Documento de trabajo
SEMINARIO PERMANENTE DE CIENCIAS SOCIALES

VOLATILITY TRANSMISSION AMONG EUROPEAN BANK CDS

Aida Alemany
Laura Ballester
Ana González-Urteaga

SPCS Documento de trabajo 2014/6
http://www.uclm.es/CU/csociales/DocumentosTrabajo

Facultad de Ciencias Sociales de Cuenca | Avda. de los Alfares, 44 | 16.071–CUENCA
Teléfono (+34) 902 204 100 | Fax (+34) 902 204 130

Autores:
Aida Alemany
aida_mnf@hotmail.com
Laura Ballester
laura.ballester@uv.es
Ana González-Urteaga
ana.gonzalezu@unavarra.es

Edita:

Facultad de Ciencias Sociales de Cuenca
Seminario Permanente de Ciencias Sociales
Codirectora: Pilar Domínguez Martínez
Codirectora: Silvia Valmaña Ochaita
Secretaria: María Cordente Rodríguez
Secretaria: Nuria Legazpe Moraleja
Avda. de los Alfares, 44
16.071–CUENCA
Teléfono (+34) 902 204 100
Fax (+34) 902 204 130
http://www.uclm.es/CU/csociales/DocumentosTrabajo

I.S.S.N.: 1887-3464 (ed. CD-ROM) 1988-1118 (ed. en línea)
D.L.: CU-532-2005

Impreso en España – Printed in Spain.

VOLATILITY TRANSMISSION AMONG EUROPEAN BANK CDS

Aida Alemany

Intermoney Valora Consulting, Madrid, Spain

Laura Ballester

University of Valencia, Valencia, Spain

Ana González-Urteaga*

Public University of Navarre, Pamplona, Spain

ABSTRACT

From 2007 subprime crisis to the recent Eurozone debt crisis the European banking industry has experienced a terrible financial instability situation with increasing levels of CDS spreads (used as a proxy of credit risk). This paper investigates whether volatility transmission channels in European banking markets have changed after three significant crises' events during the period January 2006 to March 2013. The global financial crisis is characterized by a unidirectional volatility shocks spillovers effect in credit risk from inside to outside the Eurozone. By contrast, the Eurozone debt crisis is revealed to be local in nature with the euro as the key element suggesting a market fragmentation between distressed peripheral and non-distressed core Eurozone countries, whereas retaining the local currency have acted as a firewall. With these findings we are able to shed light on the impact of the different crises on the European banking credit risk dynamics.

Keywords: CDS spreads, credit risk, volatility spillovers, financial crisis.

JEL-codes: G01**,** G15, C58.

* L. Ballester would like to express her gratitude for the funding received from UV-INV-PRECOMP-80704 and A. González-Urteaga acknowledges financial support from ECO2012-35946-C02-01 and ECO2012-34268. The authors would like to thank Pedro Serrano, Alfonso Novales, Pilar Soriano, Helena Chuliá and Juan Ángel Jiménez for their valuable comments and suggestions. Corresponding author: ana.gonzalezu@unavarra.es.

RESUMEN

A partir de la crisis *subprime* en 2007 y hasta la reciente crisis de deuda de la zona euro el sector bancario europeo ha experimentado una terrible situación de inestabilidad financiera traducida en un aumento de los niveles de los CDS (utilizados como aproximación del riesgo de crédito). Este trabajo investiga si los canales de transmisión de volatilidad en los mercados bancarios europeos han cambiado después de tres importantes eventos de crisis durante el período comprendido entre enero de 2006 y marzo de 2013. La crisis financiera global se ha caracterizado por un efecto *spillover* unidireccional de los shocks en volatilidad del riesgo de crédito desde el interior al exterior de la Eurozona. Por el contrario, la crisis de deuda de la Eurozona se revela como una crisis de naturaleza local con el euro como elemento clave, lo que deja de manifiesto la existencia de una fragmentación del mercado entre los países periféricos más castigados por la crisis y los países del centro de la Eurozona con menores dificultades, mientras que por otro lado, mantener la moneda local ha actuado como cortafuegos. Estos resultados arrojan luz sobre el impacto del riesgo de crédito bancario en Europa para diferentes estados de crisis financieras.

Palabras clave: CDS spreads, riesgo de crédito, *spillovers* de volatilidad, crisis financieras.

Indicadores JEL: G01**,** G15, C58.

1. INTRODUCTION

In 2007 and after knowing the seriousness of the problems of the real state sector of the country, the US financial system suffered the called subprime crisis, which was eventually taking greater dimensions given that many international banks made large investments in the sector, creating a false wealth. A few months later, Lehman Brothers Holdings Inc., the fourth largest investment bank in the US, suffered the consequences of the crisis, announcing the bankruptcy filing.

The serious tensions that emerged in the international financial markets in 2007 and 2008 broke the stability that had characterized the first ten years of the EMU (European Monetary Union), affecting the real sector and causing a rapid deterioration in the major economies of Europe, leading to the *Eurozone sovereign debt crisis*.

In early 2010, concerns in Europe, due to the inability of Greece to hold its debt, intensified and finally approved a rescue package of 750,000 million euros aimed at ensuring financial stability in Europe by creating a European Financial Stability Fund (EFSF). However, these bailouts have not removed the risk, which has been transferred mainly to governments and taxpayers of other countries. In addition, for the first time, the current sovereign debt crisis severely tested the robustness of the Eurozone since its inception in 1999.

We have seen how different financial crisis, originated in particular regions or countries, have extended geographically. As financial markets are becoming increasingly integrated and globalized, information generated in one country could affect other markets, that is shocks originated in one market may be transmitted to other financial markets. In fact, the vulnerability of the international financial system to shocks seems to have been increased due to the recent crises, and it has become an interesting topic analysed by academics and professionals.

After a greater pace of geographic, product diversification, convergence and consolidation at domestic and international level, the banking industry have witnessed a terrible instability situation from 2007 to nowadays. Given this background, the investigation of the degree of interconnectedness and intensity of the interaction among the global banking industry before and during this turbulent period is imperative. More specifically, understanding the volatility transmission patterns is crucial for asset valuation, risk management, economic and monetary policy, capital requirements and optimal resources allocation. From an investor's point of view, understanding how markets move together may result in superior portfolio construction and hedging strategies, while regulators may mainly be interested in the actual causes and consequences of such spillovers.

The main objective of this study is to analyse whether volatility transmission patterns in European banking markets have changed after some significant events during the period January 2006 to March 2013. This time period allows us to investigate both the tranquil period prior to mid-2007 and a number of phases of market instability: the financial turmoil from August 2007 to Lehman Brothers' failure, the global financial crisis from September 2008 to May 2010, and the subsequent Eurozone sovereign debt crisis from May 2010 to nowadays. We establish the event's dates that limit the four sub-periods following *Drudi et al. (2012)*. Although some warning signals were perceived since July 2007, the subprime crisis became manifest in Europe in August 9, 2007 (hereafter SC), with the bad news from BNP Paribas French bank that caused a sharp increase in the cost of the credit. As a result of the financial turmoil, Lehman Brothers announced the bankruptcy in September 15, 2008. After this second event (hereafter LB), the financial crisis intensified and spread around the world with a huge impact on the Eurozone banks. The Greek was the most dramatic case. The markets were concerned about the sustainability of its public debt, and finally on May 8, 2010 the first Greece's bailout was approved, that is the third and last considered event (hereafter GB).

Following the most recent literature, we use Credit Default Swaps (CDS) spreads as an indicator of bank risk. A CDS is essentially an insurance contract that provides protection against the risk of a credit event of the reference entity. The CDS spread is the periodic rate that a protection buyer pays on the notional amount to the protection seller for transferring the risk of a credit event for some period. Since late 2008, the CDS market has attracted considerable attention and CDS are considered a good proxy for bank riskiness and default probability. They reflect market perceptions about the financial health of banks, signalling regarding financial stability. Besides, nowadays they are the most liquid products in this market and they represent around the half of the credit derivatives.

The decision to focus on financial institutions is the special nature of the banking business in their role as financial intermediaries in the economy both as providers of liquidity transformation and monitoring services. Banks are major users of derivative instruments both as end users and as dealers, and derivatives such as CDS provide a relatively important channel to alter the bank risk. The study of the impact of CDS spreads in the banking industry has become a critical issue in the last two years. After LB, the financial markets experienced huge upheaval and credit spreads widened to unprecedented levels for financial institutions, playing a key role in the global financial crisis and causing damage especially to the banking sector and, consequently, on financial stability. The importance of credit risk in the banking sector has increased and extraordinary measures have been taken by central banks and governments to prevent a collapse of the financial sector that threatened the entire economy. In this sense, despite the importance of bank credit risk in financial markets, relatively little research exploring the volatility transmission of CDS has appeared in the literature on the CDS market.

In order to analyse volatility patterns in CDS, we use an asymmetric multivariate GARCH model, allowing volatility and covariance to be sensitive to the sign and size of the innovations. More precisely, the methodological approach follows a three-step procedure. We start by computing banks' CDS returns following *Berndt and Obreja (2010)*. We then build equally-weighted portfolios sorted by geographical zone using average CDS data of each zone's countries. The use of portfolios provides an efficient way to summarize all the information included in individual bank CDS returns, with the advantage of smoothing the noise presents in the data, mainly due to transitory shocks in individual companies. That way, we first have Non-Euro portfolio, which consists of European banks outside the EMU: Denmark, Norway, Sweden, Switzerland and UK. The second portfolio Euro comprises the banks of countries inside the EMU, which are distinguished as well between Euro-Peripheral, that consists of banks of Greece, Italy, Portugal and Spain and Euro-Core, with Austria, Belgium, France, Germany and Netherlands. In a next step, for each sub-period and each portfolio, we estimate a Vector Autoregressive (VAR) model to the CDS returns' conditional mean equation in order to clean up any autocorrelation behavior. Finally, to model the conditional variance-covariance matrix we use an asymmetric version of BEKK model (*Baba et al., 1989* and *Engle and Kroner, 1995*).

We make the following contributions to the existing literature. Firstly, to our best knowledge, this is the first study of volatility transmission patterns using CDS spreads exclusively for the banking sector. Secondly, we analyse volatility spillovers using geographical zone portfolios' information instead of individual banks, to examine the different volatility patterns between Euro and Non-Euro CDS markets first, and between Euro-Peripheral and Euro-Core portfolios later. Thirdly, we differentiate three critical financial recent events to measure the differences between pre and post event's date, in order to investigate whether the volatility transmission patterns have changed after these significant events. And finally, we applied the asymmetric BEKK model used in the literature of stocks volatility to CDS market to contrast if as in the case of stock returns, CDS returns have asymmetric responses regarding volatility.

All our results offer a consistent message: it seems quite clear that variances and correlations contain asymmetries and are changing in time. The preliminary data analysis of CDS returns indicates that there are differences in variance between periods indicating a change on the pattern of volatility transmission in the different portfolios over time.

This outcome is confirmed by the results of the VAR-BEKK model estimation. We distinguish changes in volatility transmission patterns in terms of shocks in Euro and Non-Euro markets depending on the event. While the impact of the SC is noticeable, LB does not seem to change the volatility transmission's picture between the portfolios. Finally, after GB, Euro's volatility is affected by own positive and, to a greater extent, negative shocks, while Non-Euro's volatility interestingly is no longer affected by Euro's shocks.

Euro-Peripheral and Euro-Core results show significant variability in terms of past volatilities and shocks depending on the event. After SC, both portfolios are affected not only by its own past volatility but also by the other portfolio past volatility. LB changes again the conditional variances patterns, showing a similar pattern as before SC. And finally, following GB, Euro-Peripheral's volatility is affected by its own past volatility but also by the other and the indirect past volatility portfolio, although unexpectedly Euro-Core its only affected by its own past volatility. However, both portfolios are affected by its own and other past shocks, with a greater impact of the negative ones.

The Asymmetric Volatility Impulse-Response Functions support the unidirectional variance causality from Euro to Non-Euro from SC to GB. However, the reverse is not true in any period. In addition to that, there exist bidirectional volatility spillovers inside the Eurozone, with a particularly striking effect of negative shocks in the period between SC and LB, where about 67% (30%) of the shock in the Euro-Peripheral (Euro-Core) volatility is spilled into the Euro-Core (Euro-Peripheral) volatility.

The remainder of the paper is organised as follows. Section 2 reviews the existing literature. Section 3 describes the data and offers some preliminary analysis. Section 4 deals with the methodology approach, while Section 5 presents the empirical results. Finally, Section 6 concludes.

2. LITERATURE REVIEW

Reference papers on CDS markets starts to grow during the last seven years with different purposes. Several research papers are focused on the exploration of the relationship between the CDS and bond market such as *Hull et al. (2004), Longstaff et al. (2005), Delatte et al. (2010), Hassan et al. (2011), Carboni (2011)* and *Coudert and Gex (2011).* Another strand of the literature is related to the theoretical arbitrage relationship between CDS spreads and corporate bond spreads analysing the CDS-bond basis, which measure the difference between the CDS spread of a specific company and the credit spread paid on a bond of the same company. *Blanco et al. (2005), Bai and Collin-Dufresne (2011), Nashikkar et al. (2011)* and *Fontana and Scheicher (2010)* are examples of this line of research.

Another group of papers analyse the relationship between CDS spreads and the stock market with different perspectives. In this sense, we can distinguish papers focused on corporate sector using equity and iTraxx CDS indices, such as *Berndt and Obreja (2010)* for European CDS returns. Especially for the banking industry, see *Calice et al. (2011)* for the pre-crisis period and *Ehlers et al. (2010)* for the financial crisis. In sovereign market, *Longstaff et al. (2011)* study credit risk using a set of sovereign CDS contracts for 26 developed and emerging countries. In the same line *Pan and Singleton (2008)* explore the time-series properties of the risk-neutral mean arrival rates of credit events implicit in the term structures of sovereign CDS spreads for Mexico, Turkey and Korea. Regarding with the factors related with the CDS spreads we can distinguish between papers focused on banking sector (*Annaert et al., 2013, Chiaramonte and Casu, 2013* and *Demirguc-Kunt and Huizinga, 2013)* and determinants in sovereign market such as *Hull et al. (2004)* and *Longstaff et al. (2011)*.

In the most recent years, some papers have studied the interdependencies between CDS markets in order to analyse the impact during the financial crisis using different methodological approaches. *Alter and Schüler (2012)* analyse the relationship between the default risk of several European states and financial institutions during 2007-2010 within a vector error correction model to study log-run and short-run dependencies. In addition, other papers have detected this interconnectedness in the context of the recent financial crisis as well. For instance, *Dieckmann and Plank (2012)*, using banks and sovereign CDS spreads, present different evidence of a risk transfer.

Related with interdependence, the study of contagion is another recent topic in CDS market. Since the pioneer studies in international transmission of shocks in returns such as *Eun and Shim (1989)*, most of the empirical studies have focused on the analysis of relations in mean among different markets. Studies on volatility transmission started in the 90s applied to international stock markets, such as *Engle et al. (1990)*, *Hamao et al. (1990)*, *Susmel and Engle (1994)*, *Koutmos and Booth (1995)* among others. In fact, it seems that some markets have even more interdependence in volatility than in returns.

From the first studies on volatility transmission to nowadays[2], an extensive literature has mainly focused on international shock transmission between stock market indices, stocks, exchange rates, interest rates and spot and futures markets. As far as we know, there are few studies that focus on volatility transmission using CDS market. Therefore, relations, results and ideas about volatility spillovers in CDS are still not clear.

Caporin et al. (2012) analyse the sovereign risk contagion using CDS spreads for the major euro area countries during 2008-2011. Using several econometric approaches they show that the propagation of shocks in Europe's CDS's has been

[2] *Soriano and Climent (2006)* present a complete review study on volatility transmission models.

remarkably constant even though in a significant part of the sample periphery countries have been extremely affected by their sovereign debt and fiscal situations. They conclude that, the integration among the different countries is stable, and the risk spillover among countries is not affected by the size of the shock. Using Granger-causality test *Kalbaska and Gatkowski (2012)* analyse the dynamics of the CDS market of PIIGS countries (Portugal, Ireland, Italy, Greece and Spain), France, Germany and UK for the period of 2005-2010. The analysis of the data shows that sovereign risk mainly concentrates in the EU countries. Finally, *Elyasiani et al. (2013)* have detected strong interdependencies among the banking and insurance industries in the EU, UK and US, during the crisis period.

Overall, the existing literature in CDS market has identified a number of interdependencies and contagion relationships mainly focused on sovereign CDS, but little attention has been paid to the banking sector. We cover this gap analysing volatility spillovers only for the banking industry using a large sample of European commercial banks. As far as we know, *Ballester et al. (2013)* is the only other paper that investigates contagion for US and European bank CDS, but with a different methodological approach. They use a GVAR model and they define contagion in terms of returns spillovers, whereas we study volatility spillovers based on the estimation of multivariate GARCH models.

In fact, in this study, we contribute to the current literature by analysing volatility transmission patterns focusing exclusively on the European banking sector with an extensive sample period that includes the relatively tranquil period prior to mid-2007, the financial turmoil from mid-2007 to September 2008, the global financial crisis from September 2008 to May 2010 and the more recent European sovereign debt crisis from May 2010 to the current period, March 2013. The importance of study globally the impact of spillovers after the SC, LB and GB significant events is an important issue to address how financial crises affect volatility transmission patterns.

3. DATA

The sample consists of daily[3] CDS spreads for the Large Financial Institutions (LFIs) in Europe collected from Thomson Datastream database concretely obtained by CMA New York[4]. The CDS spread shows the five-year CDS premium mid expressed in basis points. We consider five year CDS quotes since these contracts are generally considered the most liquid and constitute the most traded maturity for CDS (see *Blanco et al., 2005* and *Coudert and Gex, 2011*, among others).

The sample period spans from January, 2006 to March, 2013. This period of study allows us to investigate three critical financial recent events that could have a different impact in CDS markets: the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and the first Greece's bailout (May 8, 2010), GB. In order to analyse separately the volatility transmission patterns before and after the events, the sample has been divided into four sub-samples, covering pre and post events' periods[5].

Banking firms are selected as the banks with the highest total assets value in each country as representatives of the LFIs in Europe. This criterion results in 90,809 (unbalanced) panel observations with 50 banks in 14 countries in 1,885 days. Table A.1 in Appendix A shows all the banks included in the sample and for each bank, the available number of observations and the total assets value.

Using daily spread data we first calculate the investor's actual CDS return following the novelty approach of *Berndt and Obreja (2010)*. This strategy replicates the payoff of the contract[6] capturing the variation in default risk due to increments in CDS spreads as well as incorporate, the level of CDS spreads in the probability of default. Moreover, stationary series are obtained using returns series instead of spreads.

Then, we build equally-weighted portfolios sorted by geographical zone using average CDS data of each zone's countries. Euro portfolio consists of all the countries

[3] Using daily data provides us with more observation points and, thus, enhances the estimation efficiency, as well as fully the short lived (*Elyasiani et al., 2013*).

[4] *Mayordomo et al. (2013)* conclude that among the six most widely used CDS data bases CMA is the data source leading the others.

[5] Each event is included in the post-event period.

[6] See Appendix B for methodological details.

inside the EMU, Austria, Belgium, France, Germany, Netherlands, Greece, Italy, Portugal and Spain, whereas Euro-Peripheral and Euro-Core portfolios distinguish between peripheral countries with sovereign debt problems (Greece, Italy, Portugal and Spain) and the rest (Austria, Belgium, France, Germany and Netherlands). Finally, Non-Euro portfolio is constructed using data from Denmark, Norway, Sweden, Switzerland and UK, the European countries outside the EMU.

Figure 1 displays the daily time evolution of bank CDS spreads and returns for the four portfolios, while their summary statistics are reported in Table 1 together with the ones corresponding to each country.

In Pre-SC period, the CDS spreads are stable around 15 bps on average for the four portfolio series, being Non-Euro the one with the lowest average level, around 10 bps. The standard deviation confirms the stability observed in this period for the four portfolios. Analysing the CDS returns series, Euro-Core portfolio shows the higher volatility in CDS returns (15.44), while the Euro-Peripheral (3.26) and Non-Euro (3.08) portfolio show much lower volatility.

However, stability begins to decrease after the first event occurs (SC), showing an abrupt increase of CDS spreads in the four portfolios. They experience a significant increasing trend following the months after the SC, which increase the average and standard deviation. Specifically, Eurozone portfolios rise at over 300%, while Non-Euro shows the largest increase of CDS spreads, 410%. Volatility levels go up and are located around 11 and 14 for Euro-Peripheral and Non-Euro, respectively. Euro-Core descends slightly the level of volatility (14.55), but still continues to show the largest value.

The upward trend is intensified after LB event. The average of Euro-Peripheral portfolio rises to 163 bps. If we observe the peak achieved, 537 bps, it is noted that is caused by the maximum of Greece's CDS spreads, 1,050 bps. Moreover, Euro-Core and Non-Euro portfolios reach 274 bps and 228 bps, respectively. After these values, the CDS spreads start to decrease. Besides, LB almost doubles the levels of volatility returns, reaching the Euro-Peripheral portfolio a volatility of 27.88 and thus, being the most volatile of the portfolios.

After the GB event, two different evolutions could be observed in portfolios' series. On the one hand, Non-Euro and Euro-Core portfolios with relatively low levels of CDS spreads and on the other hand, portfolios that include the Peripheral countries series. Concretely, Euro-Peripheral portfolio reached the highest peak (1,625 bps) of the sample due to the sovereign debt problems that suffer the Euro-Peripheral countries, such as Greece with 4,191 bps of maximum or Portugal with 1,484 bps. The Euro-Core countries are affected albeit in a much smoother way, reaching a maximum of 385 bps. The relative stability of Non-Euro portfolio differs from the rest of EMU's countries.

At the country level, there are five countries with higher mean and volatility levels: Belgium (384; 160), Greece (1,444; 589), Italy (347; 149), Portugal (758; 307) and Spain (447; 152). The CDS spreads of Greece (4,191) and Portugal (1,484) show the higher maximum levels, in contrast with Norway (54) and Denmark (62) which show the lower minimums.

All the portfolios present a negative and decreasing return values between Pre-SC and Pre-GB periods. This fact suggests that during periods of financial distress CDS returns are not fully explained by the default component but also by a systematic component, that is, by the overall market situation. Pre-SC negative but practically zero returns are indicative of the most stable sample period. As we expected, there are significant differences between Euro and Non-Euro portfolio returns in terms of negative returns and volatility levels and moreover, between Euro-Core and Euro-Peripheral returns.

Table 2 presents some descriptive tests for the portfolios' CDS returns. The Jarque-Bera test rejects normality for all the portfolios and periods, which is caused mainly by the excess kurtosis and the skeweness. Fat tailed and non-normal distributions are common characteristics of observed financial returns. The tenth order Ljung-Box tests reveal significant autocorrelation in the four portfolios both in level and squared returns, so that there is persistence in mean as well as in variance. These results suggest using ARCH/GARCH models in order to capture the dynamic of the volatility. The ARCH test indicates that the returns exhibit conditional heteroskedasticity, which justifies the use of multivariate volatility specifications. The model considered should accommodate all these features. Finally, both the ADF and PP test reject a single unit root for the four portfolios in all the studied periods. They are stationary and thus, we consider a VAR specification for the mean.

Table 3 displays equality of mean (Panel A.1 and A.2) and variance tests (Panel B.1 and B.2), both between different portfolios and sub-periods, whereas Panel C shows correlations between portfolios period by period. First of all, we observe that we cannot reject, in general, the null hypothesis of equal means. In addition to that, as it can clearly be observed, there are differences in variance between periods (Panel B.1), indicating a change on the pattern of volatility transmission in the different portfolios over time. Further analysis reveals how the distinct crises studied, the financial turmoil, the global financial crisis and the Eurozone crisis, characterized by SC, LB and GB events, respectively, have affected the transmission of volatility, although in different ways. The first two crises, the subprime and global financial crisis, affect all portfolios with a significant increase in volatility (see Table 1, Panel B), although the effect on the Euro-Core portfolio is not immediate (it is not appreciable until after LB). By contrast, the Eurozone crisis affects only the Eurozone countries, with particular impact on the Euro-Peripheral portfolio, whose volatility soars significantly.

These results explain the significant differences on variance of the Euro-Peripheral and Euro-Core portfolios, observed in all periods except on the Post-LB (Panel B.2), as well as, between Euro and Non-Euro, that shows an exception on the Post-SC period caused by the Euro-Peripheral countries. In summary, there are significant differences on variances between portfolios in the four periods indicating that the different areas have different sensitivity to the risk factors that affect the CDS, which in turn justifies the use of a multivariate model.

Finally, it stands out the lack of correlation observed in periods of financial stability (Table 3, Panel C). With SC the correlation extraordinarily increases, while after LB and until the end of the sample, the correlations decrease but continue to remain high, especially between Non-Euro and Euro-Core portfolios. Indeed, it is the only case in which after GB the correlation increases.

4. METHODOLOGY APPROACH

4.1. The model

Since the concept of Autoregressive Conditional Heterocedasticity (ARCH) that was introduced in *Engle (1982)* to explain the tendency of large residuals to cluster together, numerous studies have applied and extended this methodology. After implementing this model, related studies explained that volatility seems to be quite a bit more persistent that can be explained by an ARCH model. *Bollerslev (1986)* proposed the Generalized ARCH (GARCH) model as an alternative in which the variance term depends upon the lagged variances as well as the lagged squared residuals.

Different extensions of univariate and multivariate GARCH methodologies have been applied in the literature to analyse the volatility transmission between international financial markets. As we are interested in the interrelationship between different portfolios, a multivariate GARCH framework is necessary. Among the different multivariate GARCH specifications that have been proposed in the literature, the most used are the VECH, Diagonal VECH, EWMA, Restricted Correlation Models (DIAG, CC, DCC) and BEKK model. Each one of them imposes different restrictions in the conditional variance.

In VECH model (*Bollerslev et al., 1988*) certain restrictions must be accomplished in order to assure a positive definite variance-covariance matrix. This model has a large number of free parameters (even in the bivariate case), and it is clearly unwieldy with more than two variables. The Diagonal VECH (*Bollerslev et al., 1988*) is the most straightforward extension of a univariate model and assumes that individual conditional variances and covariances only depend on their own lags and lagged squared residuals. Therefore, important information such as the relations between variances and covariances is lost. EWMA (Exponentially Weighted Moving Average) is a very tightly parameterized variance model. There is just a single real parameter governing the evolution of the variance. It is an extension of the (non-drifting) IGARCH model to more than one variable. The restricted correlation methods all use GARCH models for the individual variances, but generate the covariances in a more restricted fashion.

The simplest of the restricted models is Diagonal (DIAG). This estimates separate univariate GARCH models on each dependent variable. The specification for the covariances between variables is that they are all zero. The next step up in complexity is the Constant Correlation specification (CC) proposed by *Bollerslev (1990)*. This model generally has a well-behaved likelihood function, and can handle a bigger set of variables than the more fully parameterized models, but it does have the drawback of requiring the correlation to be constant. In some applications, time-varying correlations are essential. *Engle (2002)* proposed a method of handling this which he dubbed Dynamic Conditional Correlations (DCC). This adds two scalar parameters which govern a GARCH(1,1) model on the covariance matrix as a whole.

The main problem with extending multivariate models is that the covariance matrix has to be positive definite at each time period in order for the likelihood to be defined. Even if the variance of each equation stays positive, if the cross terms stray out of bounds for just one data point, a set of parameters gives an undefined function value. The BEKK formulation (*Engle and Kroner, 1995*) directly imposes definiteness on the variance-covariance matrix, and this is its main advantage. Moreover, this model reduces significantly the number of parameters to be estimated without imposing strong constraints on the shape of the interaction between variables. For all these reasons, this is the specification that best fits our objectives.

Empirical evidence indicates that stock returns exhibit ARCH effects and international stock markets are related both at the mean and the variance level. It has also been recognized that they exhibit asymmetrical conditional behaviour, that is, that positive values of the residuals have a different effect than negative ones. Moreover, conclusions obtained from volatility transmission models could be erroneous when asymmetries are not modelled (*Susmel and Engle, 1994* and *Bae and Karolyi 1994*). It is reasonable to assume that the same characteristics could hold for CDS returns data. Thus, we consider a multivariate asymmetric BEKK model for the conditional variance, in order to analyse volatility transmission patterns within a particular pairwise of bank CDS returns portfolios in different geographical areas.

More specifically, the econometric model used to analyse the directional volatility transmissions between each pair of portfolios' CDS returns has two parts: the mean and the variance-covariance equation. The conditional mean equation models the

CDS returns as a Vector Autoregressive VAR(p) model, in order to clean up any autocorrelation behaviour. Using matrix algebra:

$$\begin{bmatrix} R_{1,t} \\ R_{2,t} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} + \begin{bmatrix} \beta_{11,1} & \beta_{12,1} \\ \beta_{21,1} & \beta_{22,1} \end{bmatrix} \begin{bmatrix} R_{1,t-1} \\ R_{2,t-1} \end{bmatrix} + \cdots + \begin{bmatrix} \beta_{11,p} & \beta_{12,p} \\ \beta_{21,p} & \beta_{22,p} \end{bmatrix} \begin{bmatrix} R_{1,t-p} \\ R_{2,t-p} \end{bmatrix} + \begin{bmatrix} u_{1,t} \\ u_{2,t} \end{bmatrix} \quad (1)$$

where $R_{1,t}$ and $R_{2,t}$ are the CDS returns of the selected portfolios. In particular, we estimate it first for the Euro and Non-Euro pair, and second, for the Euro-Peripheral and Euro-Core pair. μ is the vector of constants, $\beta_{ij,k}$ for $i,j = 1,2$ and $k = 1, \dots, p$ are the parameters that measure the own and cross-effects of past returns and u is the vector of non-orthogonal innovations. The VAR lag p has been chosen following the Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC) and the likelihood ratio test (LR)[7] for the different lag lengths.

The estimation process is applied for the four sub-periods described previously in the data section to analyse the changes in volatility transmission before and after three events: the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and first Greece's bailout (May 8, 2010), GB.

The innovations gathered in u are non-orthogonal, since in general the covariance matrix $\sum = E(u_t u_t')$ is not diagonal. However, it is often more useful to look at the moving average representation with orthogonalized innovations. If we choose any matrix G so that $G \sum G' = I$, then the new innovations $\varepsilon_t = G u_t$ satisfy $E(\varepsilon_t, \varepsilon_t') = I$. These orthogonalized innovations will be used as input in the variance-covariance equation. They have the convenient property that they are uncorrelated both across time and across equations. In addition to that, since they are uncorrelated, it is very simple to compute the variances of linear combinations of them. Moreover, it can be rather misleading to examine a shock to a single variable in isolation when historically it has always moved together with several other variables. Orthogonalization takes this co-movement into account.

Such a matrix G can be gotten from inverting any solution F of the factorization problem $FF' = \Sigma$. There are many such factorizations of a positive definite Σ. Those based on the Choleski factorization, where G is chosen to be lower triangular but suffers

[7] In general, there is consistency between criteria, but failing that, we look at the LR test in order to avoid the over-parametrization.

from the problem of imposing a semi-structural interpretation on a mechanical procedure. In this study we follow a structural decomposition approach, dubbed SVARS, proposed by *Bernanke (1986)* and *Sims (1986)* independently.

To model the conditional variance-covariance matrix in t, (H_t), we use an asymmetric version of BEKK model (*Baba et al., 1989*, *Engle and Kroner, 1995* and *Kroner and Ng, 1998*). The compacted form of this bivariate model is:

$$H_t = C'C + B'H_{t-1}B + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + D'\eta_{t-1}\eta'_{t-1}D \tag{2}$$

where *C* is a lower-triangular and positive definite matrix, with $C'C$ representing the unconditional part of the conditional variance-covariance matrix; *A* and *B* are parameters matrices dictating the multivariate ARCH and GARCH evolution, where the ortogonalized error term, ε_t, coming from the conditional mean equation (1) shows the asymmetric effects in volatility, with $\eta_{1,t} = \max(0, -\varepsilon_{1,t})$ and $\eta_{2,t} = \max(0, -\varepsilon_{2,t})$, and thereby, a positive and significant value of *D* means that the negative residuals tend to increase the variance more than positive ones. Among the many equivalent ways to introduce the asymmetric effect into the model, we choose the one followed by *Glosten et al. (1993)*.

In order to estimate the model in equation (2), it is assumed normally distributed innovations in the estimation process, which implies that the parameters of the BEKK system are estimated by maximizing the conditional log-likelihood function:

$$L(\theta) = -\frac{TN}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(ln|H_t(\theta)| + \varepsilon'_t H_t^{-1}(\theta)\varepsilon_t) \tag{3}$$

where *T* denotes the sample size, $N = 2$ equations in the system and q denotes the vector of all the parameters to be estimated. Numerical maximization techniques were used to maximize this non-linear log-likelihood function based on the Broyden, Fletcher, Goldfarb and Shanno (BFGS) algorithm[8]. Quasi-maximum likelihood method estimation is applied since *Bollerslev and Wooldridge (1992)* show that the standard errors calculated using this method are robust even when the normality assumption is violated.

[8] The BFGS method is described in *Press et al. (1988).*

This model enables us to analyse the volatility spillovers between both markets, since it allows for both own market and cross-market influences in the conditional variance. However, estimated parameters from *C*, *B*, *A* and *D* matrices in equation (2), cannot be interpreted individually. Instead, we have to interpret the non-linear functions of the parameters which form the intercept terms and the coefficients of the lagged variances, covariances and error terms that appear in the following expanded equations for each portfolio conditional variances:

$$\begin{aligned} h_{11,t} &= c_{11}^2 + c_{21}^2 + b_{11}^2 h_{11,t-1} + b_{21}^2 h_{22,t-1} + 2b_{11}b_{21}h_{12,t-1} \\ &+a_{11}^2\varepsilon_{1,t-1}^2 + a_{21}^2\varepsilon_{2,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ &+d_{11}^2\eta_{1,t-1}^2 + d_{21}^2\eta_{2,t-1}^2 + 2d_{11}d_{21}\eta_{1,t-1}\eta_{2,t-1} \qquad (4) \\ h_{22,t} &= c_{22}^2 + b_{12}^2 h_{11,t-1} + b_{22}^2 h_{22,t-1} + 2b_{12}b_{22}h_{12,t-1} \\ &+a_{12}^2\varepsilon_{1,t-1}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ &+d_{12}^2\eta_{1,t-1}^2 + d_{22}^2\eta_{2,t-1}^2 + 2d_{12}d_{22}\eta_{1,t-1}\eta_{2,t-1} \end{aligned}$$

To that end, we follow *Kearney and Patton (2000)* and calculate the expected value and the standard errors of these non-linear functions. That way, we are able to conduct significance tests. If the estimated variables are unbiased, we can compute the expected value of a non-linear function of random variables (such as b_{11}^2), as the function of the expected values of the parameters (b_{11}), because it involves a first order Taylor approximation of the function around its mean. That way, the function is linearized and enables us to estimate its standard error by using the estimated variance-covariance matrix of the parameters as well as the mean and standard error vectors. This is sometimes called the delta method[9].

4.2. The Asymmetric Volatility Impulse Response Functions (AVIRF)

The Asymmetric Volatility Impulse-Response Functions (AVIRF, henceforth) measure the impact of an unexpected shock on the predicted volatility with the

[9] See Appendix C for methodological details.

advantage that it can change with the sign of the shock. The AVIRF for the asymmetric BEKK model is taken by *Meneu and Torró (2003)* by applying the volatility symmetric structure proposed by *Lin (1997)* to (2):

$$R_{s,3}^{+} = \begin{cases} a & s = 1 \\ \left(a + b + \frac{1}{2}d\right) R_{s-1,3}^{+} & s > 1 \end{cases} \tag{5}$$

$$R_{s,3}^{-} = \begin{cases} a + d & s = 1 \\ \left(a + b + \frac{1}{2}d\right) R_{s-1,3}^{-} & s > 1 \end{cases} \tag{6}$$

where $R_{s,3}^{+}$ and $R_{s,3}^{-}$ represent the impulse-response function for conditional volatility for positive and negative initial shocks, respectively, with *s* being the lead indicator. The 3×3 parameter matrices a, b and d are computed by: $a = D_N^{+}(A' \otimes A')D_N$, $b = D_N^{+}(B' \otimes B')D_N$ and $d = D_N^{+}(D' \otimes D')D_N$, where D_N is a duplication matrix, D_N^{+} is its Moore-Penrose inverse and $\otimes$ denotes the Kronecker product between matrices, that is:

$$D_N = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad D_N^{+} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1/2 & 1/2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

This impulse-response function is a useful methodology for obtaining information on the second moment interaction between related markets. It examines how fast CDS spreads incorporate new information, which enables us to test for the speed of adjustment, analyse the dependence of volatilities across the returns of Euro and Non-Euro variables and Euro-Peripheral and Euro-Core. Moreover, it allows us to distinguish between negative and positive return shocks.

5. EMPIRICAL RESULTS

5.1. The VAR-BEKK model estimation

In this section we discuss our findings based on the VAR-Asymmetric BEKK model used to estimate the volatility transmission patterns among distinct geographical zone bank CDS returns portfolios before and after each of the selected three important events, that are SC, LB and GB.

In order to analyse volatility spillovers between different pairs of bank CDS portfolios returns, the bivariate model in equations (1) and (2) is estimated. We do that for the four sub-periods considered, to analyse the impact of the different events, following a three-step procedure. First, the VAR model is estimated. Second, the residuals are orthogonalized. And third, Quasi-Maximum Likelihood (QML) estimator is used to obtain robust estimates of the asymmetric BEKK model.

The estimated parameters for the VAR-BEKK model that can be found in Appendix D[10] cannot be interpreted individually. Instead, we have to focus on the non-linear functions that form the intercept terms and the coefficients of the lagged variance, covariance and error terms. These results are gathered in Table 4, which displays the expected value and the standard errors of these non-linear functions for each of the four sub-periods characterized by the selected three important events.

Panel A shows the results regarding volatility transmission between Euro and Non-Euro portfolios. It highlights the different behaviour of volatility spillovers depending on the studied event. As a common trend, we observe that SC, LB and GB do not change the fact that conditional volatility in each portfolio $h_{ii,t}$ is always due to its own past volatility $h_{ii,t-1}$, but never by the other portfolio's past volatility. Euro portfolio's past volatility $h_{11,t-1}$ never affect Non-Euro volatility $h_{22,t}$, and vice versa. Therefore, there is not volatility transmission between both portfolio returns over time. SC, LB and GB do not change this volatility pattern.

The different patterns in conditional volatility are observed in terms of the positive and negative (asymmetric effect variable) past shocks. Our findings suggest that Euro portfolio's volatility $h_{11,t}$ is affected over time by its own positive and negative past shocks, depending on the period. It depends on its own past shocks $\varepsilon^2_{1,t-1}$ in Pre-SC and Post-GB periods, while the negative own past shocks $\eta^2_{1,t-1}$ are determinants innovations from SC onwards, indicating that the negative shocks on the

[10] The tenth order ARCH and Ljung-Box tests reveal that the standardized residuals of the model are free of conditional heteroskedasticiy and autocorrelation both in level and square returns. These results are not shown, but available upon request.

Euro portfolio affect more its volatility than the positive shocks. Although, Non-Euro's volatility $h_{22,t}$ is only affected by its own negative past shocks $\eta^2_{2,t-1}$ in Pre-SC.

Regarding shocks coming from the other portfolio, results show that Non-Euro portfolio's volatility $h_{22,t}$ is affected by past shocks from Euro portfolio $\varepsilon^2_{1,t-1}$ with more intensity after LB, and surprisingly this effect disappears after GB. However, in general we do not observe the opposite effect. Euro portfolio's volatility $h_{11,t}$ is only affected by Non-Euro's negative $\eta^2_{2,t-1}$ and indirect past shocks $\eta_{1,t-1}\eta_{2,t-1}$ in Pre-SC, and indirect past shocks in Post-LB.

In summary, we could distinguish significant changes in volatility transmission patterns in terms of shocks depending on the event. The impact of the SC is noticeable. After this global important event, Euro's volatility is only affected by its own negative shocks, whereas Non-Euro's volatility is affected by Euro's (positive and negative) shocks. Nevertheless, it seems that LB does not change the picture in terms of volatility transmission between the two portfolios. Before and after LB, and therefore during the whole global financial distress period, that encompasses the financial turmoil (from SC to LB) and the global financial crisis (from LB to GB), both conditional variances are affected by the same variables. Finally, after GB, Euro's volatility is affected by its own positive and, to a greater extent, negative shocks, while Non-Euro's volatility interestingly is no longer affected by Euro's shocks.

Panel B displays the volatility transmission patterns' results between Euro-Peripheral and Euro-Core portfolios. We observe that in both portfolios the own past volatility affects conditional volatility independently of the period. During Post-SC period there is volatility transmission between both portfolio returns, because the past volatility of the other portfolio affects. Moreover, in the Post-GB period the Euro-Peripheral volatility is directly affected by the Euro-Core past volatility, but unexpectedly the opposite direction is not given. Therefore, there is volatility transmission between both portfolio returns in some periods, and the different events change this volatility pattern.

In terms of the shocks, there are also different patterns in conditional volatility. Our findings suggest that Euro-Peripheral volatility is directly affected by its own (positive and negative) shocks in the Post-SC period, but just by the negative ones during Post-LB and in a greater measure after GB. However, Euro-Core volatility is affected by its own (positive and negative) shocks in all periods except the Post-SC period, and only in the last period the coefficient for its own asymmetric term is significant, indicating that after GB negative shocks on Euro-Core affect more its volatility than the positive ones.

Regarding shocks coming from the other portfolio, results show that Euro-Core is affected indirectly by Euro-Peripheral negative shocks during Post-SC, but, in general, any of the portfolios are affected by the other's shocks until GB. After this event, both are significantly affected directly and indirectly by the other's shocks, with a greater impact of the negative ones. These results indicate that, after GB, there has been an increase in the volatility transmission between the two Eurozone portfolios, Euro-Peripheral and Euro-Core.

Overall, we could distinguish significant variability in volatility spillovers between the two Eurozone portfolios in terms of past volatility and shocks depending on the event. The impact of SC is remarkable. After this first event, both volatility portfolios are affected not only by its own past volatility (as it was before SC) but also by the other past volatility portfolio (even indirectly). LB changes this pattern to the one observed previous to SC, whereas after GB Euro-Peripheral's volatility is affected by its own and other's past volatility. Regarding shocks, the behaviour of both portfolios varies over time in different directions and in general with a relatively small effect until GB. After this last event, it is outstanding how both portfolios are affected by its own, other and indirect positive and negative past shocks, with a greater impact of the negative ones.

5.2. The Asymmetric Volatility Impulse Response Functions (AVIRF)

A preliminary analysis of the AVIRFs[11] indicates that there exists a significant volatility spillover from Euro to Non-Euro from SC to GB, but the reverse is not detected. It can be observed that positive shocks in Euro take less than 10 days to be absorbed, while the negative ones takes longer, more than 40 days, to die out. In the

[11] Not shown, available upon request.

case of the Eurozone, there is evidence in favour of bidirectional volatility transmission between Euro-Peripheral and Euro-Core portfolios, although the results confirm that a negative shock has a stronger impact than a positive one. Moreover, the volatility spillover values are in general much lower than in the Euro / Non-Euro case.

Given these results, we summarize all the outcomes in Figure 2, which shows the values of the AVIRFs in each of the four sub-periods for two significant values of the lead indicator *s* (that is, for *s* equals 1 and 10). Panel A shows the case of Euro (in blue) and Non-Euro (in red) portfolios, while Panel B presents Euro-Peripheral (in blue) and Euro-Core (in red) portfolios. Positive and negative shocks are distinguished by a solid and dash line, respectively. This way of presenting the results allows us to analyse the time evolution of the volatility spillovers and particularly, the effects of the distinct three events considered.

Panel A.1 reveals that positive and negative shocks in the Euro portfolio have an important immediate effect on the Non-Euro volatility during the Post-SC period (about 33%, when positive, and 38%, when negative, of the shock) and to a lesser extent during the Post-LB period (about 15% and 12% of the positive and negative shock, respectively, but interestingly, the effect disappears after GB. Panel A.2 shows that positive shocks take less than 10 days to be absorbed, while negative ones takes longer to die out. For instance, about 3% (30%) of a positive (negative) shock in Euro is spilled into Non-Euro volatility after 10 days during Post-SC. By contrast, there is no significant volatility spillover from Non-Euro to Euro in any of the sub-periods.

In addition, it can be observed that positive and negative shocks in Euro have a similar impact on its own volatility (about 20%), although the onset of the subprime crisis change the picture. After the SC event, positive shocks are no longer significant, while the negative ones have an even more important effect than before the event (about 37% of the shock during Post-SC and lower but still noteworthy after that). On the other hand, only during the Pre-SC period negative shocks in Non-Euro have a significant effect (about 44%) on its own volatility, and it takes a very long time to die out due to its persistence (after 10 days the effect is still about 32%).

Therefore, these results confirm the unidirectional variance causality from Euro to Non-Euro observed in the asymmetric VAR-BEKK model's estimates from SC to

GB. It can be said that before the SC event Non-Euro was only affected by its own negative shocks, but after SC and until GB the main source of information comes from negative unexpected returns arising from Euro and it then spreads into the Non-Euro market. However, the reverse is not true in any period.

Regarding the Eurozone (Panel B), there is evidence in favour of bidirectional volatility transmission between Euro-Peripheral and Euro-Core portfolios. During the tranquil Pre-SC period, the only kind of shock affecting both portfolios are its own shocks, specially the negative ones, taking less than 10 days to be absorbed in the case of Euro-Peripheral and a longer time in the case of Euro-Core.

However, the picture changes after the SC. Both types of shocks in Euro-Peripheral have a similar and important effect (about 25%) on its own volatility with the negative ones being more persistent, and which spill into Euro-Core volatility with an impressive value of 67% (after 10 days the impact is about 16%). On the other hand, about 30% (20%) of a negative (positive) shock in the Euro-Core volatility is spilled into the Euro-Peripheral volatility, taking more (less) than 10 days to die out.

In the period between LB and GB it can be observed that only negative shocks in Euro-Peripheral have a striking effect (about 74%) on its own volatility, taking a very long time to be absorbed (it is still about 56% after 10 days). They also have an effect in Euro-Core, but in comparison it is hardly noticeable (about 8%). On the other hand, we can observe that positive and negative shocks coming from Euro-Core have a similar impact on its own volatility (around 15% and 20%, respectively), taking more than 10 days to die out, but they do not affect Euro-Peripheral volatility. Finally, a similar pattern can be observed in the last period. After GB, volatilities in both portfolios are interestingly only affected by their own negative shocks, although in a much lesser degree.

6. CONCLUSIONS

After the recent crisis in the euro area the interest of volatility transmission studies on CDS has increased. The CDS returns reflect market perceptions about the financial health of banks, signalling regarding financial stability, which can be used as an indicator of the bank's risk level and the probability of default.

The general objective of this paper is to analyse the volatility spillovers patterns between different pairs of bank CDS portfolios returns, firstly between Euro and Non-Euro and secondly between Euro-Peripheral and Euro-Core, for the four sub-periods considered within the sample period from January 2006 to March 2013. This long time period allows us to explore the impact of three important events, SC (August 9, 2007), LB (September 15, 2008) and GB (May 8, 2010), which limit the four sub-periods, the tranquil period prior to SC, the financial turmoil from SC to LB, the global financial crisis from LB to GB and the subsequent Eurozone crisis from GB to the end of the sample. In order to do this, we use an asymmetric multivariate GARCH model, in particular, an asymmetric VAR-BEKK model.

The results regarding Euro and Non-Euro portfolios confirm significant changes in volatility transmission patterns in terms of shocks depending on the event. The impact of the SC is noticeably. After this global important event, Euro's volatility is only affected by its own negative shocks, whereas Non-Euro's volatility is affected by Euro's (positive and negative) shocks. By contrast, it seems that LB does not change the picture in terms of volatility transmission between the two portfolios. Finally, after GB, the pattern change again. Negative shocks on the Euro returns affect more its volatility than the positive shocks, while Non-Euro's volatility interestingly is no longer affected by Euro's shocks.

The case of the two Eurozone portfolios is quite different. Results indicate significant variability in volatility spillovers in terms of past volatility and shocks depending on the event. The impact of SC is remarkable. Before this first event volatilities in Euro-Peripheral and Euro-Core were only affected by their own past volatilities, but also by other's past volatilities after SC. LB changes again the volatility transmission, showing a similar pattern as before SC, whereas after GB, Euro-Peripheral's volatility is affected by its own and other's past volatility, although unexpectedly Euro-Core its only affected by its own past volatility. Regarding shocks, the behaviour of both portfolios varies over time in different directions and in general with a relatively small effect until GB. After this last event, it is outstanding how both portfolios are affected by its own, other and indirect positive and negative past shocks, with a greater impact of the negative ones. Therefore, these results show that, after GB there has been a significant increase in the volatility transmission between the two Eurozone portfolios considered.

Finally, the AVIRF's results confirm the unidirectional variance causality from Euro to Non-Euro from SC to GB. It can be said that before the SC event Non-Euro was only affected by its own negative shocks, but after SC and until GB the main source of information comes from negative unexpected returns arising from Euro and it then spreads into the Non-Euro market. However, the reverse is not true in any period. In addition to that, there exist bidirectional volatility spillovers inside the Eurozone, with a particular striking effect of negative shocks in the period between SC and LB, where about an impressive 67% (30%) of the shock in the Euro-Peripheral (Euro-Core) volatility is spilled into the Euro-Core (Euro-Peripheral) volatility. Finally, after the GB, volatilities in both portfolios are interestingly only affected by their own negative shocks, although in a much lesser degree.

APPENDIX A. LIST OF BANKS

TABLE A.1: List of Banks

Banks are assigned to countries based on the Datastream classification. Obs. refers to the available number of observations (CDS spread) for each bank in the sample. Total assets (December 2012 data) are expressed in thousand euros. For non-euro countries Datastream average exchange rate in December 2012 is used.

Country	Bank Name	Obs.	Total Assets
Euro-Peripheral (20)			
Greece (4)	National Bank of Greece	915	104,798
	Alpha Bank	1,885	58,357
	EFG Eurobank Ergasias	1,885	67,653
	Piraeus Bank	927	70,406
Italy (7)	Unicredito Italiano	1,885	926,827
	Intesa San paolo	1,885	673,475
	Banca Monte Paschi Siena	1,885	197,081
	Unione di Banche Italiane (Ubi Banca)	1,885	132,433
	Banco Popolare	1,885	131,921
	Banco Popolare Milano	1,885	52,475
	Banca Italease	1,516	10,531
Portugal (3)	Banco Espirito Santo	1,885	83,690
	Banco Comercial Português	1,885	89,744
	Banco Português de Investimento	1,885	44,564
Spain (6)	Banco Santander	1,885	1,269,628
	Banco Bilbao Vizcaya Argentaria	1,885	637,785
	Banco Popular Español	1,885	157,618
	Banco de Sabadell	1,496	161,547
	Bankinter	1,885	58,165
	Banco Pastor	1,741	31,135
Euro-Core (16)			
Austria (2)	Erste Group Bank	1,885	213,824
	Raiffeisen Zentralbank	1,885	145,955
Belgium (2)	KBC Bank	1,885	224,824
	Dexia	1,885	357,210
France (5)	BNP Paribas	1,885	1,907,290
	Société Générale	1,885	1,250,696
	Crédit Agricole	1,885	1,842,361
	Natixis	1,885	528,370
	BPCE SA	1,885	1,147,521
Germany (4)	Deutsche Bank	1,885	2,012,329
	Commerzbank	1,885	635,878
	Deutsche Postbank	1,885	193,822
	HSH Nordbank	1,885	130,606
Netherlands (3)	ING Bank NV	1,885	836,068
	Rabobank	1,885	752,410
	ABN AMOR Bank	1,885	394,404

TABLE A.1 ***(continued):*** List of Banks

Non-Euro (14)			
Denmark (1)	Danske Bank	1,885	466,708
Norway (1)	DNB NOR ASA	1,274	273,743
Sweden (4)	Nordea Bank	1,885	677,309
	Svenska Handelsbanken	1,885	276,972
	Skandinaviska Enskilda Banken	1,885	285,047
	Swedbank	1,885	214,572
Switzerland (1)	Credit Suisse Group	1,885	752,006
UK(7)	HSBC Holdings PLC	1,885	3,318,590
	Lloyds Banking Group	1,885	1,139,523
	Standard Chartered	1,885	784,517
	Alliance and Leicester PLC	1,885	92,739
	Barclays	1,885	1,837,366
	Royal Bank of Scotland Group	1,885	1,617,422
	HBOS	1,885	717,455
Total (50)		90,809	

APPENDIX B. ESTIMATION OF BANKS' CDS RETURNS

Following *Berndt and Obreja (2010)* daily CDS return is given by

$$r_{CDS,t} = -\Delta CDS_t(T) \times A_t(T) = -\Delta CDS_t(T)\frac{1}{4}\sum_{j=1}^{4T}\delta\left(t,\frac{j}{4}\right)q\left(t,\frac{j}{4}\right)$$

where $\Delta CDS_t(T)$ is the daily change in the CDS spreads with T maturity and $A_t(T)$ is the value of a defaultable quarterly annuity over the next T years. We denote the risk-free discount factor for day t and s years out as $\delta(t,s)$ and it is fitted from Datastream Euro zero curves. Assuming a constant risk-neutral default intensity λ for each bank, the risk-neutral survival probability of the bank over the next s years can be written as $q(t,s) = e^{-\lambda(t-s)}$. As a consequence, λ can be computed directly from observed CDS spreads by $\lambda = 4log\left(1+\frac{CDS}{4L}\right)$, which can be used to calculate the annuity and hence the CDS return. L denotes the risk-neutral expected fraction of notional lost in the event of default. It is fixed at 60%.

APPENDIX C. DELTA METHOD

When a variable Y is a function of a variable X, i.e., $Y = F(X)$, the *Delta method* allows us to obtain approximate formulation of the variance of Y if: (i) Y is differentiable with respect to X and (ii) the variance of X is known.

Therefore:

$$V(Y) \approx (\Delta Y)^2 \approx \left(\frac{\partial Y}{\partial X}\right)^2 (\Delta X)^2 \approx \left(\frac{\partial Y}{\partial X}\right)^2 V(X)$$

When a variable Y is a function of variables X and Z in the form of $Y = F(X, Z)$, we can obtain approximate formulation of the variance of Y if (i) Y is differentiable with respect to X and Z and (ii) the variance of X and Z and the covariance between X and Z are known.

This is:

$$V(Y) \approx \left(\frac{\partial Y}{\partial X}\right)^2 V(X) + \left(\frac{\partial Y}{\partial Z}\right)^2 V(Z) + 2\left(\frac{\partial Y}{\partial X}\right)\left(\frac{\partial Y}{\partial Z}\right) Cov(X, Z)$$

Once the variances are calculated it is straightforward to calculate the standard errors.

APPENDIX D. ESTIMATION RESULTS FOR THE VAR-BEKK MODEL

Table D.1: VAR-BEKK model

This table shows the estimation of the model defined in equations (1) and (2) for Euro (E) and Non-Euro (NE) CDS portfolios returns (Panel A) and for Euro-Peripheral (EP) and Euro-Core (EC) CDS portfolios returns (Panel B). It reports estimated parameters for the mean equation and for the variance-covariance matrix. Results are shown for the full period, from January 2006 to March 2013, and four sub-periods identified by three significant events: the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and Greece's bailout (May 8, 2010), GB, respectively. In all the cases the necessary conditions for the stationarity of the process are satisfied. * Significance at the 10% level; ** Significance at the 5% level; *** Significance at the 1% level.

Panel A: Euro and Non-Euro portfolios

Panel A.1: Pre-SC (Jan06 – Aug07)

	$R_{E,t}$	$R_{NE,t}$
μ	-0.0015	-0.0010
$R_{E,t-1}$	-0.4330***	-0.0030
$R_{E,t-2}$	-0.2477***	0.0156
$R_{E,t-3}$	-0.1428***	-0.0097
$R_{NE,t-1}$	0.2135	-0.2633***
$R_{NE,t-2}$	0.1211	-0.2895***
$R_{NE,t-3}$	0.1137	-0.0266

$$\hat{C} = \begin{bmatrix} 0.0992^{***} & - \\ -0.0129 & 0.2163^{***} \end{bmatrix} \qquad \hat{B} = \begin{bmatrix} 0.8963^{***} & -0.0065 \\ -0.0038 & 0.8681^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.4108^{***} & -0.1252^{***} \\ -0.0590^{*} & 0.0089 \end{bmatrix} \qquad \hat{D} = \begin{bmatrix} 0.2081^{***} & -0.0156 \\ 0.1303^{***} & 0.6596^{***} \end{bmatrix}$$

Panel A.2: Post-SP / Pre-LB (Aug07 – Sep08)

	$R_{E,t}$	$R_{NE,t}$
μ	-0.0081	-0.0087
$R_{E,t-1}$	0.1556	0.0939
$R_{E,t-2}$	0.1323	0.2862**
$R_{NE,t-1}$	0.0401	-0.0274
$R_{NE,t-2}$	-0.0686	-0.2327**

$$\hat{C} = \begin{bmatrix} 0.1530^{***} & - \\ -0.2590^{**} & 0.2694^{***} \end{bmatrix} \qquad \hat{B} = \begin{bmatrix} 0.8805^{***} & -0.0188 \\ 0.0169 & 0.7336^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.0948 & 0.5767^{***} \\ -0.1175 & -0.1168 \end{bmatrix} \qquad \hat{D} = \begin{bmatrix} 0.6045^{***} & -0.2079 \\ 0.1017 & 0.3043^{***} \end{bmatrix}$$

Table D.1 *(continued)*: VAR-BEKK model

Panel A: Euro and Non-Euro portfolios *(continued)*

Panel A.3: Post-LB / Pre-GB (Sep08 – May10)

	$R_{E,t}$	$R_{NE,t}$
μ	-0.0090	0.0047
$R_{E,t-1}$	0.4505***	0.3007***
$R_{NE,t-1}$	-0.0428	-0.0047

$$\hat{C} = \begin{bmatrix} 0.1293^{***} & - \\ -0.0665 & -0.0000 \end{bmatrix} \quad \hat{B} = \begin{bmatrix} 0.9293^{***} & -0.0121 \\ 0.0294^{*} & 0.9103^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.0127 & 0.3525^{***} \\ 0.1643^{***} & 0.1607^{*} \end{bmatrix} \quad \hat{D} = \begin{bmatrix} -0.5007^{***} & 0.1746 \\ 0.1425^{**} & -0.0532 \end{bmatrix}$$

Panel A.4: Post-GB (May10 – Mar13)

	$R_{E,t}$	$R_{NE,t}$
μ	0.0018	-0.0003
$R_{E,t-1}$	0.1300***	0.0428***
$R_{E,t-2}$	0.0181	-0.0116
$R_{E,t-3}$	-0.1404***	-0.0265
$R_{NE,t-1}$	0.4063***	0.2503***
$R_{NE,t-2}$	-0.1023	-0.0314
$R_{NE,t-3}$	0.1159	-0.0480

$$\hat{C} = \begin{bmatrix} 0.1602^{***} & - \\ -0.0362 & 0.0569^{*} \end{bmatrix} \quad \hat{B} = \begin{bmatrix} 0.9145^{***} & -0.0181 \\ 0.0446 & 0.9658^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.1318^{***} & 0.1413^{***} \\ 0.1154 & 0.1024 \end{bmatrix} \quad \hat{D} = \begin{bmatrix} 0.4321^{***} & -0.1477^{*} \\ 0.0489 & -0.1472 \end{bmatrix}$$

Table D.1 *(continued):* VAR-BEKK model

Panel B: Euro-Peripheral and Euro-Core portfolios

Panel B.1: Pre-SC (Jan06 – Aug07)

	$R_{EP,t}$	$R_{EC,t}$
μ	-0.0012	-0.0015
$R_{EP,t-1}$	-0.2016***	0.3544
$R_{EP,t-2}$	-0.0305	-0.0751
$R_{EP,t-3}$	0.1133**	0.0479
$R_{EC,t-1}$	0.0024	-0.4466***
$R_{EC,t-2}$	-0.0095	-0.2452***
$R_{EC,t-3}$	0.0019	-0.1475***

$$\hat{C} = \begin{bmatrix} 0.3647^{***} & - \\ -0.0237 & -0.0575 \end{bmatrix} \quad \hat{B} = \begin{bmatrix} 0.8499^{***} & -0.0151 \\ -0.0043 & 0.9002^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.3160^{***} & 0.0646^{***} \\ 0.0135 & 0.4348^{***} \end{bmatrix} \quad \hat{D} = \begin{bmatrix} 0.3011^{***} & -0.0004 \\ -0.0472^{**} & -0.2696 \end{bmatrix}$$

Panel B.2: Post-SP / Pre-LB (Aug07 – Sep08)

	$R_{EP,t}$	$R_{EC,t}$
μ	-0.0095	-0.0037
$R_{EP,t-1}$	0.2648***	0.3449
$R_{EP,t-2}$	0.0856	0.1984*
$R_{EC,t-1}$	-0.0364	-0.0709
$R_{EC,t-2}$	-0.0850	-0.0191

$$\hat{C} = \begin{bmatrix} 0.4513^{***} & - \\ -0.4492^{***} & -0.0000 \end{bmatrix} \quad \hat{B} = \begin{bmatrix} 0.8499^{***} & -0.0151 \\ -0.0043 & 0.9002^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.4944^{***} & -0.3468^{**} \\ 0.4438 & -0.3533 \end{bmatrix} \quad \hat{D} = \begin{bmatrix} 0.1987 & -0.7434^{***} \\ -0.2968 & -0.3739^{**} \end{bmatrix}$$

Table D.1 ***(continued)*****:** VAR-BEKK model

Panel B: Euro-Peripheral and Euro-Core portfolios *(continued)*

Panel B.3: Post-LB / Pre-GB (Sep08 – May10)

	$R_{EP,t}$	$R_{EC,t}$
μ	-0.0204*	0.0039
$R_{EP,t-1}$	0.4063***	0.1760***
$R_{EC,t-1}$	0.0643	0.1824***

$$\hat{C} = \begin{bmatrix} 0.3077^{***} & - \\ -0.1536^{**} & -0.1009 \end{bmatrix} \quad \hat{B} = \begin{bmatrix} 0.7860^{***} & 0.0664 \\ 0.0565 & 0.8753^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} 0.1285 & 0.1011 \\ 0.0466 & 0.3808^{***} \end{bmatrix} \quad \widehat{D} = \begin{bmatrix} -0.8476^{***} & 0.2685 \\ 0.0251 & -0.2209^{**} \end{bmatrix}$$

Panel B.4: Post-GB (May10 – Mar13)

	$R_{EP,t}$	$R_{EC,t}$
μ	0.0072	-0.0012
$R_{EP,t-1}$	0.0785*	-0.0129
$R_{EP,t-2}$	0.0618	0.0035
$R_{EP,t-3}$	-0.1481***	-0.0190
$R_{EC,t-1}$	0.6403***	0.3852***
$R_{EC,t-2}$	-0.2708	-0.0884*
$R_{EC,t-3}$	0.2422*	-0.0490

$$\hat{C} = \begin{bmatrix} 0.1138^{***} & - \\ 0.0120 & 0.1057^{***} \end{bmatrix} \quad \hat{B} = \begin{bmatrix} 0.9184^{***} & -0.0023 \\ 0.0335^{***} & 0.9565^{***} \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} -0.0438^{***} & 0.0690^{***} \\ -0.1674^{***} & 0.1392^{***} \end{bmatrix} \quad \widehat{D} = \begin{bmatrix} -0.4252^{***} & 0.1715^{***} \\ -0.0846^{***} & -0.3141^{***} \end{bmatrix}$$

REFERENCES

ALTER, A. and SHÜLER Y.S. (2012). "Credit spread interdependencies of European states and banks during the financial crisis", *Journal of Banking and Finance,* 36, pp. 3444-3468.

ANNAERT, J., DE CEUSTER M., VAN ROY, P. and VESPRO, C. (2013). "What determines Euro area bank CDS Spreads?", *Journal of International Money and Finance,* 32, pp. 444-461.

BABA, Y., ENGLE, R.F., KRAFT, D.F. and KRONER, K.F. (1989). *Multivariate Simultaneous Generalized ARCH*. University of California at San Diego. Editorial Mimeo.

BAE, K.H. and KAROLYI G.A. (1994). "Good news, bad news and international spillovers of stock return volatility between Japan and the US", *Pacific-Basin Finance Journal,* 2, pp. 405-438.

BAI, J. and COLLIN-DUFRESNE, P. (2011). "The CDS-Bond Basis during the Financial Crisis of 2007-2009", Working paper.

BALLESTER, L., CASU, B. and GONZÁLEZ-URTEAGA, A. (2013). "Bank Fragility and Contagion: Evidence from the CDS market", Working paper.

BERNANKE, B. (1986). "Alternative Explanations of the Money-Income Correlation", Carnegie-Rochester Conference Series on Public Policy, 25, pp. 49-100.

BERNDT, A. and OBREJA, I. (2010). "Decomposing European CDS Returns", *Review of Finance,* 14, pp. 189-233.

BLANCO, R., BRENNAN, S. and MARSH, I.W. (2005). "An empirical analysis of the dynamic relationship between investment grade bonds and credit default swaps", *Journal of Finance*, 60, 5, pp. 2255-2281.

BOLLERSLEV, T. (1986). "Generalized Autoregressive Conditional Heteroskedasticity", *Journal of Econometrics*, 31, 309-328.

BOLLERSLEV, T., ENGLE, R.F. and WOOLDRIDGE, J.M. (1988). "A Capital Asset Pricing Model with Time Varying Covariances", *Journal of Political Economy,* 96, 1, pp. 116-131.

BOLLERSLEV, T. (1990). “Modelling the Coherence in Short-Run Nominal Rates: A Multivariate Generalized ARCH Approach”, *Review of Economics and Statistics*, 72, 3, pp. 498-505.

BOLLERSLEV, T. and WOOLDRIDGE, J.M. (1992). “Quasi-Maximum Likelihood Estimation and Inference in Dynamic Models with Time-Varying Covariances”, *Econometric Review*, 11, 2, pp. 143-172.

CALICE, G., IOANNIDIS, C. and WILLIAMS, J. (2011). “Credit Derivatives and the Default Risk of Large Financial Institutions”, *Journal of Financial Services Research*, pp. 1-23.

CAPORIN M., PELIZZON L., RAVAZZOLO F. and RIGOBON R. (2012). “Measuring Sovereign Contagion in Europe”, Norges Bank Working Paper 2012/05

CARBONI, A. (2011). “The Sovereign Credit Default Swap Market: Price Discovery, Volumes and Links with Banks' Risk Premia”, Bank of Italy Temi di Discussione Working Paper No. 821.

CHIARAMONTE, L. and CASU, B. (2013). “The Determinants of Bank CDS spreads: Evidence from the financial crisis”, *The European Journal of Finance,* forthcoming.

COUDERT, V. and GEX, M. (2011). “The Interactions between the Credit Default Swap and the Bond Markets in Financial Turmoil”, CEPII Working Papers series 2011-02.

DELATTE, A.L., GEX, M. and LOPEZ-VILLAVICENCIO, A. (2010). “Has the CDS Market Influenced the Borrowing Cost of European Countries During the Sovereign Crisis?”, Working paper.

DEMIRGUC-KUNT, A. and HUIZINGA, H. (2013). “Are banks too big to fail or too big to save? International evidence from equity prices and CDS spreads”, *Journal of Banking and Finance,* 37, 3, pp. 875-894.

DICKEY, D.A. and FULLER W.A. (1981). “Likelihood Ratio Statistics for Autorregressive Time Series with a Unit Root”, *Econometrica,* 49, pp. 1057-1072.

DIECKMANN, S. and PLANK T. (2012). “Default Risk of Advanced Economies: An Empirical Analysis of Credit Default Swaps during the Financial Crisis”, *Review of Finance*, 16, 4, pp. 903-934.

DRUDI F., DURRÉ A. and MONGELLI F.P. (2012). "The Interplay of Economic Reforms and Monetary Policy: The case of the Eurozone", *Journal of Common Market Studies*, 50, pp. 881-898

EHLERS S., GURTLER M. and OLBOETER S. (2010). "Financial Crisis and Information Transfer- An Empirical Analysis of the Lead-Lag Relationship between Equity and CDS iTraxx Indices", Working Paper.

ELYASIANI E., KALOTYCHOU, E. and STAIKOURAS, S.K. (2013). "Return and Volatility Spillover among Banks and Insurers: Evidence from Pre- and Post-Crisis Periods"**,** Cass Working Paper Series 11-12

ENGLE, R.F. (1982). "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation", *Econometrica*, 50, pp. 987-1007.

ENGLE, R.F., ITO, T. and LIN, W.L. (1990). "Meteor Showers or Heat Waves? Heteroskedastic Intra-daily Volatility in the Foreign Exchange Market", *Econometrica*, 58, 3, pp. 525-542.

ENGLE, R.F. and K.F. KRONER. (1995). "Multivariate Simultaneous Generalized Arch", *Econometric Theory*, 11, 1, pp. 122-150.

ENGLE, R.F. (2002). "Dynamic Conditional Correlation-A Simple Class of Multivariate Generalized Autoregressive Conditional Heteroskedasticity Models", *Journal of Business and Economic Statistics*, 20, 3, pp. 339-350.

EUN, C.S. and SHIM, S. (1989). "International transmission of stock market movements", *Journal of Financial and Quantitative Analysis*, 24, pp. 241-256.

FONTANA, A. and SCHEICHER, M. (2010). "An Analysis of Euro Area Sovereign CDS and Their Relation with Government Bonds", ECB Working Paper No. 1271.

GLOSTEN, L.R., JAGANNATHAN, R. and RUNKLE, D.E. (1993). "On the relationship between the expected value and the volatility of the nominal excess return on stocks", *Journal of Finance*, 48, 5, pp. 1779-1801.

HAMAO, Y., MASULIS, R.W. and NG, V. (1990). "Correlations in Price Changes and Volatility across International Stock Markets", *Review of Financial Studies*, 3, 2, pp. 281-307.

HASSAN, M.K., NGENE, G.M. and Yu, J.S. (2011). “Credit Default Swaps and Sovereign Debt Markets”, Networks Financial Institute Working Paper 2011-WP-03.

HULL, J., PREDESCU, M. and WHITE, A. (2004). “The relationship between credit default swaps spreads, bond yields, and credit rating announcements”, *Journal of Banking and Finance*, 28, pp. 2789-2811.

KALBASKA A. and GATKOWSKI, M. (2012). “Eurozone Sovereign Contagion: Evidence from the CDS Market (2005-2010)”, *Journal Behavior and Organization*, 83, pp. 657-673.

KEARNEY, C. and PATTON, A.J. (2000). “Multivariate GARCH Modeling of Exchange Rate Volatility Transmission in the European Monetary System”, *Financial Review*, 35, 1, pp. 29-48.

KOUTMOS, G. and BOOTH, G. (1995). “Asymmetric Volatility Transmission in International Stock Markets”, *Journal of International Money and Finance*, 14, 6, pp. 747-762.

KRONER, K.F. and NG, V.K. (1998). “Modelling Asymmetric Comovements of Asset Returns”, *The Review of Financial Studies*, 11, 4, pp. 817-844.

LIN, W.L. (1997). “Impulse Response Function for Conditional Volatility in GARCH Models”, *Journal of Business and Economic Statistics*, 15, 1, pp. 15-25.

LONGSTAFF, F.A., MITHAL, S. and NEIS E. (2005). “Corporate Yield Spreads: Default Risk or Liquidity? New Evidence from the Credit-Default Swap”, *Journal of Finance*, 60, pp. 2213-2253.

LONGSTAFF, F.A., PAN, J., PEDERSEN, L.H. and SINGLETON, K.J. (2011). “How sovereign is sovereign credit risk?”, *American Economic Journal: Macroeconomics*, 3, pp. 75-103.

MAYORDOMO, S., PEÑA, J.I. and SCHWARTZ, E.S. (2013). “Are All Credit Default Swap Databases Equal? ”, *European Financial Management*, forthcoming.

MENEU, V. and TORRÓ, H. (2003). “Asymmetric Covariance in Spot-Futures Markets”, *Journal of Futures Markets*, 23, 11, pp. 1019-1046.

NASHIKKAR, A., SUBRAHMANYAM, M.G. and MAHANT, S. (2011). "Liquidity and Arbitrage in the Market for Credit Risk", *Journal of Financial and Quantitative Analysis*, 46, 3, pp. 627-656.

PAN. J.P. and SINGLETON, K.J. (2008). "Default and Recovery Implicit in the Term Structure of Sovereign CDS Spreads", *Journal of Finance*, 63, pp. 2345-2384.

PHILLIPS, P.C.B. and PERRON, P. (1988). "Testing for a Unit Root in Time Series Regression", *Biometrica*, 75, pp. 335-346.

PRESS, W.H., FLANNERY, B.P., TEUKOLSKY, S.A. and VETTERING, W.T. (1988). *Numerical Recipes in C*. New York: Cambridge University Press.

SIMS, C.A. (1986). "Are Forecasting Models Usable for Policy Analysis? ", *Federal Reserve Bank of Minneapolis Quarterly Review*, 10, 1, pp. 2-16.

SORIANO, P. and CLIMENT, F. (2006). "Volatility Transmission Models: A Survey", *Revista de Economía Financiera*, 10, pp. 32-81.

SUSMEL, R. and ENGLE, R.F. (1994). "Hourly Volatility Spillovers between International Equity Markets", *Journal of International Money and Finance*, 13, 1, pp. 3-25.

TABLE 1: Descriptive statistics of bank CDS spreads

This table presents the summary statistics for the daily 5-year CDS spreads in basis points for the full period, from January 2006 to March 2013, and four sub-periods identified by three significant events: the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and Greece's bailout (May 8, 2010), GB, respectively. The banks of the sample are summarized in equally weighted portfolios sorted first by country, then by geographic zone. The lack of statistics for Norway in the first sub-period is due to the lack of data for the Norwegian bank until May 2008.

	CDS Spreads																			
	Full Period Jan06 – Mar13				**Pre-SC Jan06 – Aug07**				**Post-SC / Pre-LB Aug07 – Sep08**				**Post-LB / Pre-GB Sep08 – May10**				**Post-GB May10 – Mar13**			
	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Euro	12.08	903.02	230.97	214.04	12.08	37.58	17.15	3.96	34.81	132.81	70.35	23.86	109.29	338.54	158.18	35.24	224.97	903.02	453.32	162.35
Euro-Peripheral	12.90	1625.25	348.71	374.99	12.90	34.24	16.31	2.92	29.86	124.92	63.69	23.48	108.75	537.09	163.45	55.09	353.45	1625.25	749.25	280.38
Greece	15.00	4190.93	619.42	773.49	15.00	30.06	21.21	3.24	21.58	21.58	21.58	0.00	21.58	1049.75	160.98	185.19	597.27	4190.93	1444.43	588.55
Italy	9.06	694.92	194.26	168.76	9.06	46.61	16.23	5.85	43.25	183.10	99.25	34.15	67.72	379.23	163.49	80.71	139.72	694.92	347.49	149.14
Portugal	10.50	1483.57	344.02	391.22	10.50	41.39	14.29	3.66	28.46	126.70	69.33	28.90	66.50	547.43	125.55	56.15	307.66	1483.57	758.17	306.79
Spain	10.42	769.57	237.14	208.46	10.42	27.39	13.51	2.39	25.21	225.85	64.60	40.18	121.74	350.67	203.80	51.91	231.22	769.57	446.91	152.07
Euro-Core	10.13	384.92	136.77	94.22	10.13	40.24	17.82	6.03	37.37	153.84	75.68	25.12	98.31	274.42	153.96	42.04	122.19	384.92	216.58	71.98
Austria	3.82	510.24	152.09	91.60	3.82	117.83	38.25	24.52	74.15	188.30	98.04	27.63	123.05	510.24	215.60	86.35	123.83	364.58	199.81	57.13
Belgium	6.70	709.49	221.56	185.23	6.70	27.90	9.21	2.83	27.05	177.50	96.69	33.12	136.14	395.70	228.23	69.40	175.11	709.49	383.87	159.92
France	5.18	356.17	111.40	82.24	5.18	58.22	19.61	10.65	23.41	131.53	57.75	24.15	60.31	177.62	98.79	21.91	100.89	356.17	190.31	65.72
Germany	10.22	276.11	104.98	64.05	10.22	45.72	15.65	4.02	32.62	121.35	65.85	17.84	88.94	182.29	129.31	23.03	90.88	276.11	155.79	43.84
Netherlands	3.83	254.39	93.82	66.11	3.83	27.73	6.38	2.82	15.16	157.23	60.08	28.42	58.94	172.73	97.89	25.61	92.63	254.39	153.14	45.50
Non-Euro	7.50	245.59	92.30	62.65	7.50	23.77	10.91	2.54	16.49	117.60	55.70	25.06	63.79	227.82	116.72	38.37	78.17	245.59	137.66	46.64
Denmark	3.50	344.80	103.07	91.86	3.50	8.20	5.26	1.38	4.10	80.00	34.49	23.25	60.56	225.00	115.91	43.24	61.67	344.80	176.46	85.55
Norway	37.50	212.00	100.46	39.38	-	-	-	-	37.50	68.00	53.93	7.01	49.53	188.11	100.50	37.69	54.20	212.00	106.27	38.86
Sweden	10.18	242.37	83.45	57.23	10.18	25.42	16.47	4.27	13.17	93.75	36.32	25.95	76.61	242.37	128.10	40.41	67.00	216.95	113.23	40.62
Switzerland	9.20	262.88	90.10	55.96	9.20	51.30	13.62	5.18	23.50	188.30	73.55	31.41	52.80	262.88	112.98	47.57	78.97	213.45	125.93	35.13
UK	4.37	285.29	109.70	70.40	4.37	30.89	8.31	3.50	25.00	204.85	84.63	39.05	74.60	230.15	126.10	36.04	97.67	285.29	166.40	42.24

TABLE 2: Descriptive tests of bank CDS returns

Panel A: skewness, excess of kurtosis and Jarque-Bera tests for the zero skewness, zero excess of kurtosis and normal distribution null hypothesis, respectively. Panel B: Q(10) and $Q^2(10)$ Ljung-Box tests for tenth order serial correlation in the returns and squared returns, and ARCH(10) Engle's test for tenth order ARCH. Panel C: ADF(10) and PP(10) refer to the Augmented Dickey and Fuller (1981) and Phillips and Perron (1988) unit root tests for 10 lags. Results are shown for the full period, from January 2006 to March 2013, and four sub-periods identified by three significant events: the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and Greece's bailout (May 8, 2010), GB, respectively. The banks of the sample are summarized in equally weighted portfolios sorted by geographic zone using average CDS returns of each zone's countries. * Significance at the 10% level; ** Significance at the 5% level; *** Significance at the 1% level.

Panel A:	CDS returns: Skewness (Sk.), Excess of Kurtosis (Ex.Kr.) and Jarque-Bera test (JB)														
	Full Period Jan06 – Mar13			Pre-SC Jan06 – Aug07			Post-SC / Pre-LB Aug07 – Sep08			Post-LB / Pre-GB Sep08 – May10			Post-GB May10 – Mar13		
	Sk.	Ex.Kr.	JB	Sk.	Ex.Kr.	JB	Sk.	Ex.Kr.	JB	Sk.	Ex.Kr.	JB	Sk.	Ex.Kr.	JB
Euro	1.77***	51.22***	207,060.49***	-0.18	1.98***	70.97***	0.76***	5.43***	380.77***	-1.48***	10.57***	2,160.78***	1.54***	27.84***	24,535.01***
Euro-Peripheral	4.22***	128.23***	1,297,133.82***	0.57***	15.42***	4,167.59***	-0.15	5.92***	421.29***	-4.02***	34.76***	22,807.28***	3.04***	57.63***	104,978.02***
Euro-Core	-0.15***	6.91***	3,760.74***	-0.19	2.31***	96.31***	0.73***	5.53***	392.11***	-0.50***	7.76***	1,099.31***	-0.03	4.98***	777.63***
Non-Euro	-0.03	7.54***	4,469.18***	-0.79***	14.36***	3,635.51***	1.19***	8.33***	898.63***	-0.52***	5.33***	529.54***	0.12	4.32***	586.92***

Panel B:	CDS returns: conditional heteroskedasticity tests														
	Full Period Jan06 – Mar13			Pre-SC Jan06 – Aug07			Post-SC / Pre-LB Aug07 – Sep08			Post-LB / Pre-GB Sep08 – May10			Post-GB May10 – Mar13		
	Q(10)	$Q^2(10)$	ARCH(10)	Q(10)	$Q^2(10)$	ARCH(10)	Q(10)	$Q^2(10)$	ARCH(10)	Q(10)	$Q^2(10)$	ARCH(10)	Q(10)	$Q^2(10)$	ARCH(10)
Euro	128.76***	86.18***	70.92***	58.68***	89.78***	42.19***	23.19**	100.47***	73.76***	119.45***	121.53***	81.78***	55.70***	24.56***	21.47**
Euro-Peripheral	112.92***	60.05***	55.45***	22.34**	27.66***	92.00***	28.40***	21.30**	18.35**	175.30***	66.66***	98.57***	45.27***	19.93**	18.90**
Euro-Core	97.77***	507.38***	237.71***	65.98***	107.95***	47.40***	19.33**	110.57***	75.76***	60.68***	232.30***	86.20***	95.54***	144.53***	72.88***
Non-Euro	97.70***	582.09***	255.33***	49.29***	105.34***	78.15***	9.57	105.34***	82.54***	35.20***	159.78***	65.80***	70.98***	166.07***	72.21***

Panel C:	CDS returns: unit root tests									
	Full Period Jan06 – Mar13		Pre-SC Jan06 – Aug07		Post-SC / Pre-LB Aug07 – Sep08		Post-LB / Pre-GB Sep08 – May10		Post-GB May10 – Mar13	
	ADF(10)	PP(10)	ADF(10)	PP(10)	ADF(10)	PP(10)	ADF(10)	PP(10)	ADF(10)	PP(10)
Euro	-13.42***	-34.48***	-8.21***	-36.04***	-3.99***	-13.83***	-3.85***	-13.51***	-8.63***	-22.52***
Euro-Peripheral	-13.98***	-36.38***	-5.53***	-22.70***	-4.16***	-13.17***	-0.86	-13.48***	-9.08***	-23.70***
Euro-Core	-13.08***	-34.79***	-9.20***	-41.06***	-4.05***	-14.82***	-7.24***	-15.66***	-7.93***	-20.01***
Non-Euro	-12.71***	-34.76***	-5.50***	-25.86***	-4.02***	-16.06***	-5.80***	-16.86***	-8.15***	-21.20***

TABLE 3: Mean Test, Levene Test and correlations

Mean test between sub-periods (Panel A.1) and portfolios (Panel A.2) tests the null hypothesis of equality of daily mean returns. The Levene's statistic between sub-periods (Panel B.1) and portfolios (Panel B.2) tests the null hypothesis of equality of daily variances. Panel C displays the correlations between portfolios. Results are shown for the full period, from January 2006 to March 2013, and four sub-periods identified by three significant events: the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and Greece's bailout (May 8, 2010), GB, respectively. The banks of the sample are summarized in equally weighted portfolios sorted by geographic zone using average CDS returns of each zone's countries. E, NE, EP and EC refer to Euro, Non-Euro, Euro-Peripheral and Euro-Core portfolios, respectively. * Significance at the 10% level; ** Significance at the 5% level; *** Significance at the 1% level.

Panel A.1:	**Mean Test between subperiods**		
	Event 1: SC $H_0: \mu_{Pre-CS} = \mu_{Post-CS}$	Event 2: LB $H_0: \mu_{Pre-LB} = \mu_{Post-LB}$	Event 3: GB $H_0: \mu_{Pre-GB} = \mu_{Post-GB}$
Euro	2.078	0.272	1.319
Euro-Peripheral	5.185**	1.749	1.579
Euro-Core	0.781	0.089	0.226
Non-Euro	2.336	0.409	0.087

Panel A.2:	**Mean Test between portfolios**				
	Full Period Jan06–Mar13	**Pre-SC Jan06-Aug07**	**Post-SC / Pre-LB Aug07-Sep08**	**Post-LB / Pre-GB Sep08-May10**	**Post-GB May10-Mar13**
$H_0: \mu_E = \mu_{NE} = \mu_{EP} = \mu_{EC}$	0.029	0.001	0.022	1.802	0.121
$H_0: \mu_E = \mu_{NE}$	0.061	0.001	0.011	1.433	0.103
$H_0: \mu_{NE} = \mu_{EP}$	0.059	0.000	0.056	4.239**	0.182
$H_0: \mu_{NE} = \mu_{EC}$	0.030	0.001	0.000	0.068	0.000
$H_0: \mu_{EP} = \mu_{EC}$	0.023	0.001	0.045	2.866*	0.180

Panel B.1:	**Levene Test between subperiods**		
	Event 1: SC $H_0: \sigma^2_{Pre-SC} = \sigma^2_{Post-SC}$	Event 2: LB $H_0: \sigma^2_{Pre-LB} = \sigma^2_{Post-LB}$	Event 3: GB $H_0: \sigma^2_{Pre-GB} = \sigma^2_{Post-GB}$
Euro	18.21***	35.82***	57.15***
Euro-Peripheral	171.85***	44.25***	79.26***
Euro-Core	0.03	19.14***	3.26*
Non-Euro	164.80***	16.50***	0.92

Panel B.2:	**Levene Test between portfolios**				
	Full Period Jan06–Mar13	**Pre-SC Jan06-Aug07**	**Post-SC / Pre-LB Aug07-Sep08**	**Post-LB / Pre-GB Sep08-May10**	**Post-GB May10-Mar13**
$H_0: \sigma^2_E = \sigma^2_{NE} = \sigma^2_{EP} = \sigma^2_{EC}$	81.55***	123.94***	3.01**	3.27**	113.91***
$H_0: \sigma^2_E = \sigma^2_{NE}$	144.53***	129.30***	0.13	4.08**	150.34***
$H_0: \sigma^2_{NE} = \sigma^2_{EP}$	159.10***	0.29	2.79*	9.02***	192.32***
$H_0: \sigma^2_{NE} = \sigma^2_{EC}$	92.79***	180.69***	1.53	4.18**	40.84***
$H_0: \sigma^2_{EP} = \sigma^2_{EC}$	70.31***	183.30***	8.95***	1.27	134.67***

Panel C:	**Correlations**				
	Full Period Jan06–Mar13	**Pre-SC Jan06–Aug07**	**Post-SC / Pre-LB Aug07–Sep08**	**Post-LB / Pre-GB Sep08–May10**	**Post-GB May10–Mar13**
$\rho_{E,NE}$	0.62	0.19	0.85	0.73	0.64
$\rho_{NE,EP}$	0.42	0.19	0.73	0.53	0.46
$\rho_{NE,EC}$	0.76	0.17	0.83	0.75	0.85
$\rho_{EP,EC}$	0.44	0.09	0.74	0.55	0.50

TABLE 4: Results of the linearized asymmetric BEKK model

This table shows the non-linear functions of the parameters of the BEKK model by periods. h_{11} and h_{22} denote the conditional variance for the different return series. Panel A shows the results of the Euro and Non-Euro portfolios conditional variance equations, while Panel B shows the Euro-Peripheral and Euro-Core conditional variance equations. * Significance at the 10% level; ** Significance at the 5% level; *** Significance at the 1% level.

Panel A: Euro and Non-Euro portfolios

Panel A.1: Pre-SC (Jan06 – Aug07)

Euro portfolio conditional variance equation

$$h_{11,t} = \underset{(*)}{0.0100} + \underset{(***)}{0.8034}h_{11,t-1} - 0.0068h_{12,t-1} + 1.46x10^{-5}h_{22,t-1} + \underset{(***)}{0.1687}\varepsilon_{1,t-1}^2 - \underset{(**)}{0.0485}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0034\varepsilon_{2,t-1}^2 + 0.0433\eta_{1,t-1}^2 + \underset{(**)}{0.0542}\eta_{1,t-1}\eta_{2,t-1} + \underset{(*)}{0.0169}\eta_{2,t-1}^2$$

Non-Euro portfolio conditional variance equation

$$h_{22,t} = \underset{(***)}{0.0468} + 4.32x10^{-5}h_{11,t-1} - 0.0114h_{12,t-1} + \underset{(***)}{0.7537}h_{22,t-1} + \underset{(*)}{0.0156}\,\varepsilon_{1,t-1}^2 - 0.0022\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 7.99x10^{-5}\varepsilon_{2,t-1}^2 + 0.0002\,\eta_{1,t-1}^2 - 0.0206\eta_{1,t-1}\eta_{2,t-1} + \underset{(***)}{0.4350}\eta_{2,t-1}^2$$

Panel A.2: Post-SC / Pre-LB (Aug07 – Sep08)

Euro portfolio conditional variance equation

$$h_{11,t} = 0.0905 + \underset{(***)}{0.7753}h_{11,t-1} + 0.0299h_{12,t-1} + 0.0002h_{22,t-1} + 0.0089\varepsilon_{1,t-1}^2 + 0.0222\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0138\varepsilon_{2,t-1}^2 + \underset{(***)}{0.3655}\eta_{1,t-1}^2 + 0.1229\eta_{1,t-1}\eta_{2,t-1} + 0.0103\eta_{2,t-1}^2$$

Non-Euro portfolio conditional variance equation

$$h_{22,t} = 0.0726 + 0.0003h_{11,t-1} - 0.0276h_{12,t-1} + \underset{(***)}{0.5382}h_{22,t-1} + \underset{(*)}{0.3326}\,\varepsilon_{1,t-1}^2 - 0.1348\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0136\varepsilon_{2,t-1}^2 + 0.0432\,\eta_{1,t-1}^2 - 0.1265\eta_{1,t-1}\eta_{2,t-1} + 0.0926\eta_{2,t-1}^2$$

Panel A.3: Post-LB / Pre-GB (Sep08 – May10)

Euro portfolio conditional variance equation

$$h_{11,t} = 0.0211 + \underset{(***)}{0.8637}h_{11,t-1} + 0.0547h_{12,t-1} + 0.0008h_{22,t-1} + 0.0001\varepsilon_{1,t-1}^2 + 0.0041\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0270\varepsilon_{2,t-1}^2 + \underset{(**)}{0.2507}\eta_{1,t-1}^2 - \underset{(*)}{0.1427}\eta_{1,t-1}\eta_{2,t-1} + 0.0203\eta_{2,t-1}^2$$

Non-Euro portfolio conditional variance equation

$$h_{22,t} = 2.4403 + 0.0001h_{11,t-1} - 0.0221h_{12,t-1} + \underset{(***)}{0.8286}h_{22,t-1} + \underset{(**)}{0.1243}\,\varepsilon_{1,t-1}^2 + 0.1133\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0258\varepsilon_{2,t-1}^2 + 0.0304\,\eta_{1,t-1}^2 - 0.0186\eta_{1,t-1}\eta_{2,t-1} + 0.0028\eta_{2,t-1}^2$$

Panel A.4: Post-GB (May10 – Mar13)

Euro portfolio conditional variance equation

$$h_{11,t} = 0.0269 + \underset{(***)}{0.8363}h_{11,t-1} + 0.0817h_{12,t-1} + 0.0019h_{22,t-1} + \underset{(**)}{0.0173}\varepsilon_{1,t-1}^2 + 0.0304\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0133\varepsilon_{2,t-1}^2 + \underset{(***)}{0.1867}\eta_{1,t-1}^2 + 0.0422\eta_{1,t-1}\eta_{2,t-1} + 0.0023\eta_{2,t-1}^2$$

Non-Euro portfolio conditional variance equation

$$h_{22,t} = 0.0032 + 0.0003h_{11,t-1} - 0.0350h_{12,t-1} + \underset{(***)}{0.9329}h_{22,t-1} + 0.0199\,\varepsilon_{1,t-1}^2 + 0.0289\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0104\varepsilon_{2,t-1}^2 + 0.0218\,\eta_{1,t-1}^2 + 0.0435\eta_{1,t-1}\eta_{2,t-1} + 0.0216\eta_{2,t-1}^2$$

TABLE 4 *(continued)*: Results of the linearized asymmetric BEKK model

Panel B: Euro-Peripheral and Euro-Core portfolios

Panel B.1: Pre-SC (Jan06 – Aug07)

Euro-Peripheral portfolio conditional variance equation

$$h_{11,t} = 0.1336^{(*)} + 0.7224^{(***)}h_{11,t-1} - 0.0073h_{12,t-1} + 1.87x\ 10^{-5}h_{22,t-1} + 0.0998\varepsilon_{1,t-1}^2 + 0.0085\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0001\varepsilon_{2,t-1}^2 + 0.0906\eta_{1,t-1}^2 - 0.0284^{(*)}\eta_{1,t-1}\eta_{2,t-1} + 0.0022\eta_{2,t-1}^2$$

Euro-Core portfolio conditional variance equation

$$h_{22,t} = 0.0033 + 0.0002h_{11,t-1} - 0.0284h_{12,t-1} + 0.8104^{(***)}h_{22,t-1} + 0.0041\,\varepsilon_{1,t-1}^2 + 0.0562^{(*)}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.1890^{(*)}\varepsilon_{2,t-1}^2 + 2.07x10^{-7}\eta_{1,t-1}^2 + 0.0002\eta_{1,t-1}\eta_{2,t-1} + 0.0727\eta_{2,t-1}^2$$

Panel B.2: Post-SC / Pre-LB (**Aug07 – Sep08**)

Euro-Peripheral portfolio conditional variance equation

$$h_{11,t} = 0.4055^{(***)} + 0.2146^{(*)}h_{11,t-1} + 0.0460^{(***)}h_{12,t-1} + 0.2464^{(***)}h_{22,t-1} + 0.2445^{(*)}\varepsilon_{1,t-1}^2 + 0.4389\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.1970\varepsilon_{2,t-1}^2 + 0.0394\eta_{1,t-1}^2 - 0.1179\eta_{1,t-1}\eta_{2,t-1} + 0.0881\eta_{2,t-1}^2$$

Euro-Core portfolio conditional variance equation

$$h_{22,t} = 2.30x10^{-15} + 0.1963^{(***)}h_{11,t-1} + 0.3429^{(***)}h_{12,t-1} + 0.1497^{(***)}h_{22,t-1} + 0.1203\,\varepsilon_{1,t-1}^2 + 0.2451\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.1248\varepsilon_{2,t-1}^2 + 0.5526\,\eta_{1,t-1}^2 + 0.5559^{(**)}\eta_{1,t-1}\eta_{2,t-1} + 0.1398\eta_{2,t-1}^2$$

Panel B.3: Post-LB / Pre-GB (Sep08 – May10)

Euro-Peripheral portfolio conditional variance equation

$$h_{11,t} = 0.1183^{(*)} + 0.6179^{(***)}h_{11,t-1} + 0.0888h_{12,t-1} + 0.0031h_{22,t-1} + 0.0165\varepsilon_{1,t-1}^2 + 0.0119\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0021\varepsilon_{2,t-1}^2 + 0.7185^{(*)}\eta_{1,t-1}^2 - 0.0426\eta_{1,t-1}\eta_{2,t-1} + 0.0006\eta_{2,t-1}^2$$

Euro-Core portfolio conditional variance equation

$$h_{22,t} = 0.0101 + 0.0044h_{11,t-1} + 0.1162h_{12,t-1} + 0.7662^{(***)}h_{22,t-1} + 0.0102\,\varepsilon_{1,t-1}^2 + 0.0770\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.1450^{(*)}\varepsilon_{2,t-1}^2 + 0.0721\,\eta_{1,t-1}^2 - 0.1186\eta_{1,t-1}\eta_{2,t-1} + 0.0488\eta_{2,t-1}^2$$

Panel B.4: Post-GB (May10 – Mar13)

Euro-Peripheral portfolio conditional variance equation

$$h_{11,t} = 0.0131^{(***)} + 0.8434^{(***)}h_{11,t-1} + 0.0616^{(***)}h_{12,t-1} + 0.0011^{(***)}h_{22,t-1} + 0.0019\varepsilon_{1,t-1}^2 + 0.0146^{(**)}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0280^{(***)}\varepsilon_{2,t-1}^2 + 0.1808^{(***)}\eta_{1,t-1}^2 + 0.0720^{(***)}\eta_{1,t-1}\eta_{2,t-1} + 0.0071^{(***)}\eta_{2,t-1}^2$$

Euro-Core portfolio conditional variance equation

$$h_{22,t} = 0.0111^{(***)} + 5.41x10^{-6}h_{11,t-1} - 0.0044h_{12,t-1} + 0.9148^{(***)}h_{22,t-1} + 0.0047^{(*)}\varepsilon_{1,t-1}^2 + 0.0192^{(***)}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.0194^{(***)}\varepsilon_{2,t-1}^2 + 0.0294^{(***)}\,\eta_{1,t-1}^2 - 0.1077^{(***)}\eta_{1,t-1}\eta_{2,t-1} + 0.0986^{(***)}\eta_{2,t-1}^2$$

FIGURE 1: Time evolution of bank CDS spreads and returns portfolios

Daily bank CDS spreads in basis points (Panel A) and returns (Panel B) for the four equally weighted portfolios, sorted by the geographical area where banks are headquartered. The sample period is January 2006 to March 2013. The vertical black solid lines identify the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and Greece's bailout (May 8, 2010), GB, respectively. The scaling in Euro is from 0 to 1,000 and from -4 to 6; in Euro-Peripheral is from 0 to 1,800 and from -6 to 12; in the others is from 0 to 400 and from -2 to 2, for Panel A and B respectively.

Panel A: **Panel B:**

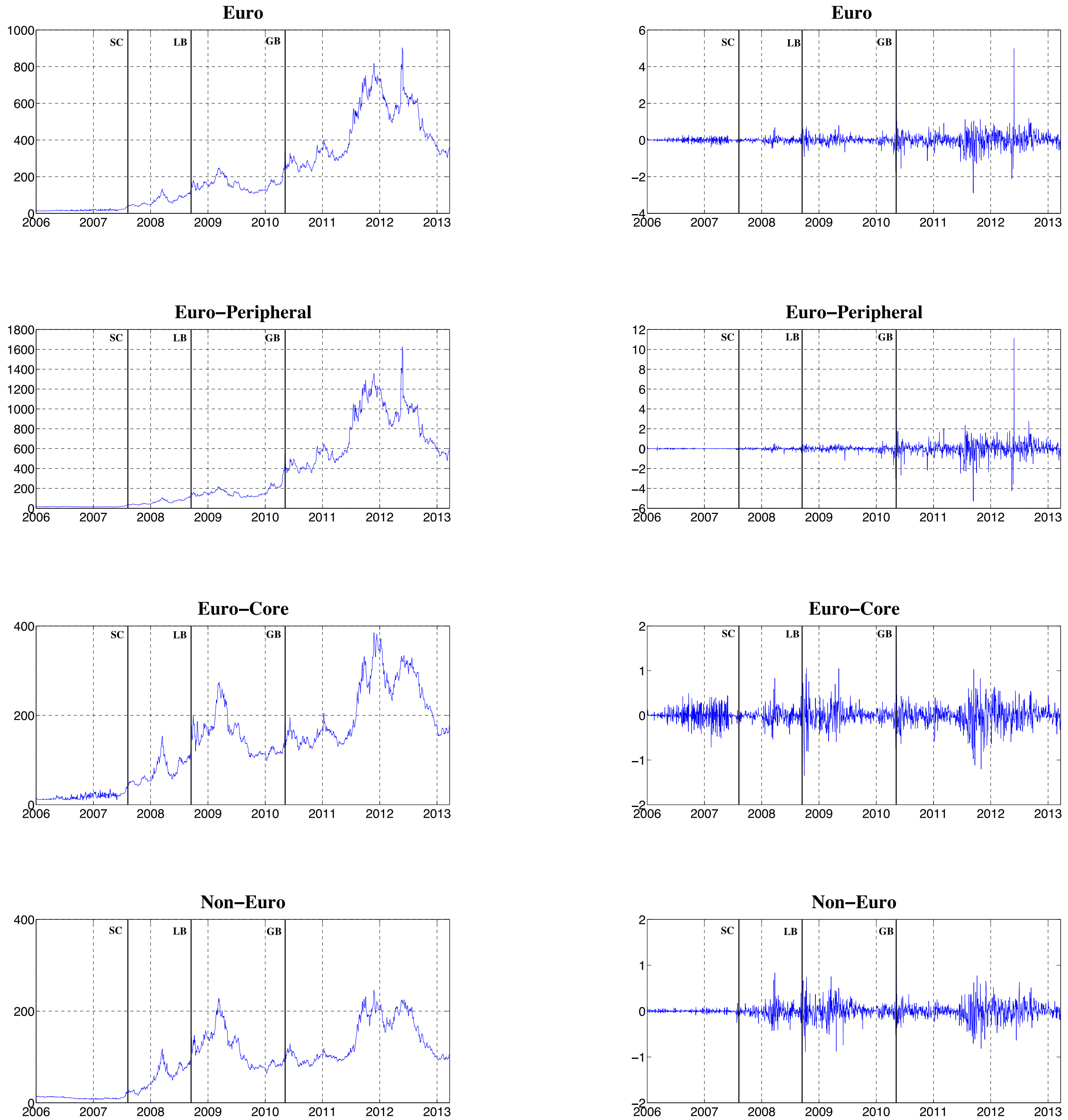
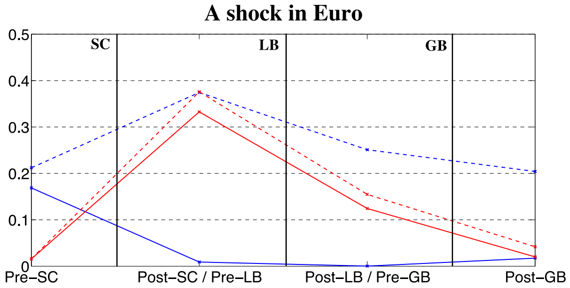


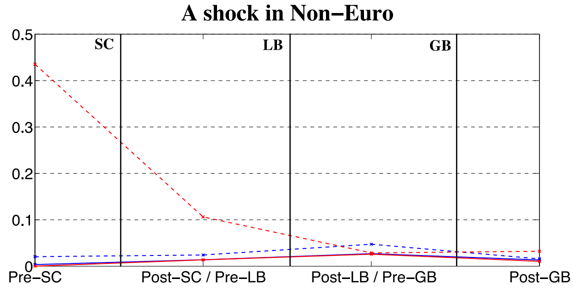
FIGURE 2: AVIRF to unexpected shocks from the VAR-Asymmetric BEKK

This figure reports the Asymmetric Volatility Impulse Response Functions for two significant values of the lead indicator *s* (that is, for *s* equals 1 and 10), and where positive and negative shocks are distinguished by a solid and dash line, respectively. The sample period is January 2006 to March 2013. The vertical black solid lines identify the burst of the subprime crisis (August 9, 2007), SC, Lehman Brothers default (September 15, 2008), LB, and Greece's bailout (May 8, 2010), GB, respectively, and they identify the four sup-periods. Panel A shows the case of Euro (in blue) and Non-Euro (in red) portfolios, and the scaling is from 0 to 0.5. Panel B presents Euro-Peripheral (in blue) and Euro-Core (in red) portfolios, and the scaling is from 0 to 0.8.

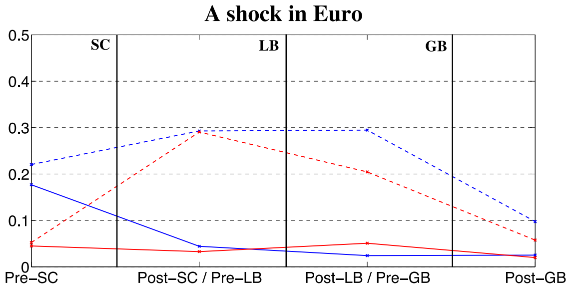
Panel A: Euro and Non-Euro portfolios

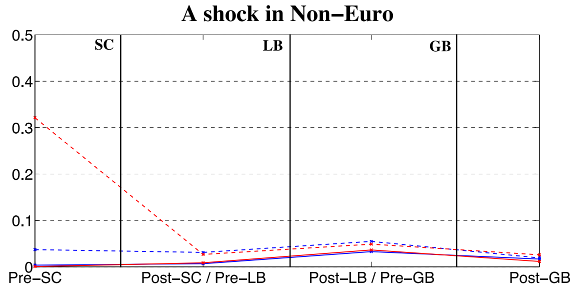
Panel A.1: *s* = 1





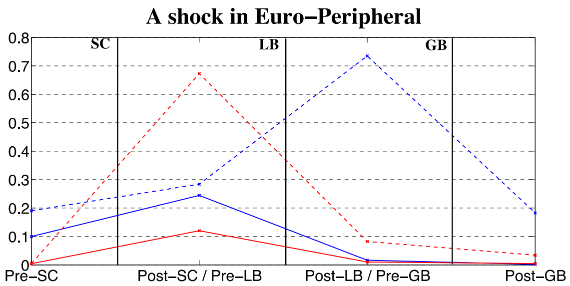
Panel A.2: *s* = 10

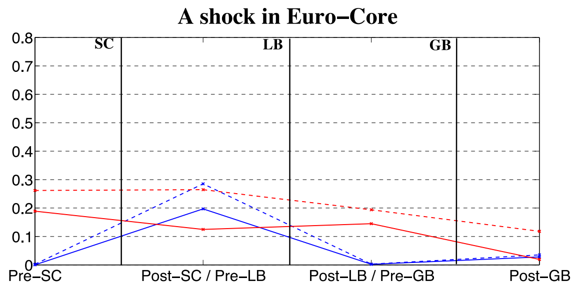




Panel B: Euro-Peripheral and Euro-Core portfolios

Panel B.1: *s* = 1





Panel B.2: *s* = 10