Transmission of News in Eurozone Bank Holdings and European Bank Markets in the light of the Greek Debt Crisis

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Abstract

This paper examines the interdependence of European bank sectors under two different aspects. Firstly, we investigate the symmetric transmission mechanism between six Eurozone countries' (Germany, France, Greece, Ireland, Italy and Spain) bank holdings in order to uncover the volatility and error interrelationship of these holdings and their impact on the Greek bank holdings. Also, we analyse the impact from the Greek bank holdings on the other Eurozone countries' bank holdings. In addition, we examine the impact of the Greek bank holdings on the transmission mechanism among all six cross-country bank indices. Secondly, we investigate the interrelationship of Greek bank market with two emerging cross-country bank indexes and two developed ones. The two groups concern Greece, France and Germany and Greece, Poland and Czech Republic, respectively.

We find very strong volatility and error spillovers for five Eurozone countries' (Germany, Greece, Ireland, Italy and Spain) bank holdings, whereas French bank holdings are less integrated with the other five ones.

Moreover, the results indicated that the Greek bank market is integrated better with the two emerging bank indexes rather than the two developed ones. In addition, the Greek debt crisis seemed to play an important role on the volatility transmission mechanism since the volatility and error spillovers are larger in magnitude in the after crisis period than in the pre crisis period for both group of countries. Based on the results regarding the degree of volatility persistence, the number of days that the innovations in the post crisis period last is larger than the number of days of the pre crisis period for both groups of countries under study.

Keywords: Interdependencies, Volatility and Error Spillovers, European Banking Markets, Eurozone Bank Holdings

GEL Classification: G15, G20, C61, C3

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1. Introduction

The formation of the European Union (EU) and the introduction of the euro as a common currency, for the majority of the EU countries, have changed the dependencies and interlinks between financial institutions (i.e. banks) and also between financial markets within Europe. Consequently, the interdependence of the European bank sectors and/or European financial markets has become a considerable research area, since the nature and quantification of spillovers between more integrated financial sectors and assets has crucial implications for asset allocation and risk management. One more incident, which reinforces the strong argument in favor of a thorough examination of the interdependence of the European bank markets, is the emergence of the Greek debt crisis in late 2009, which spilled-over rapidly the following years into other, mainly Southern European, countries. Therefore, the Greek debt crisis became a European debt crisis.

In Europe, banks hold a substantial amount of sovereign debt in both their trading and banking books (Blundell-Wignall and Slovik, 2010) and are thus exposed to one another. Even though the Greek economy has less than a 3% share of the total Eurozone GDP, doubts regarding the ability of Greece to service its debt impacts on domestic banks as well as those of other Eurozone countries which hold Greek bonds as part of their assets portfolio. Therefore, the index of European bank stocks responds by lowering the prices of the equity of such banks that hold Greek debt (Bahnot et al., 2013).

Another issue that arises from the Greek debt crisis is that, according to MSCI[4], the Greek stock market has been downgraded from a developed to an emerging market (effective from November 2013). Additionally, Dow Jones & Company[5] has placed- from 2013 - the Greek stock market on the watch list for reclassification to an emerging market. Indeed, the reason for the above downgrades was the extreme fall (more than 80%) of the FTSE ASE index from October 2007 to January 2013, as well as that Greece was forced to accept two European Union-led bailout packages in order to reset its past debts. The fall of the Greek stock exchange also means the fall of the Athex banking index, which holds the highest weight on the price of FTSE ASE index.

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[4] see www.msci.com
[5] see www.dowjones.com

After the crisis of 1987 a number of studies (e.g. Koutmos and Booth, 1995, Baele, 2005, Bartram, 2006) have emerged, finding that volatility is transmitted from one market to another, as markets interrelate, and this may influence banks as well. In the banking sector, bank equities are traded similarly to stock equities and are considered on similar regulations as stocks. Consequently, one can study bank equities and deduce their own conclusions, having applied such models that measure the banking performance and efficiency in stock markets. The recent Greek and European debt crisis, and also the financial integration achieved in Europe over the past decade, offer unique conditions for research analyses of the significance of banks' cross-border exposures to foreign government bonds. Bhanot et al. (2013) have examined the relationship between sovereign yield spreads of Greece and abnormal returns of financial sector shocks of Portugal, Italy, and Spain during the Greek debt crisis, finding evidence of spillovers from Greece to the other three countries. Other studies look at the impact of bank holdings of government debt, finding that the banks' performances are not affected by the holdings of government debt of Italy, Spain, Portugal and Ireland (Angeloni and Wolff, 2012; Wolff, 2011). Instead, there is an impact because of the fact that Greek debt kept in their books. A similar study by Brutti and Saure (2011) finds that financial interdependence contributes directly to the transmission of sovereign default risk. They based their analysis on the euro crisis using a VAR model and estimated how shocks from crises are transmitted over cross-country sovereign debts.

Taking into account all the above, we examine in this paper the interdependence of European bank sectors under two different aspects.

The first objective of this paper is to investigate the symmetric transmission mechanism between six Eurozone countries' (Germany, France, Greece, Ireland, Italy and Spain) bank holdings in order to uncover the volatility and error interrelationship of these holdings and their impact on the Greek bank holdings, and also the impact from the Greek bank holdings on the other Eurozone countries' bank holdings. In addition, we examine the impact of the Greek bank holdings on the transmission mechanism among all six cross-country bank indices. As we have already mentioned, banks that keep sovereign debt from other countries in their books are at high risk. In this paper, we are able to capture the dynamic spillover effect of Eurozone cross-country bank equities affected by the Greek bank holdings.

Our study yields interesting results. Initially, we find very strong volatility and error spillovers for five Eurozone countries' (Germany, Greece, Ireland, Italy and Spain) bank holdings; France exhibits more mitigated relations and the results show that French bank holdings are less integrated with the other five countries' bank holdings. Furthermore, cross-country bank equities have significant spillover effects when the Greek bank holdings affect banks in our model, but with less strong interrelationships compared to the previous (bank holdings transmissions) study. Once again, France bears the fewest significant volatility and error spillovers.

The second objective of this paper is to examine the links and the asymmetric volatility and error transmission mechanism of the Greek banking sector with either the banking sectors of the most developed Eurozone countries (Germany and France) or the banking sectors of two of the most advanced non-Eurozone emerging EU countries (Poland and the Czech Republic). Our main purpose, among others, is to estimate whether the Greek banking sector is integrated better with the first set of Eurozone and developed countries or with the second set of non-Eurozone and emerging countries. The motivation of this second objective of our paper starts from the current Greek debt crisis which has negatively influenced the impact of Greece on European markets and portends possible downgrades for the Greek market and hence the Greek banking sector. An additional motivation for the second objective of this paper derives from the fact that, in different periods, there are different economic events which may influence volatility and error spillovers among cross-country bank equities. Thus, our study is divided into two periods, before and after the Greek debt crisis, giving a separate attention to the transmission mechanism among the aforementioned countries' bank markets. While the above spillovers are significant, they are further divided into bad and good news (innovations), showing that asymmetry is important to spillovers. Finally, the results are verified using simulation processes exactly measuring the degree of asymmetry and persistence and the size of the spillover impact among cross-country bank indices.

Initially, we find that the Greek bank market is integrated better with the second group (Poland and Czech Republic) than the first group (Germany and France) of countries since the degree of integration is higher when we consider the whole period under study (i.e. from 1990 to 2012 for the first group and from 1994 to 2012 for the second group of countries).

Regardless of the larger size of volatility transmissions in the post crisis period, we observe that in the pre crisis period the degree of integration is higher between the bank markets of Greece, Germany and France. On the other hand, the degree of integration does not change from the pre crisis to the post crisis period regarding the countries of Greece, Poland and Czech. Similarly, the volatility transmission is larger in magnitude in the after crisis period for the second group of countries.

There are no volatility spillovers from Germany to Greece in both periods. The Greek bank market risk affects French bank market at a higher magnitude after the crisis than before. Greece is not affected by Germany and France in the after crisis period.

Greek bank market volatility affected only the Czech Republic bank market risk and vice versa in the pre crisis period, testing the countries' spillovers of Greece, Poland and Czech Republic. On the contrary, in the after crisis period, there is mutual volatility transmission only between the Greek and Polish bank markets. The asymmetric response of volatility is present in Greece and Poland in the post crisis period, but to all three bank indices of Greece, Poland and Czech Republic in the pre crisis period.

Finally, another remarkable point derived from our results is that in the after crisis period the volatility persistence, as far as the remaining noise is concerned, for both groups of countries is much higher than in the pre crisis period. This is rational, especially when we consider periods of high risk, since it confirms that the European bank market is an efficient market.

This paper is organized as follows. Section 2 presents the literature review. Section 3 refers to the methodology. Section 4 analyses the data used, the results and finally Section 5 concludes.

2. Literature Review

The interdependence of stock markets has been examined empirically by numerous researchers. Some of them used a single-variable model and others a multi-variable one, where the transmission of price and volatility among stock markets could be examined successfully. For instance, Becker et al. (1990) showed that the information within the American stock market could be used to earn profits from the Japanese stock market. Hamao et al. (1990) examined the interdependence of short-term volatility for the stock price returns of the stock exchanges of New York, Tokyo and

London for a period of three years (1985-1988). In their analysis they used a single-variable ARCH model to investigate the interdependence of stock price returns. They found evidence that stock price volatility is transmitted from the stock market of New York to London and Tokyo, as well as from London to Tokyo. Furthermore, they did not observe different effects on the volatility of these stock markets before and after the crash period of 1987. The results showed that the effect on the Japanese stock market was significant while on the other stock markets it was not. Koutmos (1996) provides evidence for 'lead/lag' interdependencies among the stock markets of the United Kingdom, France, Germany and Italy. Koch and Koch (1991) provide documentation for simultaneous 'lead/lag' interdependencies among eight national stock markets. They explained that trading hours of the countries in the same region overlap so that the markets share the news or information more, hence co-move more.

One of the problems that the researchers were faced with was that their results were 'biased', as 'spillovers' were not validated because they used a univariate model. Following, there are other examples with multivariate ARCH-type models. For instance, the study of Booth et al. (1997) provides new evidence on the effect of stock price return volatilities among the Scandinavian stock markets. The impact of 'good' and 'bad' news on stock price returns' volatility was analyzed with a multivariate EGARCH model. The transmission of news was asymmetric, since the effects were most pronounced for 'bad' news than for 'good' news with considerable stock price volatilities, being, however, short-intensive. They found that there was a common variation in all examined stock markets. With the exception of Denmark, the stock price volatilities reacted more intensely to 'bad' news than to 'good' news. Also, the results showed that the effect could last for one week on these stock markets. In addition, there was transmission of stock price returns and volatilities from the Swedish to the Finnish stock market and vice versa.

Kanas (1998) examined the interdependencies of three major European stock markets, London, Paris and Frankfurt. An asymmetric EGARCH model was used to capture the possible influences of non-symmetrical variation of innovations from 1984 to 1993. Mutual transmissions of information were found to exist between London-Paris and Paris-London, whereas equivalent effects were not observed from London to Frankfurt. In almost all cases, the 'bad' news in a market had more influence on the stock price volatility of another market than 'good' news. Furthermore, the analysis for the period before the crash of October 1987 (1984-1987) and after the crash

(1987-1993) showed that the effects during the second period were larger in magnitude. These findings suggest that the markets became more interdependent in the post-crash period.

Moreover, Baele (2005) studied the degree to which efforts to expand the economy in Europe had changed the size of the influence of economic news from the USA and some European stock markets to 13 other specific European stock markets. His dataset consisted of weekly stock price returns of 13 European stock markets which participated in the EU and two regional stock markets for the period from 1980 to 2001. He found that changes in the magnitude of the effects were statistically and economically significant. While in the EU and in the USA the size of the influence of news had arisen throughout the twenty years of examination, the impact was more decisive on the EU. He showed that the USA continued to be the dominant market, which affected European stock markets; however, there was also important interdependence amongst European stock markets.

Koutmos and Booth (1995) explored the mechanisms of interdependence in the stock markets of New York, London and Tokyo. The asymmetrical influence of 'good' and 'bad' news in the transmission mechanism of stock price volatility, were described by an EGARCH model. Using daily stock price returns for the period of September 1986 to December 1993, they found strong evidence that the effect of the variance in a particular stock market when the news received was negative and much stronger than when it was positive. They found evidence of transmission of news from New York to Tokyo and London, and from Tokyo to London. The analysis of the periods before and after the crash showed that the stock markets in New York and London had been more sensitive to the innovations coming from Tokyo.

Ng (2000) examined the size and the changes of stock price returns volatilities in two of the most powerful industrial countries, as well as in six stock markets in the Pacific Ocean. Ng used weekly returns to avoid the problem of synchronization of the operation of stock markets. The stock markets were the USA and Japan and also Korea, Malaysia, Singapore, Taiwan, Thailand and Hong Kong. She found that, in addition to the influence of global factors, there were significant influences of peripheral factors (Japan) on the variation of the examined stock markets. Ng made a distinction between regional stock markets (Japan) and world stock markets (USA), separating news into regional and global, respectively. She concluded that the regional and global factors were important for the volatility of the stock markets of the Pacific Ocean, although the global factor (USA) tended to exert more influence. The size of stock market volatility was caused either by regional factors or by world factors and was generally very small. In four of those six countries, news from the USA and Japan affected other markets less than ten percent (10%).

Some researchers provide evidence of interdependencies of first and second moments among stock price indices within the same stock market, such as Harris and Pisedtasalasai (2006), which studied the stock price indices of small and large capitalization in the London Stock Exchange.

In recent years there has been a research interest in the interdependence among European financial markets and/or among European bank holdings on government debt which was owing to, firstly, the introduction of the Euro as a common currency and, secondly, the recent European debt crisis. For instance, Bartram et al. (2007) analysed dependence and co-movement of European stock market indices using a time-varying copula dependence model. They found that the introduction of the Euro increased financial market dependence in the Euro area as a likely result of increased European integration. Also, they found that some non Euro area markets such as the UK and Sweden increased their co-movements with the Euro area.

Arezki et al. (2011) studied the spillover effects of sovereign credit rating news across European countries and financial markets during the European debt crisis. They found that spillover effects depend both on the type of rating announcements, and on the source country experiencing the downgrade and the rating agency from which the announcements originate. They stated that some rating announcements such as rating downgrades near speculative grade (e.g. the downgrade of Greece to BBB+ from A- by Fitch on 8/12/2009) have systematic spillover effects across Eurozone countries under consideration (17 and 5 basis points increase respectively for Greek and Irish CDS spreads).

Recently, Bhanot et al. (2013) used a multivariate GARCH model in order to analyze spillovers effects from the Greek debt crisis to the banking and other financial sectors of the Eurozone countries. They found that on the days when there are announcements of rating downgrades in any of the Eurozone countries or when there is generally bad news from the IMF, there is a substantial increase in the spillover from the Greek bond market. There are spillovers from Greece, which lead to negative and significant abnormal returns on financial stocks of Portugal, Italy, and Spain. However, they did not find evidence of spillovers for financial institutions from other Eurozone countries such as Austria, Belgium, France, and the Netherlands.

Beetsma et al. (2013), focusing on the Eurozone debt crisis used data from Euro-intelligence newsflash and found that more news, on average, has raised the interest rate spread of Greece, Italy, Ireland, Portugal and Spain (GIIPS) since the fall of 2009. Also, more news in one of the latter country leads to an increase in the interest spreads of other GIIPS countries. The magnitude of the spillovers is related to the size of the cross-border bank holdings. Finally, they found spillovers from GIIPS to non-GIIPS countries and these spillovers are solely connected to 'bad' news during the period after September 2009.

Angeloni and Wolff (2012) investigated the extent to which bank holdings on government debt determine and affect the banks' performance in the Eurozone. They showed that the bank holdings on government debt are not the main determinants of the banks' performance and bank risk and sovereign risk appear to be linked by many other factors, including bank location. This means that in the Eurozone countries international investors now consider that country risk has come back. Moreover, they found that Greek debt holdings had an effect on banks' market values in the period between April and October 2011. After October, this effect disappears. Italian debt holdings had a material effect on banks' market values from October to December 2011, as did holdings of Irish and, to some extent, Portuguese debt.

Brutti and Saure (2012) indicated, among others, that a 1% shock to Greek Credit Default Swaps (CDS) causes a 0.36% increase in the CDS of the average European country, which suggests economically important transmission rates. Moreover, financial linkages contribute significantly to these spillovers. In particular, a 10% decrease in cross-border financial exposures, corresponding to a reduction of 0.075% in GDP for the average country, would decrease the spillover effects of sovereign risk by 3.4%. However, they found no robust support for transmission through bank-to-bank lending.

3. Methodology

3.1. The Six-Variable GARCH-BEKK Model

In the first study of our research, which is concentrated on European bank holdings, a six-variable GARCH-BEKK approach is used for modelling time-varying second moment (variance or covariance) effects. The GARCH-BEKK model does not require the definite matrix H_t to be positive, which should always hold to other GARCH specifications. Previous approaches examining volatility spillovers imposed the restriction that the estimated variance should be greater than zero. However, the GARCH-BEKK parameterisation is specified in a manner where no such restrictions are required in order to ensure a positive definite H_t matrix.

For the purposes of our research, we estimate the return equation for the multivariate model twice. Firstly, the return equation of each country's (Greece, France, Germany, Italy, Spain and Ireland) bank holdings under study is influenced by the martingale constant and has the following form:

$$R_{i,t} = \beta_{i0} + \varepsilon_{i,t} | \Omega_{t-1} \sim N(0,H_t) \text{ for } i=1,2,3,4,5,6 \quad (1a)$$

where, $R_{i,t}$ is the bank holding return for the six countries under study

$\beta_{,0}$ is the martingale constant drift

Secondly, we model the return equation of each country's (Greece, France, Germany, Italy, Spain and Ireland) bank index which is influenced by the Greek bank holding return. The aforementioned return equation has the following form:

$$R_{i,t} = \beta_{i0} + \sum_{j=1}^{3} \beta_{ij} R_{gbh,t} + \varepsilon_{i,t} | \Omega_{t-1} \sim N(0,H_t) \text{ for } i,j=1,2,3,4,5,6 \quad (1b)$$

where, $R_{i,t}$ is the stock bank index return for the six countries under study

$R_{gbh,t}$ is the Greek bank holding return

Next, we apply the six-variable GARCH-BEKK model (Engle and Kroner, 1995) for the variance as:

$$H_t = CC' + A' H_{t-1} A + B' \varepsilon_{t-1} * \varepsilon'_{t-1}{}' B \quad (2)$$

where, H_{t-1} is the volatility vector. A and A' are the usual and the transposed term, respectively

ε_t is the error term

C and C' are the constant vector terms, the first is the usual one and the second is the transposed term

B and B' are the error coefficient vectors, the first is the usual one and the second is the transposed term

The parameters of the six-variable systems are estimated by computing the conditional log-likelihood function at each time period as:

$$L_t(\Theta) = -\log 2\pi - \frac{1}{2} \log | H_{t+1} | - \frac{1}{2} E(\varepsilon_t)'(\Theta) H_t^{-1}(\Theta) E(\varepsilon_t)(\Theta)$$

and $L(\Theta)=\sum_{t=1}^{T}L_t(\Theta)$ (3)

where, Θ is the vector of all volatility and error estimated parameters. The numerical maximization of the log-likelihood function follows the BFGS algorithm which accounts for the maximum likelihood estimates and associated with asymptotic standard errors. It must be stressed that, in equation (1a), the assumed distribution of the volatility and error components follows the normal process, while in equation (1b) the Generalized Error Distribution (GED) process is followed.

3.2. The Trivariate VAR-EGARCH Model

In the second study of our research, we use the VAR-EGARCH multivariate model for the investigation of stock price returns and volatility interdependencies within the selected European banking sectors and among them. For this reason we present, below, the VAR-EGARCH model. Thus, the VAR-EGARCH can be written as follows:

Stock price return:

$$R_{i,t}=\beta_{i0}+\sum_{j=1}^{3}\beta_{ij}R_{j,t-1}+\varepsilon_{i,t}\,|\Omega_{t-1}\sim\mathrm{N}(0,\mathrm{H}_t) \text{ for i,j=1,2,3} \quad (4)$$

Stock price volatility:

$$\sigma_{i,t}^2=\exp[\alpha_{i,0}+\sum_{j=1}^{3}\alpha_{ij}f_j(z_{j,t-1})+\gamma_i\ln(\sigma_{i,t-1}^2)] \text{ for i,j=1,2,3} \quad (5)$$

$$f_j(z_{j,t-1})=(|z_{j,t-1}|-E(|z_{j,t-1}|)+\delta_j z_{j,t-1}) \text{ for i,j=1,2,3} \quad (6)$$

Covariance of stock prices:

$$\sigma_{ij,t}=\rho_{ij}\sigma_{i,t}\sigma_{j,t} \text{ for i,j=1,2,3 and i} \neq \text{j} \quad (7)$$

where, $R_{i,t}$ is the rate of return at time t for the market i, e.g. i = 1, 2, 3 (1=France, 2=Germany, 3=Greece for the first examined group of countries and 1=Greece, 2=Poland, 3=Czech Republic for the second examined group of countries), Ω_{t-1} is the σ-field that has been created from all the information available at time t-1, $\sigma_{i,t}^2$ is the conditional variance, $\sigma_{ij,t}$ is the conditional covariance between markets i and j, $\varepsilon_{i,t}$ is the noise at time t (e.g. $\varepsilon_{i,t} = R_{i,t} - \mu_{i,t}$), $\mu_{i,t}$ is the conditional mean of stock prices, $z_{i,t}$ is the local error of the equation (e.g. $z_{i,t} = (\varepsilon_{i,t} - \mu_{i,t}) / \sigma_{i,t}$), while δ_j captures the asymmetry.

Equation (4) describes the stock price returns of banks for three countries as ‘vector autoregression (VAR)’, where the conditional mean of stock price returns for each country is an equation of the previous day’s stock price returns. ‘Lead/lag’ relations between the stock returns of bank indices in each country can be determined by the rates β_{ij} for i≠j. A statistically significant coefficient β_{ij} means that country i is affected/led by country j, or that the stock price returns in country j can be used to predict future returns in country i.

Equation (5) describes the conditional volatility of stock price returns of bank indices in each country and it is an exponential function of previous stock price returns of bank indices and standard errors for the countries under this study. The form of the residuals is given by equation (6) and is described by the $f_j(z_{j,t-1})$. This function is asymmetrical and for z_{t-1}<0 the curve of f (.) function is equal to -1+δ_j while for z_{t-1}>0 the curve takes the form 1+δ_j. Therefore, equation (6) allows errors to affect the conditional volatility of stock price returns of bank indices asymmetrically. The term $(|z_{j,t-1}| - E(|z_{j,t-1}|)$ gauges the extent of influence while the term $\delta_j z_{j,t-1}$ measures the quality of influence. Assuming that the coefficient α_{ij} is positive, the influence of the term $z_{j,t-1}$ in the $\sigma^2_{i,t}$ (conditional volatility) will be positive or negative if the size of the term $z_{j,t-1}$ is larger or smaller than the exponential value of the term $E|z_{j,t-1}|$. The quality of news influence could be strengthened or compensated by the extent of this influence. More specifically, if the coefficient δ_j is negative, the value of stock price returns starting from country j ($z_{j,t-1}$<0) will result in asymmetric transmission of stock price volatility from country j to country i. Such an influence is in line with the impact of leverage effect which is measured by the proportion $|-1+\delta_j|/(1+\delta_j)$. The effect of stock price volatility among the stock prices of banks is measured by the rate of α_{ij} for i,j=1,2,3 and i≠j.

The asymmetric transmission mechanism of stock price volatility is explained as follows: a statistically significant rate of α_{ij} with a negative δ_j rate means that the negative innovations in stock prices in country j will have a greater influence on the stock prices of country i than positive innovations. The persistence of volatility is measured by the coefficient γ_i (equation 2). If the rate γ_i is lower than 1, the nonstandard volatility is finite, whereas if the rate for γ_i is 1, the nonstandard volatility follows a process of integration of grade 1 (integrated of order 1) (Nelson, 1991).

The conditional volatility is described in detail in equation (5) and can simultaneously measure the relationship among the stock prices of bank indices for the three countries under study. This relationship means that the correlation of bank stock price return indices of specific countries is under investigation and that the covariance is comparable to the standard deviation of the specific countries.

Assuming that there is normality, the log-likelihood for the multivariate model of VAR-EGARCH can be written as:

$$L(\Theta) = -0.5(NT)\ln(2\pi) - 0.5\sum_{t=1}^{T}(\ln|S_t| + \varepsilon_t' S_t^{-1}\varepsilon_t) \quad (8)$$

where N is the number of equations, T is the number of observations, Θ is a vector of the parameters of the model that can be estimated, ε_t' is a vector of innovations at time t and S_t is the varying conditional variance-covariance matrix.

4. Analysis of Results

4.1. Data Analysis

The data used in this paper consists of both daily and quarterly bank stock index returns and also quarterly bank holding returns for specific countries.

Concerning the first study, the period of quarterly returns starts at the fourth quarter of 2001 and expands till the first quarter of 2012 for the bank price indices of France, Germany, Greece, Ireland, Italy and Spain. In addition, we consider the transmission among bank holdings of the same countries and also the impact of Greek bank holdings on the transmission mechanism among the aforementioned six countries bank indices. As a result, we use the same formula as below:

Bank indices returns : $R_t = [\text{Ln}(P_t) - \text{Ln}(P_{t-1})]*100$ (9)

and

Bank holdings returns: $R_t = [\text{Ln}(P_{BH,t}) - \text{Ln}(P_{BH,t-1})]*100$ (10)

More specifically, we use the logarithm of the quarterly difference of returns for the specific bank stock indices and all bank holdings. In the above first study, we take the official bank indices as they are given by Datastream. The bank holdings data are taken from the Bruegel Sovereign Holdings Database.

With regard to the data of the second study, the period of the daily returns spans from 12/2/1990 to 10/2/2012 for the French, German and Greek bank indices and from 21/3/1994 to 10/2/2012 for the Polish, Czech Republic and Greek bank indices. The data are the official bank indices as they are given by Datastream. The post crisis period begins on 1/9/2009.

After collecting the data, we calculated each country's bank stock index return using the formula:

$$R_t = [\mathrm{Ln}\,(P_t) - \mathrm{Ln}\,(P_{t-1})]*100 \qquad (11)$$

where, P_t is the price level of bank stock index at time t,

P_{t-1} is the price level of bank stock index at time t-1 and

R_t is the logarithm of bank stock price index returns at time t.

4.2. Results and Analysis of the BEKK-GARCH Model for Bank Holdings (First Study)

Tables 1 and 2 present the results of the transmission flows with bank holding effects. In particular, Table 1 is based on the transmission flows of six cross-country bank holdings from France, Germany, Greece, Ireland, Italy and Spain. Table 2 shows the impact of the Greek bank holdings on the transmission flows for each of the above six countries' bank indices. The methodology used is based on a BEKK-GARCH model which considers the normal distribution in the first approach (equation 1a) and the GMM distribution in the second approach (equation 1b). In these two tables, we report only the statistically significant results and not all the volatility and error transmitted effects in order to conserve space.

Table 1 shows that the impact of volatility from the Greek to the German bank holdings is very high and equal to -3.5358, while the counter effect is equal to -0.1860. The volatility impact between the French and the Greek bank holdings is not statistically significant. The error impact from the Greek to the German bank holdings is equal to -0.6466 and the return one is equal to 0.0573. The above results, in absolute numbers, mean that Greek bank holdings affect the German ones more than the opposite. The latter observation is larger when the volatility impact rather than the error impact is considered. In addition, the Greek bank holdings affect all the other countries' bank holdings (Italy, Spain and Ireland), except the French ones. Also, it appears that the Greek bank holdings are not influenced only by the French bank holdings, regardless of the impact being either volatility or error. Diagnostic tests show that autocorrelation on residuals and on cross-product of them are not present, however normality is present on residuals.

[Insert Table 1 about here]

Table 2 provides information on the impact from the Greek bank holdings to the six cross-country bank indices. The volatility transmission effects are not statistically significant between the Greek bank index and the bank indices of Germany and France, when there is an impact from the Greek bank holdings to the above countries. However, the error transmission found to be important and bilateral between the Greek bank index and the bank indices of German and France. In particular, we found that 1% error increase in the Greek bank index affects French bank index by an increase of 0.1992% and the German bank index by an increase of 0.0532%. At the opposite direction, a 1% error increase of French and German bank indices cause an increase of 0.8702% and 0.1358% to the Greek bank index, respectively. Another point derived from Table 2 is that when there is an impact from the Greek bank holdings on the six Eurozone bank stock indices, we observe that Greece affects Italy (volatility transmission) and Spain (error transmission) but does not affect Ireland at all. Diagnostic tests show that autocorrelation is present in residuals of France, Greece and Ireland and in the cross-product of those and that normality is also present in residuals, except for Italy.

[Insert Table 2 about here]

Hence, comparing the results between Tables 1 and 2, we can infer that the bank holdings have a strong impact on the transmission flows across different Eurozone cross-country bank indices. In particular, knowing that the German Government holds a large amount of Greek bonds in recent years the transmission mechanism shows a larger influence on Germany from Greece when we consider cross-country bank holding transmission (Table 1). Moreover, a substantial finding is the absence of volatility and error impact between the Greek and the French bank holdings. The French bank holdings are the less integrated compared to the other countries' bank holdings.

There is also a significant error impact between the Greek, the German and the French bank indices when we take into account the direct influence of the Greek bank holdings (Table 2).

4.3. Preliminary Analysis for the Whole Period (Second Study)

The first panel of Table 3 presents the descriptive statistics of the bank stock index of France, Germany and Greece. We also present the test results of normality, asymmetry, kurtosis, autocorrelation and ARCH (Autoregressive Conditional Heteroscedasticity) effects. The mean of stock price returns ranges from -0.0061 for Germany to 0.0002 for Greece and the standard deviation ranges from 1.7519 for Germany to 2.3284 for Greece. Thus, the Greek bank market is the most risky market regarding this group of countries. The magnitude of asymmetry is positive for France and Greece and negative for Germany and also the kurtosis is positive and leptokurtotic as far as the normal distribution is concerned for the three countries. The tests of Ljung-Box (12) for bank index returns and squared bank index returns show linear and non-linear interdependencies among the bank index returns and squared bank index returns, respectively. At the 1% level of significance, the results of these tests are statistically significant, for the three countries, in general. The test of ARCH effects suggests that the dataset of bank index returns for all the countries can be represented fairly well by an ARCH type model. Hence, ARCH effects for Germany, France and Greece may explain the non-linear interdependencies mentioned in the research of Nelson (1991) and Booth et al. (1992).

The second panel of Table 3 presents the descriptive statistics of Greece, Poland, and Czech Republic for the bank stock index returns of these countries and also the test results of normality, asymmetry, kurtosis, autocorrelation and ARCH (Autoregressive Conditional Heteroscedasticity) effects. The mean of bank stock index returns ranges from -0.0160 for Greece to 0.0055 for Czech, while the standard deviation is equal to 2.0225 for Poland and 2.3156 for Greece. The magnitude of asymmetry shows that the bank index returns for Poland and Czech Republic are negative, while for Greece are positive. The normal distribution for all three countries seems to be leptokurtic. The tests of Ljung-Box (12) for bank stock returns and squared bank stock returns show linear and non-linear interdependencies. At the 1% level of significance, the results of these tests were statistically significant for all the three countries. The test of ARCH effects shows that in all three countries the bank stock index returns of the specific dataset can be represented fairly well by an ARCH type model. Thus, ARCH effects may properly explain well the non-linear interdependencies, following the findings of Nelson (1991) and Booth et al. (1992) research. The non-dependent correlation coefficients range from 0.105 for Poland to 0.912 for the Czech Republic and all of them have been significant.

[Insert Table 3 about here]

4.4. Determination of Asymmetric Volatility (Second Study)

In this paragraph, we investigate the importance of asymmetry on volatility transmission among the Greek and the two developed bank indices as well as among the Greek and the two emerged bank indices. Primarily, we examine, through the following tests, the importance of asymmetry on bank price index returns.

Table 4 presents the tests for determining the variability of bank index returns as developed by Engle and Ng (1993). These tests control for the asymmetry of bank index volatility for all the countries which studied. These tests are:

- the sign bias test
- the negative size bias test
- the positive size bias test
- the joint test

The first test, namely the sign bias test, examines the effect of positive and negative residuals to volatility not predicted by the initial model. Specifically, square residuals are regressed on a constant and the pseudo S_t^-. Therefore, we examine the effect of ‘good’ and ‘bad’ news on the bank stock index returns’ volatility. The second test, namely the negative size bias test, examines the large and small but negative influence of residuals on the volatility of banks stock index returns and is based on a regression of residuals against a constant and the $S_t^- E_{t-1}$. The t-statistic which has been estimated for the $S_t^- E_{t-1}$ is used for this test. The third test, namely the positive size bias test, looks at small or large but positive effects of residuals on volatility of bank stock index returns and base its results on regressing the residuals against a constant term and the $(1\text{-}S_t^-)E_{t-1}$. The t-statistic is also used in this test in order to check for possible biases apart from the $(1\text{-}S_t^-)E_{t-1}$ usual ones. Finally, the fourth test, namely the joint test, uses the F-statistic which comes from the regression of the residuals against the three variables of S_t^-, $S_t^- E_{t-1}$ and $(1-S_t^-)E_{t-1}$.

For the specific two groups of the countries under study (France, Germany, Greece and Greece, Poland, Czech) the asymmetric tests show that an asymmetric model may capture the trends in the datasets and successfully identify the bank index return volatility for each country and across them. The sign bias test fails to comply with the asymmetrical distribution of the dataset at the significance level of 10% for Greece in the first group, and for Poland and the Czech Republic in the second one. A strong impact of asymmetry is observed for (a) the negative size bias test, (b) the negative size bias test and (c) the joint test at the significant level of 1% for the two groups of three countries under consideration. To sum up, based on the above test results, we may use an asymmetric model like EGARCH in order to examine a strong dynamic interdependence among bank price indices.

[Insert Table 4 about here]

4.5. Volatility Spillovers for the Bank Indices (Second Study)

4.5.1. Results and Analysis of the VAR-EGARCH Model

Table 5 presents the results of the VAR-EGARCH model for the period from 12-2-1990 to 10-2-2012. The parameters of β_{ij} (panel A of Table 5) of the model show the 'lead/lag' relationship among France, Germany and Greece. Table 5 shows that the bank stock index returns in Greece are associated with previous bank stock index returns in Germany (0.1037). Furthermore, it appears that the bank stock index returns of France are associated with past bank index returns of Germany (0.0576), while Germany seems to interlink with past bank stock index returns in France (0.0557). Thus, the results indicate that there is an interdependence of bank stock index returns between Germany and Greece and a lopsided effect between Germany and France, while there seems not to be a correlation between bank stock index returns of Greece and France. Therefore, Greece and France are the countries which receive the greatest impact in returns from Germany. Table 5 shows that the 'uncentered R-squared' for the three developed countries ranges from 0.0054 to 0.0235 which means that the rate of divergence in the bank stock index returns is quite small. This means that there is an indication of non-linearity in the model.

Analyzing Table 5 (panel A) results, it is observed that there is an almost mutual transmission of volatility (market risk) for all bank stock indices with an exception for the transmission from Germany to Greece. Most notably, market risk of France affects Germany (0.0219) and Greece (0.0512), Germany's market risk affects France (0.0314), and Greece's market risk affects Germany (0.0273) and France (0.0285). From the δ_i coefficient results we observe that for the whole period under study the transmission mechanism of volatility is asymmetric for Germany and Greece. This means that negative innovations stemming from Germany (-0.1426) and France (-0.2580) have more influence on volatility of bank index returns for these countries than positive innovations, while for Greece (-0.0313) the sign is correct, proved to be statistically insignificant. The results reinforce the belief that size and sign effects are important for the volatility transmission mechanism among the countries under study.

The parameters of β_{ij} (panel B of Table 5) for the VAR-EGARCH model show the 'lead/lag' relationship among Greece, Poland and the Czech Republic for the whole period under study. Specifically, it is indicated that the bank stock index returns in Greece are associated with the Czech previous bank stock index returns (0.0322) but not with the Polish ones. The relationship between the Czech and Polish bank index returns (0.0368) seems to be statistically significant. There are no other first moment interactions among these emerging countries. Furthermore, the 'uncentered R-squared' for these three countries ranges from 0.0119 to 0.0205, which means that the rate of divergence in the bank stock index's returns is quite small. This means that there is an indication of non-linearity in the model.

Following the analysis of results in panel B of Table 5, a bilateral mutual transmission of volatility (market risk) among all the bank stock indices is observed. Specifically, Greece affects Poland (-0.0331) and the Czech Republic (0.0360), Poland affects the Czech Republic (0.0705) and Greece (-0.0272) and the Czech Republic affects Poland (0.0151) and Greece (0.0278). From the above observations we interpreted that the volatility transmission between Greece and Poland is significant but with low persistence. Also, there is a strong volatility impact from Poland to the Czech Republic.

The δ_i coefficient shows that the volatility transmission mechanism is asymmetrical for all emerging countries. For all three countries, negative innovations influence the bank stock index volatility more than the positive innovations of these particular countries. In the second group of countries, the asymmetry of Greece is statistically significant and negative and this is in contrast to the first group's asymmetry results for the same country. The above results reinforce the belief that magnitude and sign effects are important for the volatility transmission mechanism of bank index returns among the emerging countries.

[Insert Table 5 about here]

To sum up, in the first group of countries the coefficient of asymmetry δ_i is statistically insignificant for Greece. This means that the Greek bank index volatility does not affect, with different signs, the French or the German bank index volatility. In addition, we found that the transmitted volatility effect from Germany to Greece is not statistically significant. On the contrary, in the second group of countries, Greek asymmetric volatility (market risk) plays an important role on the transmission of volatility in the Polish and Czech Republic emerging bank markets.

4.5.2. Impact of Innovations on Volatility for the Whole Period

Table 6 shows the volatility persistence and asymmetry for the bank stock index returns of France, Germany and Greece (panels A1 and A2) and also for those of Greece, Poland and the Czech Republic (panels B1 and B2).

The volatility shocks in panel A1 last about 24.15 days in the case of Greece, 33.14 days for Germany and 28.18 days for France. In addition, the volatility persistence (panel B1) for Greece, Poland and the Czech Republic last 29.79, 36.33, and 26.11 days, respectively. The results show that news persists for a long period in these two different groups of countries and leaves plenty of room to investors.

In panels A2 and B2, the results of asymmetric impact of positive and negative innovations on volatility are presented. It has been found that asymmetry is larger for Greece in the second group under study (1.32) than in the first group (1.06). For the rest of the countries, the responses by markets are larger in France (1.70) and the Czech Republic (1.63), followed by Germany (1.33) and Poland (1.23). Thus, asymmetry has been found to play an important role in both transmission mechanisms (positive and negative innovations). However, there is an almost double impact of bad news on France and Czech Republic than there is of good news.

[Insert Table 6 about here]

We next perform a simulation on the different impact of good and bad innovations on cross-market volatility. Table 7 shows that the total impact of spillover effects from market j to market i is measured by $\alpha_{ij}(1+\delta_j)$ for an 1% positive innovation and $\alpha_{ij}\,|-1+\delta_j\,|$ for a 1% negative innovation. For example, a +1% (-1%) innovation on day t-1 in the French banking sector increases volatility by 0.0974% (0.1653%) the following day within the same market. Moreover, there is an increase of 0.1101% (0.1468%) within the German banking sector and also, an increase on day t by 0.2384% (0.2539%) within the Greek banking sector when there is an impact by +1% (-1%) on day t-1. In addition, we observe that all the responses regardless of being the impact of innovation positive or negative on volatility, are positive for the trivariate VAR-EGARCH model of France, Germany and Greece.

Important findings are the smallest response which comes from the German to the Greek bank sector after a +1% (-1%) impact of innovations from the former. In particular, this response is equal to 0.0063% for positive innovations and 0.0084% for negative innovations. On the other hand, the Greek market affects the German more and the result is equal to 0.0264% for positive innovations and (0.0281%) for negative innovations.

In the second group of our study (panel B2) an important finding concerning its sign is the negative bilateral responses for both Poland and Greece. To be more specific, the response of +1% (-1%) from the Polish to the Greek market is equal to a decrease by 0.0243% (0.0300%) and the respective response from the Greek market to the Polish market is equal to a decrease by 0.0285% (0.0376%). The rest of the results in Table 7 are interpreted similarly.

[Insert Table 7 about here]

4.6. The Impact of Greek Debt Crisis on Spillovers (Second Study)

4.6.1. Pre and Post Crisis Analysis of the VAR-EGARCH Model

Panels A and B of Tables 8 and 9 present the results of pre and post Greek debt crisis for the two groups (France, Germany, Greece and Greece, Poland, the Czech Republic) regarding their bank stock indices. The analysis will be focused on the dynamic of volatility interdependences among the three bank indices of the two groups as mentioned above and also on the magnitude of volatility interdependence between the two periods under study.

Panels A of Tables 8 and 9 present the results of the pre and post crisis periods for the trivariate VAR-EGARCH model of France, Germany and Greece. The results for the volatility (market risk) transmission are not significant concerning the impact from Germany to Greece in the pre crisis period. The rest of the results in the pre crisis period indicate that there is a significant impact from Greece to France (0.0296), from France to Greece (0.0063), from Greece to Germany (0.0335) and also there are bilateral effects between France and Germany.

The results show that Greece affects France with a higher magnitude after the crisis (0.0541) than before the crisis (0.0296), and there are also higher bilateral interactions between France and Germany in the after crisis period. However, there are no volatility spillovers from France to Greece and from Germany to Greece in the post crisis period.

Looking at all the results of the pre and post crisis periods, we can infer that transmission of volatility is larger in magnitude after the crisis for all the cases except for the statistically significant impact from Greece to Germany which was found to be similar in the pre crisis (0.0335) compared to the post crisis period (0.0329). This means that the Greek debt crisis did not affect, more, the volatility transmission from Greece to Germany as it was found to be almost equal in the two periods under study. In addition, Germany did not affect Greece in both periods which indicate that Greece does not receive information from Germany. Also, Greece does not receive information from France in the post crisis period.

Furthermore, we observe that asymmetrical response of the volatility and the volatility persistence are important in both crisis periods under study. The results show that the ‘uncentered R-squared’ of the three countries does not diverge significantly in the two periods. The correlation between France, Germany and Greece has been increased after the crisis. Autocorrelation and normality are present in the two periods under study.

Panels B of Tables 8 and 9 present the results of the pre and post crisis periods for the trivariate VAR-EGARCH model of Greece, Poland and Czech. In particular, we notice that in the pre crisis period, the interdependence was not significant from Greece to Poland and vice versa. In addition, there was no impact from the Czech

Republic to Poland. On the contrary, the transmission of volatility was found to be significant from Greece to the Czech Republic (0.0535) and vice versa (0.0446).

In the after crisis period, there is no transmission of volatility from Czech Republic to Greece, from the Czech Republic to Poland and from Greece to the Czechs. In contrast to the pre crisis period, in the after crisis period an impact is observed from Greece to Poland (-0.0436) and vice versa (-0.0797) with lower persistence of volatility in both cases and from the Poles to the Czechs (0.0871) with a higher persistence of volatility.

Comparing the results between the pre and post crisis periods, we can infer that the Czech Republic does not affect Poland in either period, having an overall similar degree of interdependence. In general, interdependences have a larger impact on magnitude when the transmission of volatility is observed after the crisis rather than before the pre crisis period. Furthermore, volatility persistence is high and significant, with an asymmetrical response of volatility which being significant as well, in the two periods under study. Specifically, in the pre crisis period, the asymmetry plays a significant role in all three bank stock indices of Greece, Poland and Czech.

In the after crisis period, asymmetry is substantial for Greek and Polish bank markets but not for the Czech bank market. It is also shown that the 'uncentered R-squared' of the three countries of Greece, Poland and Czech Republic diverge more in the after-crisis period than in the pre crisis period. The correlation coefficients between Greece, Poland and Czech Republic are larger in the after crisis period rather than in the pre crisis period. This correlation is important, especially, between the Czech Republic and Poland and sheds light on the unilateral volatility effect from Poland to Czech. Autocorrelation and normality are present in the two periods under study.

[Insert Tables 8 and 9 about here]

To sum up, in the pre crisis period, the Greek volatility (market risk) affected the French market risk and the opposite happened as well. Also, the Greek market risk affected the German one. In the after crisis period, the Greek market risk affects French market risk with higher magnitude and also affects the German one at the same level. Moreover, the Greek bank market is not affected by the German and the French bank market risks in the after crisis period.

As far as the second group of emerging countries is concerned, it appears that the Greek market risk affected the Czech Republic market risk and vice versa in the pre crisis period. On the other hand, the Greek market risk affected the Polish bank market and the Polish bank market risk affected the Greek bank market in the after crisis period. Overall, the results reveal that spillovers change significantly between the two groups of countries after the crisis.

4.6.2. Impact of Innovations on Volatility from the Pre and Post crisis periods

Table 10 shows the verification of volatility persistence and asymmetric results for the banking sector returns of France, Germany and Greece (panels A1 and A2) and also of Greece, Poland and Czech Republic (panels B1 and B2) in the pre crisis period. The volatility persistence in panel A1 lasts about 29.7889 days for France, 29.6584 for Germany and 17.0231 for Greece. In addition, the volatility persistence in panel B1 for Greece, Poland and Czech Republic lasts 16.9365, 31.5944, and 25.5155 days, respectively. This means that in both groups the impact of news on volatility, in the pre crisis period, lasts for a long time.

In panels A2 and B2, the results of the asymmetric impact of positive and negative innovations on volatility for the pre crisis period are presented. It has been found that asymmetry is not statistically significant for Greece when it is associated with the transmission mechanisms of France and Germany. In conjunction with these two countries, it is observed that the importance of bad news in relation to good news is 1.4724 times larger for France and 1.3752 larger for Germany. Concerning the second group of the three countries an important asymmetric response to negative news has been found, being 1.2227 larger than positive news in Greece, 1.1238 for Poland and 1.5618 for the Czech Republic. Thus, asymmetry plays an important role in the pre crisis period to both groups with the largest impact for the Czech Republic and France. However, asymmetry was not significant for Greece in the first group.

[Insert Table 10 about here]

Table 11 shows the verification of volatility persistence and asymmetric results of banking sector's price index returns for France, Germany and Greece (panels A1 and A2) and also for Greece, Poland and the Czech Republic (panels B1 and B2) in the post crisis period. Volatility persistence in panel A1 lasts about 32.5027 days in the case of France and 62.0984 for Germany and 18.3849 for Greece. In addition, volatility persistence in panel B1 for Greece, Poland and the Czech Republic lasts 18.4867, 47.1284, and 82.1704 days, respectively. Thus, volatility persistence in the post crisis period lasts for a longer time than volatility persistence in the pre crisis period.

In panels A2 and B2, the results of asymmetric impact of positive and negative innovations on volatility, in the post crisis period, are presented. The asymmetry has a very statistically significant role for France (bad news is 8.2549 times larger than good news) when associated with the transmission mechanism of Germany and Greece. In conjunction with the last two countries, it is observed that the importance of bad news in relation to good news is 2.1210 times larger for Germany and 1.7859 times larger for Greece. In the second group, Greece responds to bad news 2.4764 times more than to positive news, Poland 2.6677 times respectively, whereas asymmetry for the Czech Republic is not present. Thus, the asymmetry indicates an important role in the post crisis period in both group cases (except for the Czech) with the largest impact to be accounted to France. For Greece, the asymmetrical response to news is found to be more significant and important in the second group rather than in the first one.

[Insert Table 11 about here]

In the pre crisis period, we perform a simulation on the different impact of good and bad news on cross-market volatility. Table 12 presents that a +1% (-1%) innovation in the French banking sector increases volatility by 0.1072% (0.1579%) the following day within the French banking sector. Moreover, there is an increase by 0.1107% (0.1522%) within the German banking sector and also an increase by 0.2645% (0.2636%) within the Greek banking sector. In addition, we observe that for all the responses, regardless of being the impact of innovation positive or negative on the volatility, are positive for the trivariate VAR-EGARCH model for France, Germany and Greece. Only the impact from Germany to Greece has been found to be not statistically significant when a +1% (-1%) increases (decreases) of innovations in Germany happens. All the other effects are statistically significant and vary from (0.0050% to 0.1522%) on their impacts from the one to the other bank market.

On the contrary, in the trivariate VAR-EGARCH model of Greece, Poland and the Czech Republic, the response of the Czech Republic to Greece on day t is positive and equal to 0.04813% (0.0588%) after +1% (-1%) increases (decreases) of innovations in Greece on day t-1. Similarly, the opposite response is positive but equal to 0.0348% (0.0543%). Poland does not affect Greece as the asymmetry is not important on the transmission mechanism.

[Insert Table 12 about here]

In the post crisis period, the impact from France to Greece and from Germany to Greece is not statistically significant after a 1% (-1%) increases (decreases) of innovations in the French or German banking sectors. Thus, Greece is not affected by the other countries' banking sectors. On the contrary, Greece affects Germany and France, varying its impact from 0.0236% to 0.0693% with respect to +1% (-1%) increases (decreases) of innovations in the Greek bank market.

In the second group, Greece affects Poland only, and Poland affects both Greece and the Czech Republic. There is no impact from the Czech Republic to Greece, and also Greece does not affect the Czech Republic. In particular, there is a decrease in volatility impact from Greece to Poland by 0.0250% (0.0621%) after an increase by +1% or a decrease by (-1%) of the Greek innovations. Furthermore, there is a decrease on volatility impact from Poland to Greece on day t by 0.0434% (0.1159%), respectively, having considered the increase (decrease) of +1% (-1%) of Poland innovations on day t-1. Finally, the impact from Poland to Czech Republic on day t causes an increase by 0.0474% (0.1267%) after an increase or decrease of +1% (-1%) of the innovations in Poland at day t-1.

[Insert Table 13 about here]

5. Conclusions

In this paper, we investigate the interrelationship among European bank holdings of specific Eurozone countries, but also those that exist among European bank markets, either developed or emerging, related to the Greek bank market in the light of the recent Greek debt crisis. Volatility and error spillover patterns are analyzed using a GARCH-BEKK model for the first study and an asymmetric VAR-EGARCH model for the second one. Our paper yields the following main results:

1. There are strong volatility and error spillovers between the Greek and the German bank holdings. Greek bank holdings have been found to affect the German ones in higher magnitude than vice versa. Also, French bank holdings are affected at a higher magnitude than the German ones. However, the volatility and error spillover effect between the Greek and the French bank holdings are not statistically significant. Consequently, Greek bank holdings are not influenced by the French bank holdings. Greek bank holdings affect all the other Eurozone countries' bank holdings (Italy, Spain and Ireland) under study. In general, empirical results on bank holding volatility

spillovers show that Greece, Ireland and Spain affect the volatility on bank holdings more than the other Eurozone countries. This is an interesting statistical result, as Ireland and Spain are the countries which followed Greece in the European financial support mechanism, namely EFSF (European Financial Stability Facility), in the light of the Greek and, consequently, the EuroZone debt crisis.

2. Taking into account the impact of Greek bank holdings in the GARCH-BEKK model, we find that there is no volatility effect from the Greek bank index to the German and French bank indices. However, the error transmission between the Greek bank index and the bank indices of German and France has been found to be important and bilateral. Moreover, we observe that the Greek bank index volatility affects the Italian bank index and also there is an error impact from the Greek to the Spanish bank index.

3. The comparison of the Greek bank market with the most two developed Eurozone EU countries (Germany and France) bank markets shows remarkable volatility spillovers among them, with an exception for the volatility transmission from Germany to Greece, for the whole period under study (12/2/1990 to 10/2/2012). Nevertheless, the volatility transmission mechanism is not asymmetrical for Greece, as it is for the other two countries.

On the other hand, mutual volatility transmission effects are observed among all the bank stock indices for the second group of emerging countries (Poland, Czech Republic and Greece). The asymmetry has been found to be important for the whole period (21/3/1994 to 10/2/2012) in this second group of countries. This means that the Greek bank index affects and is affected by the bank indices of the non-Eurozone EU emerging markets more than the developed ones.

4. The impact of innovations on volatility always leads to positive response concerning the group of France, Germany and Greece for the whole period. We observe the smallest response from the German to the Greek bank sector after a +1% (-1%) impact of innovations from the German one, whereas the Greek bank market affects the German bank market at most. In the second group of our study, an important finding is the negative bilateral responses for both Poland and Greece, regarding the sign of innovations.

5. The pre and post crisis spillover results indicate that volatility transmission in magnitude is almost equal from the Greek to the German bank market. There are no volatility spillovers from the German bank market to the Greek bank market in either

period. The Greek bank market affects the French bank market at a higher magnitude after the crisis rather than before. The Greek bank market is not affected by the German and French bank markets after the advent of the Greek debt crisis. Also, there are bilateral interactions between France and Germany in both periods, but at a higher magnitude in the post crisis period.

For the second group, the Greek bank market volatility affected the Czech Republic bank market risk and vice versa in the pre crisis period. On the other hand, there is volatility transmission between the Polish and Greek bank markets in the after crisis period. The asymmetrical response of volatility is present only in Greece and Poland in the post crisis period, but in all the three bank indices of Greece, Poland and Czech Republic in the pre crisis period.

Our results advocate that interdependence is substantially differentiated among the countries in the two groups, which shows the dynamic of the bank market risk in the after crisis period.

6. Based on the results regarding the degree of volatility persistence, the number of days that the innovations in the post crisis period last is larger than the number of days of the pre crisis period for both groups under study. This specifies that the European bank markets are more efficient in the after crisis period.

7. In the pre crisis period, all the results, concerning the asymmetric impact of positive and negative innovations on volatility, are positive for the developed group of France, Germany and Greece. In the post crisis period, the Greek bank market volatility is not affected by other countries' bank index innovations. On the contrary, the Greek bank market affects-positively-the volatility of both the German and French bank markets in relation to a +1% (-1%) increases (decreases) of innovations in the Greek bank market on the previous day. In the post crisis period, asymmetry has a very statistically significant role for the French bank market (bad news is 8.2549 times larger than good news) when it is associated with the transmission mechanism of the German and Greek bank markets.

Additionally, for the second group (Greece, Poland and Czech), the impact of innovations on the volatility of bank markets is asymmetrical in both periods, with an exception for the Czech Republic in the post crisis period. The response to negative news is higher in the post crisis period, especially for Greece and Poland.

8. After and during the crisis in the EU, the impact of innovations between Greece and Poland shows a decrease in their bank market volatility (market risk). This is an

interesting empirical result, especially for risk managers and investors who seek successful decisions for controlling and minimising market risks during this economically turbulent era for the EU.

In general, the differences of transmission results between the pre crisis and the post crisis periods advocate that there is a dynamic spillover mechanism between the European bank indices in the two groups under study, showing that asymmetric volatility and some other factors (i.e. autocorrelations, correlations, persistence) within the markets may play a substantial role for investors, risk managers and regulators. In addition, the transmission of bank holdings has been found to be statistically important between different Eurozone countries, indicating, thus, the significance of the role of sovereign debt in bank markets.

Our analysis sheds light on the complexity of the dynamics underlying the European bank markets and the Eurozone bank holdings and could be proved useful in designing risk management and portfolio management strategies.

However, future research would reveal further evidence on the direct impact of debt on spillovers among European or other world markets, other than the Greek one.

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Appendix

Table 1: Cross-country European Bank Holdings with Transmission Flows

Mean stock price returns: $R_{bh,t} = \beta_{i,0} + \varepsilon_{i,t}$, for bh = 1,2,3,4,5,6

Volatility: $H_t = CC' + A' H_{t-1} A + B' \varepsilon_{t-1} * \varepsilon'_{t-1} B$

Cross-country bank Holdings Q4 2001 – Q1 2012	France(1) Germany(2) Greece(3) Ireland(4) Italy(5) Spain(6)
α_{11}	-0.3239(0.1142)*
α_{15}	0.1468(0.0325)*
α_{16}	0.0874(0.0310)*
α_{21}	-2.3182(0.9693)**
α_{22}	0.2207(0.1333)***
α_{23}	-3.5358(0.6432)*
α_{24}	-4.8816(1.1136)*
α_{25}	0.6310(0.2587)**
α_{26}	-1.1755(0.2156)*
α_{32}	-0.1860(0.0472)*
α_{33}	-0.3736(0.1555)**
α_{34}	-0.8189(0.2992)*
α_{35}	-0.1922(0.0949)**
α_{36}	-0.7185(0.0979)*
α_{41}	1.2112(0.2060)*
α_{42}	-0.0838(0.0255)*
α_{43}	0.4829(0.1410)*
α_{44}	0.8613(0.2284)*
α_{45}	0.1207(0.0471)*
α_{46}	0.2915(0.0612)*
α_{51}	-2.8910(0.8670)*
α_{52}	0.5643(0.1136)*
α_{53}	2.2498(0.3806)*
α_{54}	4.7794(0.8860)*
α_{55}	-0.3725(0.1960)***
α_{56}	0.6251(0.2163)*
α_{61}	-1.7847(0.7018)*
α_{63}	3.0708(0.4130)*
α_{64}	-1.8165(0.6301)*
α_{66}	-0.4893(0.1490)*

β_{11}	0.5113 (0.0525)
β_{12}	0.0397(0.0081)*
β_{15}	0.0811(0.0150)*
β_{21}	1.8637(0.3642)*
β_{22}	0.4446(0.0552)*
β_{23}	-0.6466(0.2017)*
β_{24}	-1.3394(0.3809)*
β_{25}	-0.4516(0.1032)*
β_{32}	0.0573(0.0192)*
β_{33}	0.1811(0.0613)*
β_{34}	0.2782(0.0964)*
β_{35}	0.1217(0.0214)*
β_{36}	0.1173(0.0205)*
β_{43}	0.1781(0.0451)*
β_{46}	-0.0675(0.0185)*
β_{52}	0.1075(0.0393)*
β_{54}	1.1775(0.2595)*
β_{55}	0.5212(0.0618)*
β_{61}	-0.4808(0.2582)***
β_{62}	-0.2658(0.0480)*
β_{63}	0.5199(0.1302)*
β_{64}	-0.8666(0.2406)*
β_{66}	0.3493(0.0598)*

Diagnostic Tests

	France	Germany	Greece	Ireland	Italy	Spain
$E(z_{i,t})$	0.0000	0.0000	0.0000	-0.0000	-0.0000	0.0000
$E(z_{i,t}^2)$	23.9149	3.9918	14.7313	26.0223	5.7545	6.6474
LB(12); $z_{i,t}$	11.836	27.988*	12.567	16.964	10.773	14.742
LB(12); $z_{i,t}^2$	9.145	14.333	20.548***	11.291	8.181	16.947
D	0.182*	0.151**	0.127***	0.219*	0.149**	0.147**

LB(12) for the product of formal errors

LB($z_{12,t}$) =25.374**, LB($z_{13,t}$)=16.981, LB($z_{14,t}$)=6.278, LB($z_{15,t}$)=16.648, LB($z_{16,t}$)=5.448

LB($z_{23,t}$) =8.256 , LB($z_{24,t}$)=23.992**, LB($z_{25,t}$)=20.818***, LB($z_{26,t}$)=21.133**

LB($z_{34,t}$) =14.610 , LB($z_{35,t}$)=13.898, LB($z_{36,t}$)=17.749

LB($z_{45,t}$) = 11.126, LB($z_{46,t}$)=8.978

LB($z_{56,t}$) =14.905

Table 2: The impact of Greek Bank Holdings on the Transmission of Bank index Returns of Six European Countries

Mean stock price returns: $R_{i,t} = \beta_0 + \beta_1 R_{gbh,t} + \varepsilon_{i,t}$, for i = 1,2,3,4,5,6

Volatility: $H_t = CC' + A' H_{t-1} A + B' \varepsilon_{t-1} * \varepsilon'_{t-1} B$

Transmission of Bank Index News Q4 2001 – Q1 2012	France(1) Germany(2) Greece(3) Ireland(4) Italy(5) Spain(6)
α_{14}	0.1332 (0.0335)*
α_{16}	-0.0222(0.0117)***
α_{21}	-0.4706(0.2075)**
α_{26}	-0.8165(0.0874)*
α_{36}	0.2365(0.0609)*
α_{41}	-0.5164(0.2651)**
α_{44}	-0.2148(0.0280)*
α_{45}	-0.3163(0.1686)***
α_{46}	-1.2428(0.1047)*
α_{53}	0.5251(0.1671)*
α_{54}	0.0707(0.0399)***
α_{62}	-0.3451(0.1610)**
α_{64}	-0.2191(0.0235)*
α_{65}	0.0585(0.0088)*
α_{66}	-0.2010(0.0263)*
β_{12}	1.1163(0.0106)*
β_{13}	0.1992(0.0270)*
β_{14}	0.0863(0.0166)*
β_{15}	0.6524(0.0360)*
β_{22}	-0.2051(0.0103)*
β_{23}	0.0532(0.0056)*
β_{24}	0.3789(0.0042)*
β_{31}	0.8702(0.0702)*
β_{32}	0.1358(0.0312)*
β_{33}	0.5370(0.0308)*
β_{35}	0.2418(0.0489)*
β_{41}	-2.9480(0.0007)*
β_{44}	-0.0855(0.0113)*
β_{52}	0.2079(0.0226)*
β_{53}	0.3003(0.0111)*

β_{63}	0.3420(0.0546)*
β_{65}	-0.1179(0.0451)*
β_{66}	-0.0378(0.0087)*

Diagnostic Tests

	France	Germany	Greece	Ireland	Italy	Spain
$E(z_{i,t})$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$E(z_{i,t}^2)$	19.8189	17.8269	26.1260	36.4500	14.3825	27.2700
LB(12); $z_{i,t}$	20.707***	14.318	23.155**	19.109***	16.883	14.885
LB(12); $z_{i,t}^2$	23.754**	24.386**	18.108	18.296	17.272	5.499
D	0.156**	0.131***	0.129***	0.133***	0.095	0.231*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$) = 29.527*, LB($z_{13,t}$)=7.989, LB($z_{14,t}$)=12.844, LB($z_{15,t}$)=21.433**, LB($z_{16,t}$)=6.279

LB($z_{23,t}$) =27.152* , LB($z_{24,t}$)=15.414, LB($z_{25,t}$)=23.425**, LB($z_{26,t}$)=5.744

LB($z_{34,t}$) = 19.078***, LB($z_{35,t}$)=24.079**, LB($z_{36,t}$)=6.216

LB($z_{45,t}$) = 13.562, LB($z_{46,t}$)=2.515

LB($z_{56,t}$) =6.729

Table 3: Descriptive Statistics and Diagnostic Tests

Descriptive statistics and diagnostic tests for France, Germany and Greece for the period from 12/2/90 to 10/2/12

Statistics	France	Germany	Greece
μ	0.0064	-0.0061	0.0002
σ	2.0233	1.7519	2.3284
S	0.2086	-0.1294	0.3049
K	7.8123	11.9191	7.4022
D	0.139*	0.166*	0.137*
LB(12) for R_t	78.145*	58.017*	122.604*
LB(12) for R_t^2	2361.462*	3980.800*	2573.710*
ARCH(4)	185.6975*	245.8790*	191.4790*

Table of Correlations

	France	Germany	Greece
France	1	0.692*	0.811*
Germany		1	0.849*
Greece			1

Descriptive statistics and diagnostic tests for Greece, Poland and Czech Republic for the period from 21/3/94 to 10/2/12

Statistics	Greece	Poland	Czech

μ	-0.0160	0.0206	0.0055
σ	2.3156	2.0225	2.2589
S	0.2529	-0.1714	-0.7946
K	7.8812	5.5580	10.7865
D	0.101*	0.139*	0.132*
LB(12) for R_t	93.033*	128.103*	95.439*
LB(12) for R_t^2	2755.528*	2344.918*	1749.412*
ARCH(4)	183.5818*	159.2236*	112.2612*

Table of Correlations

	Greece	Poland	Czech
Greece	1	0.367*	0.105*
Poland		1	0.912*
Czech			1

Note: (*), (**), (***) indicate the statistical significance level of 1% , 5%, 10% respectively, where μ is the mean of banks' stock price returns, σ is the standard deviation of banks' stock price returns, S is the asymmetry, K is the kurtosis and D the result of Kolmogorov-Smirnov test. LB (12) is the Ljung-Box statistics for 12 lags.

Table 4: Tests for Determining the Volatility of Banks' Stock Price Returns

Countries	Sign bias(t-test)	Negative size bias (t-test)	Positive size bias test (t-test)	Joint test (F-test)
Test for determining the volatility of banks' stock price returns for Greece, Germany and France for the period from 12-2-90 to 10-2-12				
France	1.7327***	-15.1146*	4.7120*	112.7027*
Germany	2.1878**	-18.0344*	8.0747*	174.5161*
Greece	1.1774	-16.0313*	9.7962*	167.3258*
Test for determining the volatility of banks' stock price returns for Greece, Poland and Czech Republic for the period from 21-3-94 to10-2-12				
Greece	1,6282***	-16.4136*	8.7009*	162.0085*
Poland	0.9634	-10.7992*	7.3241*	82.3659*
Czech	1,5020	-13.7860*	6.2902*	102.0600*

Sign bias test
Negative size b
Positive size bias test:
Joint test:

$$z_t^2 = a + bS_t^- + e_t \quad \text{(i)}$$

$$z_t^2 = a + bS_t^- E_{t-1} + e_t \quad \text{(ii)}$$

$$z_t^2 = a + b(1 - S_t^-)E_{t-1} + e_t \quad \text{(iii)}$$

$$z_t^2 = a + b_1 S_t^- + b_2 S_t^- E_{t-1} + b_3(1 - S_t^-)E_{t-1} + e_t \quad \text{(iv)}$$

Note: (*), (**), (***) present statistical significance in the significance level (1%), (5%), (10%). Z reflect residuals from an AR (p) filter using constant volatility. S_t^- is a unit if E is negative, and zero if not. The t-statistic for sign bias, negative size bias and positive size bias tests are the factors of b coefficients for the regressions (i), (ii) and (iii), respectively. The F-statistic is based on regression (iv).

Table 5: Maximum Valued Probabilities of the VAR-EGARCH model

Mean stock price returns: $R_{i,t} = \beta_{i0} + \sum_{j=1}^{3} \beta_{ij} R_{j,t-1} + \varepsilon_{i,t}$ for i, j = 1,2,3

Volatility: $\sigma_{i,t}^2 = \exp\{\alpha_{i0} + \sum_{j=1}^{3} \alpha_{ij} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^2)\}$ for i, j = 1,2,3

Covariance: $\sigma_{ij,t} = \rho_{ij}\sigma_{i,t}\sigma_{j,t}$ for i, j = 1,2,3 κκαi ≠ j.

Maximum valued probabilities of the VAR-EGARCH model for the countries of France, Germany and Greece for the period from 12-2-90 to 10-2-12

	France (1)		Germany (2)		Greece (3)
β_{10}	0.0229 (0.0182)	β_{20}	0.0280 (0.0148)**	β_{30}	0.0261 (0.0209)
β_{11}	0.0134 (0.0143)	β_{21}	0.0557 (0.0109)*	β_{31}	0.0099 (0.0145)
β_{12}	0.0576 (0.0176)*	β_{22}	0.0232 (0.0147)	β_{32}	0.1037 (0.0173)*
β_{13}	-0.0030 (0.0103)	β_{23}	-0.0115 (0.0078)	β_{33}	0.1204 (0.0127)*
α_{10}	0.0337 (0.0022)*	α_{20}	0.0217 (0.0016)*	α_{30}	0.0535 (0.0036)*
α_{11}	0.1314 (0.0069)*	α_{21}	0.0219 (0.0063)*	α_{31}	0.0512 (0.0092)*
α_{12}	0.0314 (0.0052)*	α_{22}	0.1285 (0.0067)*	α_{32}	0.0074 (0.0082)
α_{13}	0.0285 (0.0061)*	α_{23}	0.0273 (0.0070)*	α_{33}	0.2462 (0.0090)*
δ_1	-0.2580 (0.0362)*	δ_2	-0.1426 (0.0313)*	δ_3	-0.0313 (0.0204)
γ_1	0.9757 (0.0016)*	γ_2	0.9793 (0.0014)*	γ_3	0.9717 (0.0021)*
R^2	0.0114		0.0054		0.0235

Table of Correlations

	France	Germany	Greece
France	1	0.6154 (0.0065)*	0.2835 (0.0107)*
Germany		1	0.2831 (0.0099)*
Greece			1

Diagnostic tests

	France	Germany	Greece
E$(z_{i,t})$	-0.0000	0.0000	-0.0000
E$(z_{i,t}^2)$	0.9998	0.9998	0.9998
LB(12); $z_{i,t}$	56930.7825*	58417.3184*	42907.8901*
LB(12); $z_{i,t}^2$	42684.0647*	44508.4202*	25685.9786*
D	0.230*	0.258*	0.231*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$)=46534.7696*, LB($z_{13,t}$)=35850.7782*, LB($z_{23,t}$)=41782.3449*

Maximum valued probabilities of the VAR-EGARCH model for the countries of Greece, Poland and Czech Republic for the period from 21-3-94 to 10-2-12

	Greece (1)		Poland (2)		Czech Republic (3)
β_{10}	0.0112 (0.0213)	β_{20}	0.0485 (0.0222)**	β_{30}	0.0354 (0.0198)***
β_{11}	0.1513 (0.0143)*	β_{21}	0.0015 (0.0093)	β_{31}	0.0322 (0.0123)*
β_{12}	0.0147 (0.0106)	β_{22}	0.1064 (0.0140)*	β_{32}	0.0368 (0.0128)*
β_{13}	-0.0017 (0.0116)	β_{23}	0.0119 (0.0115)	β_{33}	0.0896 (0.0135)*
α_{10}	0.0410 (0.0035)*	α_{20}	0.0284 (0.0030)*	α_{30}	0.0494 (0.0030)*
α_{11}	0.2416 (0.0098)*	α_{21}	-0.0331 (0.0085)*	α_{31}	0.0360 (0.0069)*
α_{12}	-0.0272 (0.0097)*	α_{22}	0.1723 (0.0087)*	α_{32}	0.0705 (0.0073)*
α_{13}	0.0278 (0.0097)*	α_{23}	0.0151 (0.0072)**	α_{33}	0.1342 (0.0060)*
δ_1	-0.1378 (0.0232)*	δ_2	-0.1045 (0.0273)*	δ_3	-0.2384 (0.0331)*
γ_1	0.9770 (0.00206)*	γ_2	0.9811 (0.0021)*	γ_3	0.9738 (0.0017)*
R^2	0.0119		0.0205		0.0164

Table of Correlations

	Greece	Poland	Czech
Greece	1	0.2555 (0.0129)*	0.2180 (0.0130)*
Poland		1	0.2732 (0.0121)*
Czech			1

Diagnostic tests

	Greece	Poland	Czech
E$(z_{i,t})$	0.0000	0.0000	0.0000
E$(z_{i,t}^2)$	0.9997	0.9997	0.9997
LB(12); $z_{i,t}$	36895.5876*	41006.5628*	39290.4737*
LB(12); $z_{i,t}^2$	22170.5514*	24172.1617*	21022.1869*
D	0.239*	0.203*	0.232*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$)=31128.5364*, LB($z_{13,t}$)=26176.2651*, LB($z_{23,t}$)=27411.6274*

Note: Numbers in parentheses are the asymptotic errors. D = Result of the Kolmogorov-Smirnov test, which checks for normality (5% criticism value is 1.36 / where T is the number of observations); LB (n) is the Ljung-Box statistics for n lags (distributed as

x^2 with n degrees of freedom). $Z_{i,t}$ is the residuals in the market i. (*), (**), (***) indicate statistical significance at the significance level (1%), (5%), (10%).

Table 6: Volatility Persistence (days) and Asymmetry (times) from the VAR-EGARCH model

Panel A: France, Germany and Greece	
Panel A1: Degree of volatility persistence	
	Volatility Persistence
France	28.1765
Germany	33.1375
Greece	24.1446
Panel A2: Degree of volatility asymmetric impact of Negative and Positive innovations	
	Volatility Asymmetry
France	1.6954
Germany	1.3326
Greece	1.0646
Panel B: Greece, Poland and Czech	
Panel B1: Degree of volatility persistence	
	Volatility Persistence
Greece	29.7889
Poland	36.3267
Czech	26.1078
Panel B2: Degree of volatility asymmetric impact of Negative and Positive innovations	
	Volatility Asymmetry
Greece	1.3196
Poland	1.2333
Czech	1.6260

Note: Entries in Panel A1 and B1 denote the degree of volatility persistence, based on the half-life of a shock (defined as ln(0.5)/ln(γ_i)). Entries in Panel B1 and B2 denote the number of times that negative innovations increase volatility more than that of positive innovations, which is defined as $|-1+\delta_j|/(1+\delta_j)$. N.A. means not available.

Table 7: Total Impact of Innovations on Volatility from the VAR-EGARCH model

Panel A: For France, Germany and Greece			
Percentage change			
Innovation at t-1 from:	France at t	Germany at t	Greece at t
+1% France	0.0974	0.0162	0.0379
-1% France	0.1653	0.0275	0.0644
+1% Germany	0.0269	0.1101	NA
-1% Germany	0.0358	0.1468	NA
+1% Greece	0.0276	0.0063	0.02384
-1% Greece	0.0293	0.0084	0.2539
Panel B: For Greece, Poland and Czech			
Percentage change			
Innovation at t-1 from:	Greece at t	Poland at t	Czech Republic at t

+1% Greece	0.2030	-0.0285	0.0310
-1% Greece	0.2748	-0.0376	0.0409
+1% Poland	-0.0243	0.1542	0.0631
-1% Poland	-0.0300	0.1903	0.0778
+1% Czech	0.0211	0.0115	0.1022
-1% Czech	0.0344	0.0187	0.1661

Note: Entries represent the total impact of innovations of index j to index I, which is defined as $\alpha_{ij}(1+\delta_j)$ for a positive 1% innovation and $\alpha_{ij}\,|-1+\delta_j\,|$ for a negative 1% innovation.

Table 8: Pre Crisis Maximum Valued Probabilities of the VAR-EGARCH Model

Mean stock price returns: $R_{i,t} = \beta_{i0} + \sum_{j=1}^{3}\beta_{ij}R_{j,t-1} + \varepsilon_{i,t}$ for i, j $=1,2,3$

Volatility: $\sigma^2_{i,t} = \exp\{\alpha_{i0} + \sum_{j=1}^{3}\alpha_{ij} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma^2_{i,t-1})\}$ for i, j $=1,2,3$

Covariance: $\sigma_{ij,t} = \rho_{ij}\sigma_{i,t}\sigma_{j,t}$ for i, j $=1,2,3$ κκαi $\neq$ j.

Panel A:Maximum valued probabilities of the VAR-EGARCH model for the countries of France, Germany and Greece for the period from 12-2-90 to 31-8-09

	France (1)		Germany (2)		Greece (3)
β_{10}	0.0294 (0.0186)	β_{20}	0.0310 (0.0151)**	β_{30}	0.0352 (0.0209)***
β_{11}	0.0118 (0.0151)	β_{21}	0.0552 (0.0115)*	β_{31}	0.0181 (0.0146)
β_{12}	0.0604 (0.0186)*	β_{22}	0.0303 (0.0159)***	β_{32}	0.0936 (0.0181)*
β_{13}	-0.0123 (0.0116)	β_{23}	-0.0130 (0.0088)	β_{33}	0.1444 (0.0145)*
α_{10}	0.0294 (0.0022)*	α_{20}	0.0204 (0.0017)*	α_{30}	0.0611 (0.0043)*
α_{11}	0.1326 (0.0075)*	α_{21}	0.02567 (0.0073)*	α_{31}	0.0630 (0.0100)*
α_{12}	0.0274 (0.0052)*	α_{22}	0.1315 (0.0077)*	α_{32}	0.0084 (0.0090)
α_{13}	0.0296 (0.0065)*	α_{23}	0.0335 (0.0083)*	α_{33}	0.2641 (0.0110)*
δ_1	-0.1911 (0.0374)*	δ_2	-0.1580 (0.0346)*	δ_3	0.0018 (0.0240)
γ_1	0.9770 (0.0018)*	γ_2	0.9769 (0.0019)*	γ_3	0.9601 (0.0030)*
R^2	0.0119		0.0073		0.0366

Table of Correlations

	France	Germany	Greece
France	1	0.5802 (0.0076)*	0.2434 (0.0117)*
Germany		1	0.2536 (0.0107)*
Greece			1

Diagnostic tests			
	France	Germany	Greece
E$(z_{i,t})$	-0.0000	0.0000	0.0000
E$(z_{i,t}^2)$	0.9997	0.9997	0.9997
LB(12); $z_{i,t}$	49036.8923*	48935.3096*	32271.0941*
LB(12); $z_{i,t}^2$	41452.1232*	37277.3422*	17425.2896*
D	0.236*	0.282*	0.200*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$)=41398.8286*, LB($z_{13,t}$)=33390.2754*, LB($z_{23,t}$)=35269.2439*

Panel B: Maximum valued probabilities of the VAR-EGARCH model for the countries of Greece, Poland and Czech Republic for the period from 21-3-94 to 31-8-09

	Greece (1)		Poland (2)		Czech Republic (3)
β_{10}	0.0227 (0.0216)	β_{20}	0.0546 (0.0258)**	β_{30}	0.0373 (0.0221)***
β_{11}	0.1669 (0.0166)*	β_{21}	-0.0143 (0.0138)	β_{31}	-0.0000 (0.0171)
β_{12}	0.0123 (0.0112)	β_{22}	0.1234 (0.0151)*	β_{32}	0.0379 (0.0131)*
β_{13}	0.0042 (0.0120)	β_{23}	0.0296 (0.0130)**	β_{33}	0.1151 (0.0150)*
α_{10}	0.0517 (0.0046)*	α_{20}	0.0334 (0.0036)*	α_{30}	0.0492 (0.0032)*
α_{11}	0.2519 (0.0115)*	α_{21}	-0.00318 (0.0095)	α_{31}	0.0535 (0.0083)*
α_{12}	-0.0062 (0.0113)	α_{22}	0.1767 (0.0099)*	α_{32}	0.0625 (0.0083)*
α_{13}	0.0446 (0.0113)*	α_{23}	0.0039 (0.0087)	α_{33}	0.1388 (0.0069)*
δ_1	-0.1002 (0.0284)*	δ_2	-0.0583 (0.0299)**	δ_3	-0.2193 (0.0364)*
γ_1	0.9599 (0.0036)*	γ_2	0.9783 (0.0026)*	γ_3	0.9732 (0.0018)*
R^2	0.0262		0.0223		0.0174

Table of Correlations			
	Greece	Poland	Czech
Greece	1	0.2321 (0.0144)*	0.2067 (0.0142)*
Poland		1	0.2246 (0.0136)*
Czech			1

Diagnostic tests			
	Greece	Poland	Czech

$E(z_{i,t})$	-0.0000	0.0000	-0.0000
$E(z_{i,t}^2)$	0.9997	0.9997	0.9997
LB(12); $z_{i,t}$	28022.3505*	33630.5390*	32942.1022*
LB(12); $z_{i,t}^2$	17483.6173*	19849.6738*	17553.2007*
D	0.210*	0.224*	0.253*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$)=23610.5670*, LB($z_{13,t}$)=19995.6283*, LB($z_{23,t}$)=23231.0595*

Note: Numbers in parentheses are the asymptotic errors. D = Result of the Kolmogorov-Smirnov test, which checks for normality (5% criticism value is 1.36 / where T is the number of observations); LB (n) is the Ljung-Box statistics for n lags (distributed as x^2 with n degrees of freedom). $Z_{i,t}$ is the residuals in the market i. (*), (**), (***) indicate statistical significance at the significance level (1%), (5%), (10%).

Table 9: After Crisis Maximum Valued Probabilities of the VAR-EGARCH Model

Mean stock price returns: $R_{i,t} = \beta_{i0} + \sum_{j=1}^{3} \beta_{ij} R_{j,t-1} + \varepsilon_{i,t}$ for i, j = 1,2,3

Volatility: $\sigma_{i,t}^2 = \exp\{\alpha_{i0} + \sum_{j=1}^{3} \alpha_{ij} f_j(z_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^2)\}$ for i, j = 1,2,3

Covariance: $\sigma_{ij,t} = \rho_{ij}\sigma_{i,t}\sigma_{j,t}$ for i, j = 1,2,3 κκαi ≠ j.

Panel A: Maximum valued probabilities of the VAR-EGARCH model for the countries of France, Germany and Greece for the period from 1-9-09 to 10-2-12

	France (1)		Germany (2)		Greece (3)
β_{10}	-0.0899 (0.0749)	β_{20}	-0.0812 (0.0634)	β_{30}	-0.3019 (0.1254)**
β_{11}	0.0360 (0.0498)	β_{21}	0.0770 (0.0415)***	β_{31}	-0.0779 (0.0759)
β_{12}	0.0056 (0.0591)	β_{22}	-0.0587 (0.0494)	β_{32}	0.2087 (0.074)*
β_{13}	0.0285 (0.0269)	β_{23}	-0.0060 (0.0217)	β_{33}	-0.0004 (0.0345)
α_{10}	0.0483 (0.0089)*	α_{20}	0.0227 (0.0064)*	α_{30}	0.1065 (0.0313)*
α_{11}	0.0320 (0.0185)***	α_{21}	-0.0498 (0.0219)**	α_{31}	-0.0092 (0.0264)
α_{12}	0.1187 (0.0254)*	α_{22}	0.1601 (0.0285)*	α_{32}	0.0281 (0.0378)
α_{13}	0.0541 (0.0219)**	α_{23}	0.0329 (0.0200)***	α_{33}	0.2100 (0.0233)*
δ_1	-0.7839 (0.2612)*	δ_2	-0.3592 (0.0861)*	δ_3	-0.2821 (0.0645)*
γ_1	0.9789 (0.0035)*	γ_2	0.9889 (0.0031)*	γ_3	0.9630 (0.0116)*
R^2	0.0147		0.0029		0.0182

Table of Correlations			
	France	Germany	Greece
France	1	0.7968 (0.0135)*	0.4887 (0.0273)*
Germany		1	0.4254 (0.0305)*
Greece			1

Diagnostic tests			
	France	Germany	Greece
$\mathrm{E}(z_{i,t})$	-0.0000	-0.0000	0.0000
$\mathrm{E}(z_{i,t}^2)$	0.9987	0.9987	0.9987
LB(12); $z_{i,t}$	7837.3983*	8216.8052*	5480.3302*
LB(12); $z_{i,t}^2$	5241.1363*	4829.3739*	3298.6041*
D	0.203*	0.180*	0.223*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$)=4955.3064*, LB($z_{13,t}$)=4632.5135*, LB($z_{23,t}$)=5069.2620*

Panel B: Maximum valued probabilities of the VAR-EGARCH model for the countries of Greece, Poland and Czech Republic for the period from 1-9-09 to 10-2-12

	Greece (1)		Poland (2)		Czech Republic (3)
β_{10}	-0.2573 (0.1273)**	β_{20}	0.0064 (0.0473)	β_{30}	-0.0374 (0.0691)
β_{11}	0.0278 (0.0357)	β_{21}	0.0080 (0.0135)	β_{31}	0.0235 (0.0196)
β_{12}	0.1278 (0.0756)***	β_{22}	0.05808 (0.0424)	β_{32}	0.1546 (0.0572)*
β_{13}	-0.0626 (0.0565)	β_{23}	-0.0290 (0.0280)	β_{33}	-0.0543 (0.0329)***
α_{10}	0.1034 (0.0322)*	α_{20}	0.0161 (0.0064)*	α_{30}	0.0126 (0.0044)*
α_{11}	0.2103 (0.0311)*	α_{21}	-0.0436 (0.0240)***	α_{31}	-0.01876 (0.0131)
α_{12}	-0.0797 (0.0236)*	α_{22}	0.1434 (0.0242)*	α_{32}	0.0871 (0.0150)*
α_{13}	0.0394 (0.0254)	α_{23}	0.0080 (0.0192)	α_{33}	-0.0278 (0.0111)*
δ_1	-0.4247 (0.0899)*	δ_2	-0.4547 (0.1159)*	δ_3	0.4928 (0.4202)
γ_1	0.9632 (0.0118)*	γ_2	0.9854 (0.0045)*	γ_3	0.9916 (0.0025)*
R^2	0.0055		0.0226		0.0288

Table of Correlations			
	Greece	Poland	Czech

Greece	1	0.3734 (0.0298)*	0.2737 (0.0316)*
Poland		1	0.5049 (0.0280)*
Czech			1

Diagnostic tests

	Greece	Poland	Czech
$E(z_{i,t})$	-0.0000	0.0000	-0.0000
$E(z_{i,t}^2)$	0.9987	0.9987	0.9987
LB(12); $z_{i,t}$	5084.6131*	7090.0941*	8181.5906*
LB(12); $z_{i,t}^2$	2396.3094*	2999.0312*	5405.1885*
D	0.237*	0.173*	0.162*

LB(12) for the product of vectors of formal errors

LB($z_{12,t}$)=3204.3826*, LB($z_{13,t}$)=3510.2109*, LB($z_{23,t}$)=4043.1381*

Note: Numbers in parentheses are the asymptotic errors. D = Result of the Kolmogorov-Smirnov test, which checks for normality (5% criticism value is 1.36 / where T is the number of observations); LB (n) is the Ljung-Box statistics for n lags (distributed as x^2 with n degrees of freedom). $Z_{i,t}$ is the residuals in the market i. (*), (**), (***) indicate statistical significance at the significance level (1%), (5%), (10%).

Table 10: Pre Crisis Volatility Persistence (days) and Asymmetry (times) from the VAR-EGARCH model

Panel A: For France, Germany and Greece	
Panel A1: Degree of volatility persistence	
	Volatility Persistence
France	29.7889
Germany	29.6584
Greece	17.0231
Panel A2: Degree of volatility asymmetric impact of Negative and Positive innovations	
	Volatility Asymmetry
France	1.4724
Germany	1.3752
Greece	NA
Panel B: For Greece, Poland and Czech	
Panel B1: Degree of volatility persistence	
	Volatility Persistence
Greece	16.9365
Poland	31.5944
Czech	25.5155
Panel B2: Degree of volatility asymmetric impact of Negative and Positive innovations	
	Volatility Asymmetry
Greece	1.2227
Poland	1.1238
Czech	1.5618

Note: Entries in Panel A1 and B1 denote the degree of volatility persistence, based on the half-life of a shock (defined as ln(0.5)/ln(γ_i)). Entries in Panel B1 and B2 denote the number of times that negative innovations increase volatility more than that of positive innovations, which is defined as |-1+ δ_j |/(1+ δ_j). N.A. means the impact of positive and negative innovations on volatility is similar.

Table 11: After Crisis Volatility Persistence (days) and Asymmetry (times) from the VAR-EGARCH model

Panel A: For France, Germany and Greece	
Panel A1: Degree of volatility persistence	
	Volatility Persistence
France	32.5027
Germany	62.0984
Greece	18.3849
Panel A2: Degree of volatility asymmetric impact of Negative and Positive innovations	
	Volatility Asymmetry
France	8.2549
Germany	2.1210
Greece	1.7859
Panel B: For Greece, Poland and Czech	
Panel B1: Degree of volatility persistence	
	Volatility Persistence
Greece	18.4867
Poland	47.1284
Czech	82.1704
Panel B2: Degree of volatility asymmetric impact of Negative and Positive innovations	
	Volatility Asymmetry
Greece	2.4764
Poland	2.6677
Czech	NA

Note: Entries in Panel A1 and B1 denote the degree of volatility persistence, based on the half-life of a shock (defined as ln(0.5)/ln(γ_i)). Entries in Panel B1 and B2 denote the number of times that negative innovations increase volatility more than that of positive innovations, which is defined as |-1+ δ_j |/(1+ δ_j). N.A. means the impact of positive and negative innovations on volatility is similar.

Table 12: Pre Crisis Total impact of Innovations on Volatility from the VAR-EGARCH model

Panel A: For France, Germany and Greece			
Percentage change			
Innovation at t-1 from:	France at t	Germany at t	Greece at t
+1% France	0.1072	0.0207	0.0050
-1% France	0.1579	0.0305	0.0075
+1% Germany	0.0230	0.1107	NA
-1% Germany	0.0317	0.1522	NA
+1% Greece	0.0296	0.0335	0.2645
-1% Greece	0.0295	0.0334	0.2636
Panel B: For Greece, Poland and Czech			
Percentage change			

Innovation at t-1 from:	Greece at t	Poland at t	Czech Republic at t
+1% Greece	0.2266	NA	0.0481
-1% Greece	0.2771	NA	0.0588
+1% Poland	NA	0.1663	0.0588
-1% Poland	NA	0.1870	0.0661
+1% Czech	0.0348	NA	0.1083
-1% Czech	0.0543	NA	0.1692

Note: Entries represent the total impact of innovations of index j to index i, which is defined as $\alpha_{ij}(1+\delta_j)$ for a positive 1% innovation and $\alpha_{ij}\,|-1+\delta_j\,|$ for a negative 1% innovation. N.A. means that δ_j is not statistically significant.

Table 13: After Crisis Total Impact of Innovations on Volatility from the VAR-EGARCH model

Panel A: For France, Germany and Greece			
Percentage change			
Innovation at t-1 from:	France at t	Germany at t	Greece at t
+1% France	0.0069	-0.0107	NA
-1% France	0.0570	-0.0888	NA
+1% Germany	0.0760	0.1025	NA
-1% Germany	0.1613	0.2176	NA
+1% Greece	0.0388	0.0236	0.1507
-1% Greece	0.0693	0.0421	0.2692
Panel B: For Greece, Poland and Czech			
Percentage change			
Innovation at t-1 from:	Greece at t	Poland at t	Czech Republic at t
+1% Greece	0.1209	-0.0250	NA
-1% Greece	0.2996	-0.0621	NA
+1% Poland	-0.0434	0.0781	0.0474
-1% Poland	-0.1159	0.2086	0.1267
+1% Czech	NA	NA	-0.0415
-1% Czech	NA	NA	-0.0141

Note: Entries represent the total impact of innovations of index j to index I, which is defined as $\alpha_{ij}(1+\delta_j)$ for a positive 1% innovation and $\alpha_{ij}\,|-1+\delta_j\,|$ for a negative 1% innovation. N.A. means that δ_j is not statistically significant.