1,31	7,90	4,39	70,93
SPAIN	t+1	74,37	1,40	24,23	-	-	-	75,77
	t+5	61,89	0,70	30,62	0,43	1,18	5,18	69,38
	t+10	50,36	1,13	30,31	2,13	4,29	11,78	69,69
	t+15	42,03	1,06	29,91	3,84	7,77	15,39	70,09
TURKEY	t+1	27,69	2,09	3,88	66,33	-	-	33,67
	t+5	22,59	1,67	8,20	54,95	0,03	12,57	45,05
	t+10	20,64	2,88	13,59	43,12	0,05	19,73	56,88
	t+15	20,23	3,63	17,06	36,79	0,51	21,78	63,21
UK	t+1	76,64	0,84	1,23	5,55	15,73	-	84,27
	t+5	58,79	0,31	6,48	6,34	16,81	11,27	83,19
	t+10	46,65	0,22	12,12	5,97	15,43	19,62	84,57
	t+15	39,66	0,16	14,60	6,97	15,49	23,12	84,51
USA	t+1	27,41	0,02	0,17	0,97	0,96	70,46	29,54
	t+5	38,34	0,36	0,79	0,55	3,91	56,05	43,95
	t+10	41,10	0,26	3,43	0,85	2,89	51,47	48,53
	t+15	41,15	0,30	5,95	1,44	2,51	48,65	51,35
Contribution to others	t+1	238,36	4,35	5,29	6,52	0,96	-	
	t+5	215,54	3,86	25,24	8,55	6,54	37,77	
	t+10	193,39	5,06	55,36	10,49	10,04	70,20	
	t+15	174,51	5,91	72,81	14,34	19,70	85,62	
Contribution including own	t+1	338,36	72,10	29,52	72,86	16,70	70,46	
	t+5	302,99	60,48	55,86	63,50	23,35	93,82	
	t+10	268,60	45,00	85,67	53,61	25,46	121,66	
	t+15	241,69	34,98	102,73	51,13	35,19	134,28	
Net spillover	t+1	238,36	36,61	81,06	40,19	85,23	29,54	
	t+5	228,09	47,23	94,62	53,59	89,73	81,72	
	t+10	218,18	65,13	125,04	67,37	94,61	118,73	
	t+15	207,32	76,84	142,90	77,54	104,20	136,97	

Note: The numbers are the variance decompositions for the volatilities at time t+1, t+5, t+10 and t+15.

As reported in Table.13, Germany has still highest volatility spillovers to other countries during the crisis period. When we look at Turkey, the UK and especially the USA, we see that their spillover effects eventually increases from time t+1 to time t+15. At the same time, Spain and the UK are the mostly affected countries in terms of volatility spillover from others. Germany has also still highest net spillover during the crisis period.

Table.14 presents the results of volatility series in the post-crisis period.

Table.14 Volatility Spillovers for Stock Market Returns at post-crisis period

Countries	Time	GERMANY	GREECE	SPAIN	TURKEY	UK	USA	Contribution from others
GERMANY	t+1	100,00	-	-	-	-	-	-
	t+5	99,45	0,07	0,09	0,15	0,11	0,13	0,55
	t+10	97,78	0,57	0,24	0,29	0,24	0,88	2,22
	t+15	95,75	1,29	0,44	0,40	0,25	1,87	4,25
GREECE	t+1	7,25	92,75	-	-	-	-	7,25
	t+5	6,03	93,61	0,03	0,20	0,08	0,05	6,39
	t+10	5,61	93,94	0,05	0,13	0,23	0,04	6,06
	t+15	5,33	93,97	0,14	0,14	0,40	0,03	6,03
SPAIN	t+1	36,29	1,93	61,79	-	-	-	38,21
	t+5	38,82	3,03	57,80	0,24	0,05	0,06	42,20
	t+10	38,62	6,11	54,55	0,16	0,11	0,46	45,45
	t+15	38,11	9,25	51,33	0,18	0,12	1,00	48,67
TURKEY	t+1	9,29	0,17	0,92	89,62	-	-	10,38
	t+5	9,31	0,16	0,45	89,89	0,18	0,00	10,11
	t+10	9,59	0,47	0,31	89,05	0,56	0,00	10,95
	t+15	9,75	0,88	0,25	88,12	1,00	0,00	11,88
UK	t+1	65,21	0,29	1,59	0,38	32,53	-	67,47
	t+5	71,76	0,32	0,96	0,67	25,92	0,36	74,08
	t+10	72,76	1,14	0,85	1,02	21,76	2,46	78,24
	t+15	71,84	2,10	0,74	1,24	19,14	4,94	80,86
USA	t+1	34,01	0,08	1,57	0,49	1,51	62,33	37,67
	t+5	37,49	0,20	0,94	1,55	1,99	57,83	42,17
	t+10	41,14	0,38	0,75	1,46	3,50	52,77	47,23
	t+15	43,48	0,62	0,64	1,34	4,75	49,17	50,83
Contribution to others	t+1	152,06	2,47	4,08	0,88	1,51	-	
	t+5	163,41	3,78	2,48	2,81	2,42	0,61	
	t+10	167,72	8,67	2,21	3,06	4,64	3,83	
	t+15	168,50	14,14	2,22	3,29	6,51	7,85	
Contribution including own	t+1	252,06	95,21	65,87	90,49	34,04	62,33	
	t+5	262,85	97,39	60,28	92,70	28,34	58,44	
	t+10	265,50	102,61	56,76	92,12	26,41	56,60	
	t+15	264,25	108,11	53,55	91,41	25,65	57,02	
Net spillover	t+1	152,06	9,72	42,29	11,26	68,98	37,67	
	t+5	163,96	10,17	44,68	12,92	76,49	42,78	
	t+10	169,94	14,74	47,67	14,01	82,88	51,06	
	t+15	172,76	20,17	50,88	15,17	87,38	58,68	

Note: The numbers are the variance decompositions for the volatilities at time t+1, t+5, t+10 and t+15.

According to Table.14, Germany has the highest contribution with Greece to others at post-crisis period. We see that the volatility spillover effect of the USA decreases clearly after the 2008 crisis. Here again the UK and Spain get the highest contribution from others in terms of volatility spillovers.

In brief, Germany has the highest contribution to others in all periods. However, the spillover from Germany to others doubles in the crisis period. This effect increases in all periods from day t+1 to day t+15. Specifically Germany has the highest influence, or spillover, on Spain and UK for all over periods. These effects almost doubles in the crisis period. Although the effect in the post-crisis on Spain goes back to the level it was at before the crisis period, the amount of spillover from Germany to UK does not decrease and go back its normal level. Furthermore the level of spillover from Germany to USA also stays high after the crisis. These

suggest that the effect of the crisis between these countries has not disappeared yet. The second most influential market in the pre-crisis and crisis-period is Spain, but this changes in the post-crisis period and after the crisis Greece becomes the second most-influential market. This suggests that the dynamics are affected by the crisis and they are not exactly the same after the crisis. In the pre-crisis period Spain and UK get the highest level of spillover from other markets. On the other hand, during the crisis period almost all markets receive high level of spillover from other markets. Even the markets such as Germany, Greece and Turkey which are not influenced by the spillover before the crisis are under the effect during the crisis period. In the post-crisis period spillover effect from others start to go back to the levels they were at before the crisis.

VI. Conclusion

This study empirically examines the volatility spillover effects of the 2008 US financial crisis to six major markets, namely the US, the UK, Germany, Spain, Turkey and Greece. For our volatility spillover analysis, we use the model introduced by Diebold and Yilmaz (2009) and focus on variance decompositions that are derived from vector autoregressive (VAR) models. The data are daily and cover the period from January 2003 to December 2014 which corresponds to the global financial crisis period. In order to assess changes in the volatility spillovers between these countries due to the crisis, we divide the study period into three sub-periods, namely the pre-crisis (3 January 2003 - 31 October 2007), during crisis (1 November 2007 - 27 February 2009) and post-crisis period (3 March 2009 - 30 December 2014).

Our results support the other researcher's hypothesis in the literature section such that all the economies worldwide are affected strongly by the 2008 global crisis. As we see in correlation tables (Table.6, Table.7, Table.8 and Table.9) these six major countries are highly correlated between each other in all the periods. In addition to this, we see that these countries have positive daily mean returns in pre and post 2008 crisis except for Greece. But these countries have negative daily mean returns during the crisis period (Table.2, Table.3, Table.4 and Table.5).

The results verify that volatility spillovers are at their highest levels during the crisis period. In Table.11 and Figure.1, we see that there is an increasing spillover between these six countries as time goes by. We find that volatility spillovers suddenly almost double during the crisis period. After the crisis, the volatility spillovers come back nearly to their pre-crisis period values, but still they are higher than the pre-crisis period values.

We find evidence of the transmission of the US financial crisis to six major financial markets before, during and after the 2008 financial crisis. According to our model results in Table.12, Table.13 and Table.14, we observe that Germany has the highest contribution to others in all periods and Spain and the UK are the most affected countries in terms of volatility spillover from others in all periods. Moreover, we obtain that after the crisis Greece becomes the most-influential market. On the other hand, during the crisis period almost all markets receive high level of spillover from other markets and the effects of the crisis between these countries have not disappeared yet.

Finally, these results constitute important information for portfolio investors as well as macroeconomists in understanding the risks of contagion in these six major countries. Because global portfolio diversification is recommended due to the low correlations between global stock markets. We particularly find out that due to the fact that correlations and stock return volatility spillovers between global stock markets have increased because of the 2008 crisis, then the benefit of global diversification has decreased considerably. Consequently, there are relatively limited global portfolio diversification opportunities available for investors during the crisis. Hence, investors should know the extent of capital market integrations and volatility spillover effects for designing successful trading and hedging strategies and optimal portfolio management.

VII. References

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