Using connectedness analysis to assess financial stress transmission in EMU sovereign bond market volatility

Fernando Fernández-Rodríguez[a], Marta Gómez-Puig[b] and Simón Sosvilla-Rivero[c*]
[a]Department of Quantitative Methods in Economics, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain
[b]Department of Economic Theory, Universitat de Barcelona. 08034 Barcelona, Spain
[c]Complutense Institute for International Studies, Universidad Complutense de Madrid. 28223 Madrid, Spain

Revised version
February 2016

Abstract

This paper measures the connectedness in European Economic and Monetary Union (EMU) sovereign market volatility between April 1999 and January 2014, in order to monitor stress transmission and to identify episodes of intensive spillovers from one country to the others. To this end, we first perform a static and dynamic analysis to measure the total volatility connectedness in the entire period (the system-wide approach) using a framework recently proposed by Diebold and Yılmaz (2014). Second, we make use of a dynamic analysis to evaluate the net directional connectedness for each country and apply panel model techniques to investigate its determinants. Finally, to gain further insights, we examine the time-varying behaviour of net pair-wise directional connectedness at different stages of the recent sovereign debt crisis.

Keywords: Sovereign debt crisis, Euro area, Connectedness Analysis, Market Linkages, Vector Autoregression, Variance Decomposition.

JEL Classification Codes: C53, E44, F36, G15

[*]Corresponding author. Tel.: +34 913942342; fax: +34 913942591.

E-mail addresses: ffernandez@dmc.ulpgc.es (F. Fernández-Rodríguez), marta.gomezpuig@ub.edu (M. Gómez-Puig), sosvilla@ccee.ucm.es (S. Sosvilla-Rivero)

1. Introduction

Regulatory convergence and the elimination of currency risk[1] are two of the reasons behind the significant increase in cross-border financial activity in the euro area since the beginning of the twenty-first century (see Kalemli-Ozcan *et al*., 2009 and Barnes *et al*., 2010). This effect has been even stronger in some of the EMU peripheral countries[2]. However, although cross-border banking clearly benefits risk diversification in businesses' portfolios and is considered by monetary authorities as a hallmark of successful financial integration, it also presents some drawbacks. First, foreign capital is likely to be much more mobile than domestic capital; in a crisis situation, foreign banks may simply decide to "cut and run". Moreover, in an integrated banking system, financial or sovereign crises in a country can quickly spill over into other countries. Indeed, given the high degree of interconnectedness in European financial markets, a major fear was that the default of the sovereign/banking sector in one EMU country could have spillover effects that might result in subsequent defaults in the euro area as a whole (see Schoenmaker and Wagner, 2013)[3].

In this context, an important reason and justification for providing financial support to Greece in May 2010 was precisely the "fear" of contagion (see, for instance, Constâncio, 2012), not only because there was a sudden loss of confidence among investors, who turned their attention to the macroeconomic and fiscal imbalances within EMU countries which had largely been ignored until then (see Beirne and Fratzscher, 2013), but also because several European Union banks had a particularly high exposure to Greece (see Gómez-Puig and Sosvilla-Rivero, 2013 or Vuillemey and Peltonen, 2015)[4]. As a matter of fact, tensions in EMU sovereign bond markets led to an increase in the cost of new loans and a contraction in credit which has been particularly strong in the countries most affected by the crisis. Neri and Ropele (2013) show that the higher

[1] The introduction of the Single Banking License in 1989 through the Second Banking Directive was a decisive step towards a unified European financial market, which led to a convergence in financial legislation and regulation across member countries.

[2] In particular, the sources of external financing for Portuguese and Greek banks radically shifted on joining the euro; traditionally reliant on dollar debt, their banks were subsequently able to raise funds from their counterparts elsewhere in the EMU (see Spiegel, 2009a and 2009b).

[3] Theoretical research modelling various aspects of the costs and benefits of cross-border banking (e.g. Dasgupta 2004; Goldstein and Pauzner 2004; Wagner 2010) concludes that some degree of integration is beneficial but that an excessive degree may not be.

[4] The latter authors explore risk transmission in the euro area by examining the inter-linkages between sovereign and banking risk in EMU countries caused by the high sovereign bond holdings of European banks.

cost of credit and the contraction in lending exerted a negative and significant effect on industrial production in both the peripheral and core countries.

Indeed, from late 2009 onwards, the demand for the German bund grew due its safe haven status, and yield spreads of euro area issues with respect to Germany spiralled (see Figure 1). Besides, since May 2010, not only has Greece been rescued three times, but Ireland, Portugal and Cyprus also needed bailouts to stay afloat.

[Insert Figure 1 here]

In this scenario, where we have seen how crisis episodes in a given EMU sovereign market affect other markets almost instantaneously, some important questions have emerged that economists, policymakers, and practitioners need to address urgently[5]. To what extent was the sovereign risk premium increase in the euro area during the European sovereign debt crisis due only to deteriorated debt sustainability in member countries? Did markets' degree of connectedness play any significant role in this increase?

The literature includes two groups of theories of contagion which, though not necessarily mutually exclusive (see Dungey and Gajurel, 2013), have fostered considerable debate. On the one hand, since fundamentals of different countries may be interconnected by their cross-border flows of goods, services, and capital, or common shocks may adversely affect several economies simultaneously, transmission between countries may occur. These effects are known in the literature as "spillovers" (Masson, 1999), "interdependence" (Forbes and Rigobon, 2002), or "fundamentals-based contagion" (Kaminsky and Reinhart, 2000). On the other hand, financial crises in one country may conceivably trigger crises elsewhere for reasons unexplained by macroeconomic fundamentals – perhaps because they lead to shifts in market sentiment, change the interpretation given to existing information, or trigger herding behaviour. This transmission mechanism is known in the literature as "pure contagion" (Masson, 1999).

[5] In the mid-2000s, capital flows into the euro area were particularly large and the share of foreign holdings of euro area securities increased substantially between the introduction of the euro and the outbreak of the global financial crisis. In that context, some authors (Carvalho and Fidora, 2015, among them) show that the increase in foreign holdings of euro area bonds in that period is highly associated with a reduction of euro area long-term interest rates. Conversely, in crisis times, the important decrease in foreign holdings of sovereign debt triggered a sudden rise of their yields. This is the reason why the analysis in this paper is focused in long-term sovereign bond yields, although short-term capital is usually more volatile than the long one.

In the European context, recent events have encouraged a new discussion of contagion. Unlike previous crises, in which the country responsible for spreading the shock was relatively clear, in the euro sovereign debt crisis several peripheral countries entered a fiscal crisis at roughly the same time. Actually, when a group of countries share an exchange rate agreement (a common currency in the case of the EMU countries), crises tend to be clustered. Thus, it seems reasonable that, since the economic fundamentals of euro area countries are interconnected by their cross-border flows of goods, services, and capital, other variables beyond deteriorated debt sustainability might also be at the origin of financial stress transmission.

Researchers have already studied transmission and/or contagion between sovereigns in the euro area context using a variety of methodologies (correlation-based measures, conditional value-at-risk (CoVaR), or Granger-causality approach, among others)[6]: Kalbaska and Gatkowski (2012), Metiu (2012), Caporin *et al*. (2013), Beirne and Fratzscher (2013), Gorea and Radev (2014), Gómez-Puig and Sosvilla-Rivero (2014) or Ludwig (2014) to name a few.

Nevertheless, in this paper we will focus on the interconnection between EMU sovereign debt markets by applying a methodology which has not been widely used in this area. Specifically, we will make use of Diebold and Yilmaz (2014)'s measures of connectedness (both system-wide and pair-wise) in order to contribute to the literature on international transmission mechanisms that the sovereign debt crisis in the euro area has rekindled, and to be able to answer some of the previously posed questions[7]. Diebold and Yilmaz (2014)'s connectedness framework is closely linked with both modern network theory (see Glover and Richards-Shubik, 2014) and modern measures of systemic risk (see Ang and Longstaff, 2013 or Acemoglu *et al*., 2015) and has been used by Diebold and Yilmaz (2015) for defining, measuring, and monitoring connectedness in financial and related macroeconomic environments (cross-firm, cross-asset, cross-market, cross-country, etcetera). The degree of connectedness, on the other hand, measures the contribution of individual units to systemic network events, in a

6 See Biblio *et al*. (2012) for a review of the measures proposed in the literature to estimate those linkages.

7 The connectedness methodology has several advantages over the alternative approach of focusing on contemporaneous correlations (corrected or not for volatility). First, while correlation is a symmetrical measure, connectedness is an asymmetrical one, so the procedure provides information on the direction and magnitude of the volatility transmission (from country A to country B, from country B to country A, or both). Second, by investigating dynamic connectedness through a rolling window, we can evaluate how the strength of the connectedness evolves over time, allowing us to detect episodes of sudden and temporary increases in volatility transmission.

fashion very similar to the CoVaR of this unit (see, e. g., Adrian and Brunnermeier, 2008).

Although a substantial amount of literature has used different extensions of Diebold and Yilmaz (2012)'s previous methodology to examine spillovers and transmission effects in stock, foreign exchange, or oil markets in non-EMU countries[8], it has been scarcely applied to explore crisis transmission in the euro area. Some exceptions are Antonakakis and Vergos (2013), who examined spillovers between 10 euro area government yield spreads during the period 2007-2012; Claeys and Vašicek (2014), who examined linkages between 16 European sovereign bond spreads during the period 2000-2012; Glover and Richards-Shubik (2014), who applied a model based on the literature on contagion in financial networks to data on sovereign credit default swap spreads (CDS) among 13 European sovereigns from 2005 to 2011; and Alter and Beyer (2014), who quantify spillovers between sovereign credit markets and banks in the euro area. While the above authors apply Diebold and Yilmaz's methodology, Favero (2013) proposes an extension to Global Vector Autoregressive (GVAR) models to capture time-varying interdependence between EMU sovereign yield spreads.

Therefore, to our knowledge, not only very few papers to date have looked at the connectedness and spillover effects within euro area sovereign debt markets (in spite of its importance in order to assess whether the benefits of a sovereign bailout may outweigh its costs) but, no empirical analyses have been performed of the connectedness in sovereigns' market volatility, despite its profound importance.

In this context, the first contribution of this paper is to provide a methodological contribution and relevant empirical insights to the assessment of financial stress transmission in EMU sovereign bond market volatility. In our opinion, as volatility reflects the extent to which the market evaluates and assimilates the arrival of new information, the analysis of its pattern of transmission may provide insights into the characteristics and dynamics of sovereign debt markets. This information might help to obtain a better understanding of yield development over time, providing a barometer for the vulnerability of these markets. Secondly, the use of the connectedness' measures

[8] Awartania *et al*. (2013), Lee and Chang (2013), Chau and Deesomsak (2014) and Cronin (2014) apply this methodology to examine spillovers in the United States' markets; Yilmaz (2010), Zhou *et al*. (2012) or Narayan *et al*. (2014) focus on Asian countries; Apostolakisa and Papadopoulos (2014) and Tsai (2014) examine G-7 economies, and Duncan and Kabundi (2013) centre their analysis on South African markets.

proposed by Diebold and Yilmaz (2014) will allow us to sidestep the contentious issues associated with the definition and existence of episodes of “fundamentals-based” or “pure” contagion. Indeed, Diebold and Yilmaz (2014)’s methodology can be considered as a bridge between the two visions mentioned above since uncertainty is based on how much of the forecasting error variance cannot be explained by shocks in the variable and volatility spillovers are examined using useful information on agents’ expectations (which gauge the evolution of both fundamental and market sentiment variables). Thirdly, as volatility tracks investors’ perceived risk and is a crisis-sensitive variable which can induce “volatility surprise” (see Engle, 1993), by measuring and analyzing the dynamic connectedness in volatility we will be able to examine the “fear of connectedness” expressed by market participants as they trade.

To sum up, in this paper we explore a new challenging avenue of research, focusing our study on the analysis of connectedness in EMU sovereign debt market volatility using Diebold and Yilmaz (2014)’s methodology in order to fill the existing gap in the literature. In particular, we will focus on connectedness in EMU sovereign bond market volatility during the period from April 1999 to January 2014 and, unlike previous studies, in the analysis we will only include euro area countries and work with 10-year yields instead of spreads over the German bund, in order to be able to include Germany in the study.

Overall, our results suggest that the positive influence exerted by economically sound core countries over peripheral ones in the stability period suddenly vanished with the outbreak of the crisis, when investors disavowed the shelter that peripheral countries could find in central countries and turned their attention to the major imbalances that they presented. Consequently, during the period of stability, beside the slight differences in yield behaviour (all followed the evolution of the German bund, and spreads moved in a very narrow range) it was the central countries that triggered net connectedness relationships; in the crisis period, however, there was a major shift and this role was now played by peripheral countries. Therefore, according to our results, in a context of increased cross-border financial activity in the euro-area, the concern that in turbulent times a shock in one country might have spillover effects into others may be well founded, and global financial stability may be threatened.

The rest of the paper is organized as follows. Section 2 presents Diebold and Yılmaz (2014)’s methodology for assessing connectedness in financial market volatility, and the empirical results (both static and dynamic) obtained for our sample of EMU sovereign markets (a system-wide measure of connectedness). In Section 3 we present the empirical results regarding the evolution of net directional connectedness in each market, and explore its determinants taking into account the broad literature on sovereign spreads drivers since the outbreak of the euro area debt crisis. Section 4 examines the time-varying behaviour of net pair-wise directional connectedness at different stages of the current financial crisis. Finally, Section 5 summarizes the findings and offers some concluding remarks.

2. Connectedness analysis

2.1. Econometric methodology

The main tool for measuring the amount of connectedness is based on a decomposition of the forecast error variance, which we will now briefly describe.

Given a multivariate empirical time series, the forecast error variance decomposition results from the following steps:

1. Fit a standard vector autoregressive (VAR) model to the series.

2. Using series data up to and including time *t*, establish an *H* period-ahead forecast (up to time *t* + *H*).

3. Decompose the error variance of the forecast for each component with respect to shocks from the same or other components at time *t*.

Diebold and Yilmaz (2014) propose several connectedness measures built from pieces of variance decompositions in which the forecast error variance of variable *i* is decomposed into parts attributed to the various variables in the system. This section provides a summary of their connectedness index methodology.

Let us denote by d^{H}_{ij} the *ij*-th *H*-step variance decomposition component (i.e., the fraction of variable *i*'s *H*-step forecast error variance due to shocks in variable *j*). The connectedness measures are based on the "non-own", or "cross", variance decompositions, d^{H}_{ij}, $i, j = 1, \ldots, N, i \neq j$.

Consider an *N*-dimensional covariance-stationary data-generating process (DGP) with orthogonal shocks: $x_t = \Theta(L)u_t$, $\Theta(L) = \Theta_0 + \Theta_1 L + \Theta_2 L^2 + ...$, $E(u_t, u_t') = I$. Note that Θ_0 need not be diagonal. All aspects of connectedness are contained in this very general representation. Contemporaneous aspects of connectedness are summarized in Θ_0 and dynamic aspects in $\{\Theta_1, \Theta_2, ...\}$. Transformation of $\{\Theta_1, \Theta_2, ...\}$ via variance decompositions is needed to reveal and compactly summarize connectedness. Diebold and Yilmaz (2014) propose a connectedness table such as Table 1 to understand the various connectedness measures and their relationships. Its main upper-left *NxN* block, which contains the variance decompositions, is called the "variance decomposition matrix," and is denoted by $D^H = [d_{ij}]$. The connectedness table increases D^H with a rightmost column containing row sums, a bottom row containing column sums, and a bottom-right element containing the grand average, in all cases for $i \neq j$.

[Insert Table 1 here]

The off-diagonal entries of D^H are the parts of the N forecast-error variance decompositions of relevance from a connectedness perspective. In particular, the *gross pair-wise directional connectedness* from *j* to *i* is defined as follows:

$$C^H_{i \leftarrow j} = d^H_{ij}.$$

Since in general $C^H_{i \leftarrow j} \neq C^H_{j \leftarrow i}$, the *net pair-wise directional connectedness* from *j* to *i*, can be defined as:

$$C^H_{ij} = C^H_{j \leftarrow i} - C^H_{i \leftarrow j}.$$

As for the off-diagonal row sums in Table 1, they give the share of the *H*-step forecast-error variance of variable x_i coming from shocks arising in other variables (all others, as opposed to a single other), while the off-diagonal column sums provide the share of the *H*-step forecast-error variance of variable x_i going to shocks arising in other variables. Hence, the off-diagonal row and column sums, labelled "from" and "to" in the connectedness table, offer the total directional connectedness measures. In particular, total directional connectedness from others to *i* is defined as

$$C^H_{i \leftarrow \bullet} = \sum_{\substack{j=1 \\ j \neq i}}^{N} d^H_{ij},$$

and *total directional connectedness* from *j* to others is defined as

$$C^H_{\bullet \leftarrow j} = \sum_{\substack{i=1 \\ j \neq i}}^{N} d^H_{ji}.$$

We can also define *net total directional connectedness* as

$$C_i^H = C_{\bullet\leftarrow i}^H - C_{i\leftarrow\bullet}^H.$$

Finally, the grand total of the off-diagonal entries in D^H (equivalently, the sum of the “from" column or “to" row) measures *total connectedness*:

$$C^H = \frac{1}{N}\sum_{\substack{i,j=1 \\ j\neq i}}^{N} d_{ij}^H.$$

For the case of non-orthogonal shocks, the variance decompositions are not as easily calculated as before, because the variance of a weighted sum is not an appropriate sum of variances; in this case, methodologies for providing orthogonal innovations like traditional Cholesky-factor identification may be sensitive to ordering. So, following Diebold and Yilmaz (2014), a generalized VAR decomposition (GVD), invariant to ordering, proposed by Koop *et al.* (1996) and Pesaran and Shin (1998) will be used. The *H*-step generalized variance decomposition matrix is defined as $D^{gH} = \left[d_{ij}^{gH} \right]$, where

$$d_{ij}^{gH} = \frac{\sigma_{jj}^{-1}\sum_{h=0}^{H-1}\left(e'_i \Theta_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1}\left(e'_i \Theta_h \Sigma \Theta'_h e_j\right)}$$

In this case, e_j is a vector with *j*th element unity and zeros elsewhere, Θ_h is the coefficient matrix in the infinite moving-average representation from VAR, Σ is the covariance matrix of the shock vector in the non-orthogonalized-VAR, σ_{jj} being its *j*th diagonal element. In this GVD framework, the lack of orthogonality means that the rows of d_{ij}^{gH} do not have sum unity and, in order to obtain a generalized connectedness index $\tilde{D}^g = \left[\tilde{d}_{ij}^g \right]$, the following normalization is necessary: $\tilde{d}_{ij}^g = \frac{d_{ij}^g}{\sum_{j=1}^{N} d_{ij}^g}$, where by construction $\sum_{j=1}^{N} \tilde{d}_{ij}^g = 1$ and $\sum_{i,j=1}^{N} \tilde{d}_{ij}^g = N$

The matrix $\tilde{D}^g = \left[\tilde{d}_{ij}^g \right]$ permits us to define similar concepts as defined before for the orthogonal case, that is, *total directional connectedness*, *net total directional connectedness*, and *total connectedness.*

2.2. Data

We use daily data of 10-year bond yield collected from the Thomson Reuters Datastream for eleven EMU countries: both central (Austria, Belgium, Finland, France, Germany and the Netherlands) and peripheral countries (Greece, Ireland, Italy, Portugal and Spain). Our sample begins on 1 April 1999 and ends on 27 January 2014 (i.e., a total of 3,868 observations)[9], spanning several important financial market episodes in addition to the crisis of 2007-2008 – in particular, the euro area sovereign debt crisis from 2009 onwards. Following Parkinson (1980), we estimate the daily variance using daily high and low prices[10]. For market i on day t we have

$$\tilde{\sigma}_{it}^{2} = 0.36[\ln(P_{it}^{MAX}) - \ln(P_{it}^{MIN})]^{2}. \qquad (10)$$

where P_{it}^{MAX} it is the maximum (high) price in market I on day t, and P_{it}^{MIN} is the daily minimum (low) price. Given that $\tilde{\sigma}_{it}^{2}$ is an estimator of the daily variance, the corresponding estimate of the annualized daily percent standard deviation (volatility) is $\hat{\sigma}_{it}^{2} = 100\sqrt{365\tilde{\sigma}_{it}^{2}.}$

2.3. Static (full-sample, unconditional) analysis

The full-sample connectedness table appears as Table 2. As mentioned above, the *ij*th entry of the upper-left 11x11 country submatrix gives the estimated *ij*th pair-wise directional connectedness contribution to the forecast error variance of country *i*'s volatility yields coming from innovations to country *j*. Hence, the off-diagonal column sums (labelled TO) and row sums (labelled FROM) gives the total directional connectedness to all others from *i* and from all others to *i* respectively. The bottom-most row (labelled NET) gives the difference in total directional connectedness (to-from). Finally, the bottom-right element (in boldface) is total connectedness.

[Insert Table 2 here]

As can be seen, the diagonal elements (own connectedness) are the largest individual elements in the table, but total directional connectedness (from others or to others) tends to be much larger, except for the EMU peripheral countries. In addition, the spread of

[9] The sample starts in April 1999 since data for Greece are only available from that date onwards.

[10] We also used the absolute standardized log-return and the squared returns as alternative measures of daily volatility, being the results qualitatively similar.

the “from” degree distribution is noticeably greater than that of the “to” degree distribution for six out of the eleven cases under study.

Regarding pair-wise directional connectedness (the off-diagonal elements of the upper-left 11 × 11 submatrix), the highest observed pair-wise connectedness is from Italy to Spain (34.03%). In return, the pair-wise connectedness from Spain to Italy (25.27%) is the second-highest. The highest value of pair-wise directional connectedness between EMU central countries is from France to Austria (20.03%), followed by that from France to the Netherlands (18.85%). The total directional connectedness from others, which measures the share of volatility shocks received from other bond yields in the total variance of the forecast error for each bond yield, ranges between 7.34% (Greece) and 79.95% (Germany). As for the total directional connectedness to others, our results suggest that it varies from a low of 13.17% for Greece to 78.58% for Finland: a range of 65.41 points for connectedness to others, lower than the range of 72.61 points found for connectedness from others. Finally, we obtain a value of 54.23% for the total connectedness between the eleven countries under study for the full sample (system-wide measure) – significantly lower than the value of 78.3% obtained by Diebold and Yilmaz (2014) for US financial institutions, or the 97.2% found by Diebold and Yilmaz (2012) for international financial markets.

Given the likelihood of structural breaks during the sample period (see below) we provide a separate analysis for connectedness by sub-sampling the data into pre-crisis and crisis period (Tables 3 and 4)[11].

[Insert Tables 3 and 4 here]

As can be seen, there is a reduction in the values of the diagonal elements presented in Table 3 with respect to those reported in Table 2, while the opposite is true in seven out of eleven cases when comparing Table 4 with Table 2. This suggests a relative lower own connectedness before the crisis (being notable for Greece, Italy, Ireland and Spain) and a relative higher own connectedness during the crisis (especially in the cases of Portugal, Ireland and Germany) [12]. Furthermore, our results indicate a reduction in both the total directional connectedness from others and to others in the crisis period with respect to the pre-crisis period, being remarkable in the cases of peripheral countries.

[11] As it is shown in the next sub-Section, the pre-crisis period span from January 2000 till April 2009, whilst the crisis one goes from April 2009 till the end of the sample (January 2014).

[12] The interested reader is asked to browse through Tables 2 to 4 to find evidence for a particular country.

Finally, observe that the measure of total connectedness among the volatility of the eleven bond yields under study is higher before the crisis (86.35%) than during the crisis (49.97%).

2.4 Dynamic (rolling, conditional) analysis

The full-sample connectedness analysis provides a good characterization of "unconditional" aspects of the connectedness measures. However, it does not help us to understand the connectedness dynamics. The appeal of connectedness methodology lies in its use as a measure of how quickly return or volatility shocks spread across countries as well as within a country. This section presents an analysis of dynamic connectedness which relies on rolling estimation windows[13].

The dynamic connectedness analysis starts with total connectedness, and then moves on to net directional connectedness across countries in Section 3.

2.4.1. Total connectedness

In Figures 1 to 3 we plot total volatility connectedness over 200-day rolling-sample windows and using 10 days as the predictive horizon for the underlying variance decomposition. In Figure 1 the rolling total connectedness within the 11 countries in our sample is plotted along with the evolution of daily 10-year sovereign yields, while in Figures 2 and 3 it is plotted separately and for three groups of countries: all 11 EMU countries under study, EMU central countries, and EMU peripheral countries. The reason for splitting the sample into these two groups is that, based on a country-by-country analysis, it can be concluded that EMU countries under study are not homogeneous but comprise two categories[14].

In Figure 1, we can identify two distinct periods in the evolution of the total level of connectedness, which coincide with the evolution of 10-year yields. In the first period (which we will term the "stability period"), the level of connectedness within the 11 EMU sovereign debt markets in our sample is high, matching the close evolution of 10-year yields (the spreads moved in a narrow range and reached values close to zero). Neither the US subprime crisis of August 2007 nor the Lehman Brothers Collapse of September 2008 seemed to have a substantial effect on euro area sovereign debt markets

[13] Diebold and Mariano (2015) argue that the use of rolling-sample estimation has the advantages of being both tremendously simple to implement and coherent with a wide variety of possible data-generating process involving time-varying parameters, providing results that are generally intuitive and informative.

[14] We are grateful to an anonymous referee for suggesting the rolling analysis for these groups of countries. The classification of EMU central and peripheral countries follows the standard division presented in the literature.

and their high level of connectedness. However, when looking at the evolution of the level of connectedness for the different groups of countries (Figure 2) it can be observed that, whilst the above statement is still true for central countries, the degree of connectedness within peripheral countries began its downward trend coinciding with the Global Financial Crisis in 2007-2008. Moreover, Figure 2 also reveals that the crisis causes a decrease in the level of connectedness much higher within peripheral than within central countries.

In April 2009, coinciding with a statement by the European Central Bank (ECB) expressing its fears of a slowdown in financial market integration, and only some months before Papandreou's government announced Greece's distressed debt position (November 2009)[15], sovereign yields begin to spiral and total connectedness, not only within the 11 countries in the sample, but also within central countries began a downturn trend. From then on, in parallel with the increase in sovereign yields, connectedness decreased and entered a different regime.

[Insert Figure 2 here]

Moreover, the existence of two different regimes in the evolution of connectedness[16] and the abrupt decrease in the mean in the second regime may explain the low value (54.23%) obtained for the total connectedness (system-wide measure) between the eleven countries studied over the full period. Indeed, during the pre-crisis period (Table 3) the total value of connectedness is 86.35 while it takes a value of 49.47 during the crisis period (Table 4). Therefore, since the second regime coincides with the euro area sovereign debt crisis, we will focus our analysis on this period (denoted as the crisis period and spanning from April 2009 to January 2014) which has been split into five sub-periods.

[Insert Figure 3 here]

The first sub-period (a), which spans from June 2009 until April 23, 2010 (when Greece requested financial support), can still be defined as a pre-crisis period, since the downtrend in the total level of connectedness in euro area sovereign debt markets is

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[15] In November 2009, Papandreou's government disclosed that its financial situation was far worse than it had previously announced, with a yearly deficit of 12.7% of GDP – four times more than the euro area's limit, and more than double the previously published figure – and a public debt of $410 billion. We should recall that this announcement only served to worsen the severe crisis in the Greek economy; the country's debt rating was lowered to BBB+ (the lowest in the euro zone) on 8 December. These episodes marked the beginning of the euro area's sovereign debt crisis.

[16] Formal mean and volatility tests (not shown here to save space, but available from the authors upon request) strongly reject the null hypothesis of equality in mean and variance before and after 6 April 2009.

suddenly reversed when it is analysed within all countries and central countries. However, during sub-periods (b) and (c) this downtrend deepens for the three groups of countries. Indeed, sub-period (b) – from April 2010 to August 2011 – was a time of real turbulence in EMU sovereign debt markets: rescue packages were put in place not only in Greece (May 2010), but also in Ireland (November 2010) and Portugal (April 2011), and at the end of it (August 2011) the ECB announced its second covered bond purchase program. As noted, the uncertainty continued in European debt markets during sub-period (c) (August 2011 - July 2012). During this phase (the level of connectedness reaches its lowest values for the three groups of countries), Italy was in the middle of a political crisis and the main rating agencies lowered the ratings not only of peripheral countries but of Austria and France as well. In this context of financial distress and huge liquidity problems, the ECB responded forcefully (along with other central banks) by implementing nonstandard monetary policies – that is, policies that went further than setting the refinancing rate. In particular, the ECB's principal means of intervention were the so-called long term refinancing operations (LTRO) [17]. In November 2011 and March 2012, the ECB provided banks with a sum close to 500 billion Euros for a three-year period. However, in March 2012 the second rescue package to Greece was approved, and in June 2012 Spain requested financial assistance to recapitalize its banking sector. This was the backdrop to the ECB's President Mario Draghi's statement that he would do "whatever it takes to preserve the euro". Sub-period (d), which starts after that statement in July 2012, clearly reflects the healing effects of Draghi's words since a substantial increase in the level of total connectedness can be observed in the three groups of EMU sovereign debt markets. Nonetheless, our indicator definitely registered a new slowdown (within all countries and peripheral ones) in March 2013, when Cyprus requested financial support. Therefore, the last sub-period (e) spans from that date to the end of the sample (January 2014).

[17] When the crisis struck, big central banks like the US Federal Reserve slashed their overnight interest-rates in order to boost the economy. However, even cutting the rate as far as it could go (to almost zero) failed to spark recovery. The Fed then began experimenting with other tools to encourage banks to pump money into the economy. One of them was Quantitative Easing (QE). To carry out QE, central banks create money by buying securities, such as government bonds, from banks, with electronic cash that did not exist before. The new money swells the size of bank reserves in the economy by the quantity of assets purchased—hence "quantitative" easing. In the euro area, the principal means of intervention adopted by the ECB was the LTRO, which differed notably from the QE policies of the Federal Reserve, in which the Fed purchased assets outright rather than helping to fund banks' ability to purchase them. The LTRO is not the only non-standard monetary policy to have been implemented by the ECB since the crisis. Other measures were the narrowing of the corridor, the change in eligibility criteria for collateral, interventions in the covered bonds market and, most importantly, the ECB's launch of the security market program in 2010 involving interventions in the secondary sovereign bond market. The latter program was discontinued in 2011.

3. Net directional connectedness

The net directional connectedness index provides information about how much each country's sovereign bond yield volatility contributes in net terms to other countries' sovereign bond yield volatilities and, like the full sample dynamic measure presented in the previous section, also relies on rolling estimation windows. The time varying-indicators are displayed in Figures 4a and 4b for central and peripheral EMU countries respectively.

[Insert Figures 4a and 4b here]

Regarding the whole sample, it is noticeable that in three cases [the Netherlands and Finland (see Figure 4a) along with Portugal (see Figure 4b)], more than 50% of the computed values are positive, indicating that during most of the sample period, their bond yield volatility influenced that of the rest of EMU countries, whereas for the remaining countries the opposite is true (i.e., they are net receivers during most of the period). Interestingly, for Germany we obtain negative values in 84% of the sample. When we split the sample into stability and crisis periods, a different picture emerges. Before the crisis, with the exception of Portugal, net triggers were mainly central countries, with a percentage of positive values of 85%, 75%, 65%, 61% and 58% for the Netherlands, Finland, Belgium, Austria and France, respectively (see Figure 4a). However, during the crisis period, these countries became net receivers, with negative values of 100%, 99%, 98%, 95% and 92% for France, Finland, Belgium, Netherlands and Austria respectively. In this second period, Germany also appears as a net receiver with a negative value of 100%. Regarding peripheral countries (Figure 4b), four of the five countries studied were net receivers during the stability period, with negative values of 78%, 57%, 55% and 52% in the cases of Greece, Ireland, Spain and Italy respectively; during the crisis period Greece and Portugal became net triggers, with positive values of 99% and 52% respectively.

3.1 Determinants of net directional connectedness

3.1.1 Econometric methodology

After evaluating net directional connectedness, similarly to Ureche-Rangau and Burietz (2013) and Afonso and Nunes (2015), we use panel model techniques to analyse their determinants. We should remark that the recent European sovereign debt crisis has spurred academics to try to identify the drivers of sovereign risk in the euro area in order to help policy makers to react to similar challenges in the future. So, the analysis in this Section draws from this important literature background.

Indeed, a wide literature re-emerged with the euro debt crisis, reviving and extending, in many cases, the already existing literature on this topic in the context of emerging markets. The works by Bunda *et al.* (2009), Özatay *et al*. (2009), Comelli (2012), Piljak (2013), Riedel *et al*. (2013), Cifarelli and Paladino (2014), Csontó (2014), and Zinna (2014) are some examples of the broad literature that analyzes sovereign bond spreads on emerging economics. Some of the variables included in these authors' analysis are the relative role of global financial conditions and domestic fundamentals [Bunda *et al*. (2009), Banerji *et al.* (2014), Cifarelli and Paladino (2014), Özatay *et al*. (2009), and Zinna (2014)]; the time-varying nature of spreads determinants in crises periods compared to non-crisis times (Comelli, 2012 and Csontó, 2014); or the relevance of variables reflecting uncertainty, confidence conditions and perceptions for the upcoming economic activity (Piljak, 2013 and Riedel *et al*., 2013) in explaining sovereign spreads behavior.

Regarding developed countries, Ureche-Rangau and Burietz (2013) present empirical evidence that stress the importance of global financial conditions by showing the existence of a statistically significant link between the US subprime crisis and the euro debt crisis that might explain why the latter immediately followed the former. Afonso and Nunes (2015) focus their analysis on the relevance of perceptions about the upcoming economic activity in explaining sovereign spreads behavior. In particular, these authors find that corrections in the European Commission forecasts impinge on 10-year sovereign bond yields, particularly corrections in fiscal variables, being more pronounced in countries with less favorable economic conditions. Whilst the time-varying nature of spreads determinants in crises periods is explored by Afonso *et al.* (2015), whose findings suggest that the relationship between euro area sovereign risk and the underlying fundamentals is strongly time-varying, turning from inactive to active since the onset of the global financial crisis and further intensifying during the sovereign debt crisis. As a general rule, they outline that the set of financial and macro spreads' determinants in the euro area is, not only rather unstable, but it also generally becomes richer and stronger in significance as the crisis evolves.

Consequently, in this Section, in order to be able to empirically evaluate the relevance of the highest number of variables that have been proposed in the recent theoretical and empirical literature as potential drivers of EMU sovereign bond yields, we will adopt an eclectic approach and apply a general-to-specific modelling strategy to capture them. Besides, since the potential determinants are available at monthly or quarterly frequency, we generate a new dependent variable by computing the monthly average of the daily net directional connectedness for each country.

3.1.2. Instruments for modelling net directional connectedness

Following the recent literature, we consider two groups of potential determinants of net directional connectedness: macroeconomic fundamental variables, and indicators of market sentiments. Regarding the macro-fundamentals, we use measures of the country's fiscal position (the government debt-to-GDP and the government deficit-to-GDP, DEB and DEF hereafter), the overall outstanding volume of sovereign debt (which is considered a good proxy of liquidity differences among markets, LIQ)[18], the current-account-balance-to-GDP ratio (CAC) as a proxy of the foreign debt and the net position of the country towards the rest of the world, and the Harmonized Index of Consumer Prices monthly inter-annual rate of growth (as a measure of inflation, INF and the country's loss of competitiveness). With respect to market sentiment proxies, we use the consumer confidence indicator (CCI) to gauge economic agents' perceptions of future economic activity, and the monthly standard deviation of equity returns (VOL) in each country to capture local stock market volatility[19]. A summary with the definition and sources of all the explanatory variables used is presented in Appendix A.

3.1.3. Empirical results

Once the net directional connectedness has been calculated based in our empirical strategy, and given that the potential determinants have been constructed on a monthly frequency, we define a new dependent variable as the monthly average of the daily values of the net computed directional connectedness.

In order to establish the relevant determinants of net directional connectedness, we employ a data-based method for obtaining parsimony representation of the data

[18] Given the large size differences observed between EMU peripheral sovereign debt markets (see Gómez-Puig and Sosvilla-Rivero, 2013), it is likely that the overall outstanding volume of sovereign debt (which is considered a measure of market depth because larger markets may present lower information costs since their securities are likely to trade frequently, and a relative large number of investors may own or may have analyzed their features) might be a good proxy of liquidity differences between markets. Indeed, some of the literature suggests that market size is an important factor in the success of a debt market. Nevertheless, there is another reason to choose this variable: it might capture an additional benefit of large markets to the extent that the ''too big to fail theory'' (TFTF), taken from the banking system, might also hold in sovereign debt markets.

[19] We would expect a positive relationship between the variables CAC, LIQ and CCI with net directional connectedness; whereas the relationship would be negative for the variables DEB, DEF, INF and VOL.

generation process: the general-to-specific approach (Hendry, 1995). General-to-specific modelling seeks to mimic reduction by commencing from a general congruent specification that is simplified to a minimal representation consistent with the desired criteria and the data evidence. Starting from a general congruent model that contains all the effects likely to be relevant (see Appendix A), standard testing procedures eliminate statistically-insignificant variables, with diagnostic tests checking the validity of reductions, ensuring a congruent final selection that renders a parsimonious and interpretable econometric model that is data admissible, presents well-behaved residuals and uses conditioning variables that are weakly exogenous (see Faust and Whiteman, 1997)[20].

Tables 5 to 7 show the final results for the three groups of countries under study: all 11 EMU countries in our sample, EMU central countries, and EMU peripheral countries throughout the sample period: 2000:01-2014:01. This division makes it possible to differentiate the impact of potential determinants on bond spreads in core and peripheral countries. We report only the results obtained using the relevant model in each case: the Random Effects (RE) model in the case of all EMU countries and peripheral EMU countries; and the Fixed Effects (FE) model for the central EMU countries[21,22].

[Insert Tables 5 to 7 here]

The first column in these tables do not take into account the dynamic properties of net directional connectedness; they show the results for the whole period (pre-crisis and crisis) in order to select the best model for use in the rest of the analysis after having eliminated statistically insignificant variables. However, since we have previously detected a potential structural change in April 2009, we analyse the differences in the significance of the coefficients over time (i.e., during the stability and the crisis periods).

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[20] Phillips (1988) contends that the general-to-specific methodology performs a set of corrections that make it an optimal procedure under weak exogeneity.

[21] We consider three basic panel regression methods: the fixed-effects (FE) method, the random effects (RE) model and the pooled-OLS method. In order to determine the empirical relevance of each of the potential methods for our panel data, we make use of several statistic tests. In particular, we test FE versus RE using the Hausman test statistic to test for non-correlation between the unobserved effect and the regressors. To choose between pooled-OLS and RE, we use Breusch-Pagan's Lagrange multiplier test to test for the presence of an unobserved effect. Finally, we use the F test for fixed effects to test whether all unobservable individual effects are zero, in order to discriminate between pooled-OLS and RE. To save space, we do not show here these tests. They are available from the authors upon request.

[22] In the case of the FE model, we make use of Arellano (1987)'s proposal to adjust White standard errors to account for the possible correlation within a cluster. Petersen (2008) examines the sensitivity of standard error estimates to the presence of a firm fixed effect (in our case, country fixed effects), showing that OLS, the Fama-MacBeth standard errors and the Newey-West standard error are biased and only clustered standard errors are unbiased as they account for the residual dependence created by the firm effect.

Therefore, in addition to the independent variables chosen a dummy (DCRISIS), which takes the value 1 in the crisis period (and 0, otherwise) is also introduced in the estimations, and the coefficients of the interactions between this dummy and the rest of variables are calculated (see Gómez-Puig, 2006 and 2008). Thus, the impact of each independent variable is given by:

$\beta = \beta_1 + \beta_2$DCRISIS

We honestly think that a formal coefficient test H_0: $\beta_1 = \beta_1 + \beta_2$, to assess whether the impact of independent variables on net directional connectedness changed significantly with the start of the sovereign debt crisis is unnecessary as long as β_2 is significant. So the marginal coefficients of a variable are:

$\beta = \beta_1$ (in the stability period)

$\beta = \beta_1 + \beta_2$ (in the crisis period)

The second column in Tables 5 to 7 shows the re-estimation results with the DCRISIS dummy. Looking across the columns in these tables we see that, when examining the variables measuring market sentiment in all eleven countries (Table 5) we find a negative and significant effect for the stock-market volatility (VOL), whereas, as expected, the consumer confidence indicator (CCI) presents a positive sign. As for the local macro-fundamentals, our results suggest a negative impact on the net directional connectedness of variables measuring the fiscal position (both the debt and the deficit-to-GDP). Moreover, without exception, all coefficients register an increase in the crisis period compared to the pre-crisis one. This rise in the sensitivity to both fundamentals and market sentiment during the crisis period compared with the pre-crisis is in line with the previous empirical literature (see Gómez-Puig *et al.*, 2014 and Afonso *et al.*, 2015, among others).

Our analysis also highlights the differences between the two groups of EMU countries, central and peripheral. In net directional connectedness episodes triggered by peripheral countries, variables that gauge market participants' perceptions seem to present a higher relevance, while macroeconomic fundamentals seem to play a greater role in relationships where central countries are the triggers. In the latter case (see Table 6), three variables gauging macroeconomic fundamentals are significant with the expected sign (the loss of competitiveness (INF), the Government debt-to-GDP (DEB) and the net position towards the rest of the word (CAC)); whilst in the former (see Table 7) only the variable that captures the government deficit-to-GDP (DEF) turns out to be significant. With regard to the variables measuring market sentiment, in the two sub-samples we find a negative and significant effect for stock-market volatility (VOL), whereas, as expected, the consumer confidence indicator (CCI) presents a positive sign[23]. Again, without exception, for the two groups of countries all coefficients register an increase during the crisis compared to the pre-crisis period.

Therefore, our results indicate that the crisis had a significant impact on the markets' reactions to financial news, especially in the peripheral countries. In this respect, some authors have argued that the financial crisis might spread from one country to another due to market imperfection or the herding behaviour of international investors. A crisis in one country may give a "wake-up call" to international investors to reassess the risks in other countries; uninformed or less informed investors may find it difficult to extract the signal from the falling price and follow the strategies of better informed investors, thus generating excess co-movements across the markets. The findings presented by Beirne and Fratscher (2013), for instance, also indicate that for some EMU countries such as peripheral countries there is strong evidence of this "wake-up call" contagion, though for other countries there is much less evidence of this kind since the relevance of macroeconomic fundamentals is higher.

4. Net pair-wise directional connectedness

So far, we have discussed the behaviour of the total connectedness and total net directional connectedness measures for eleven EMU sovereign debt markets. However, in order to gain further insights, we have also examined their net pair-wise directional connectedness.

[Insert Figures 5a and 5b here]

Specifically, Figure 5a displays net pair-wise directional connectedness during the two detected regimes, whilst Figure 5b presents the results obtained during the five sub-periods into which the crisis period has been divided.

Both figures present very interesting results. Figure 5a shows that while in the stability period central countries are the triggers in the connectedness relationships, in the crisis regime, these relationships are stronger when the trigger is a peripheral country. These

[23] The only variable that does not turn out to be significant in any of the estimations is our proxy for the market liquidity.

results corroborate those presented in Figure 4 where we plotted net dynamic directional connectedness in both core and peripheral countries.

In particular, in the stability period, connectedness relationships departing from central countries accounted for 75% of the total, and in the tenth and twentieth percentile all the receiver countries are peripheral (Greece, Ireland and Italy). Conversely, in the crisis period, the connectedness relationships account for 59% of the total when peripheral countries are the triggers (in the tenth and twentieth percentile, only three relationships are detected departing from central countries), and although receivers are mostly peripheral, central countries still account for 41% of the total.

These results are very illuminating since they reinforce the idea that during the first ten years of currency union, investors' risk aversion was very low since they overestimated the healing effect that economically sound central countries might have on the rest of the Eurozone. However, the situation radically changed with the advent of the crisis; suddenly, market participants focused their attention on the substantial macroeconomic imbalances that some peripheral countries presented which not only would eventually lead them to default, but might also affect central countries that held important shares of the sovereign assets of those countries (the results suggest that both peripheral and central countries are net receivers of the connectedness relationships that mainly depart from peripheral countries).

Moreover, the main conclusions that can be drawn from Figure 5b, which displays the evolution of the net pair-wise directional connectedness during the five crisis sub-periods, are the following.

During sub-period (a), the period just before the beginning of the euro-area sovereign debt crisis (marked by Papandreou's disclosure of Greece's distressed public finances in November 2009), we not only detect a significant number (25) of net pair-wise relationships, but in 72% of the cases central countries are still the triggers. However, an important difference with respect to the pre-crisis period is that peripheral countries carry less weight as receivers. In this sub-period, they account for 60% of the total, while the rest (40%) are central countries, showing that the effects of the crisis have clearly extended to the central countries.

Nonetheless, the situation radically changes in sub-period (b), which includes the bail-outs of Greece, Ireland and Portugal. In this phase not only does the number of connectedness relationships decrease from 25 to 14, but their direction changes as well. In this second sub-period of the crisis, net pair-wise connectedness relationships mainly occur between peripheral countries, which have a weight of around 71% both as triggers and as receivers. Besides, it is worth noting that during this phase two central countries remain disconnected from the rest: the Netherlands and Finland. During sub-period (c), which includes the support to the Spanish banking sector, Figure 3 shows that the total level of connectedness still registers a downturn trend; but although the number of connectedness relationships remains low (15), the amount detected in the tenth percentile clearly increases (up to 80%). Another significant development is the fact that central countries recover their role in the relationships as both triggers and receivers (67% of the total).

However, after Mario Draghi's statement in July 2012 (sub-period d), a clear shift is observed. Now, net pair-wise relationships rise to 33 (even more than in sub-period (a)) and not only is the role of central countries as triggers stressed (they represent 76% of the total), but peripheral countries also recover their role as receivers, returning to the level of the pre-crisis period (64%). Finally, in the last sub-period (which begins with the rescue of Cyprus), we again observe a decrease in the number of pair-wise connectedness relationships; however, the majority of them take place between peripheral countries, both as triggers (53% of the total) and as receivers (65%).

5. Concluding remarks.

The contribution of the empirical analysis presented in this paper to the existing literature is twofold.

First, our results support the hypothesis that peripheral countries imported credibility from central countries during the first ten years of EMU. Nevertheless, the outbreak of the crisis ushered in a sudden shift in the sentiment of market participants who now paid more attention to the significant macroeconomic imbalances in some of the peripheral countries and the possibility of contagion to central countries.

Secondly, they suggest that the sovereign risk premium increase in the euro area during the European sovereign debt crisis was not only due to deteriorated debt sustainability in member countries, but also to a shift in the origin of connectedness relationships which, as the crisis unfolded, mostly departed from peripheral countries. In this context, where cross-border financial activity was very important and market sentiment indicators played a key role in explaining connectedness relationships triggered by peripheral countries, the risk that the default of the sovereign/banking sector in one of these countries might spread to other countries could not be disregarded by financial authorities and policymakers with responsibility for ensuring financial stability.

A natural extension of the analysis presented in this paper would be to explore the implications of connectedness in the context of fixed income portfolios, using some trading strategies that directly utilize connectedness' information on risk diversification (the higher the degree of connectedness the lower the opportunities to diversify risk). This is an item in our future research agenda.

Appendix A: Definition of the explanatory variables to model net directional connectedness

A.1. Variables that measure local macro-fundamentals.

Variable	Description	Source
Net position vis-à-vis the rest of the world (CAC)	Current-account-balance-to-GDP Monthly data are linearly interpolated from quarterly observations.	OECD
Competitiveness (INF)	Inflation rate. HICP monthly inter-annual rate of growth	Eurostat
Fiscal Position (DEB and DEF)	Government debt-to-GDP and Government deficit-to-GDP. Monthly data are linearly interpolated from quarterly observations.	Eurostat
Market liquidity (LIQ)	Domestic Debt Securities. Public Sector Amounts Outstanding (billions of US dollars) Monthly data are linearly interpolated from quarterly observations.	BIS Debt securities statistics. Table 18

A.2. Variables that measure local market sentiment.

Variable	Description	Source
Stock Volatility (VOL)	Monthly standard deviation of the daily returns of each country's stock market general index	Datastream
Consumer Confidence Indicator (CCI)	This index is built up by the European Commission which conducts regular harmonised surveys to consumers in each country.	European Commission (DG ECFIN)

Acknowledgements

The authors thank the insightful comments of two anonymous referees and the editor that have helped to substantially improve this paper. We also thank Maria del Carmen Ramos-Herrera and Manish K. Singh for excellent research assistance. Simón Sosvilla-Rivero thanks the Universitat de Barcelona and RFA-IREA for their hospitality. This paper is based upon work supported by the Government of Spain and FEDER under grant numbers ECO2011-23189 and ECO2013-48326.

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Table 1: Schematic connectedness table

	x_1	x_2	...	x_N	**Connectedness from others**
x_1	d_{11}^H	d_{12}^H	...	d_{1N}^H	$\sum_{j=1}^N d_{1j}^H, j \neq 1$
x_2	d_{21}^H	d_{22}^H	...	d_{2N}^H	$\sum_{j=1}^N d_{2j}^H, j \neq 2$
.	.	.	.		
.	.	.	.		
.	.	.	.		
x_N	d_{N1}^H	d_{N2}^H	...	d_{NN}^H	$\sum_{j=1}^N d_{Nj}^H, j \neq N$
Connectedness to others	$\sum_{i=1}^N d_{i1}^H$, $i \neq 1$	$\sum_{i=1}^N d_{i2}^H$, $i \neq 2$	...	$\sum_{i=1}^N d_{iN}^H$, $i \neq N$	$\frac{1}{N}\sum_{i,j=1}^N d_{iN}^H$, $i \neq N$

Table 2: Full-sample connectedness

	GER	FRA	ITA	SPA	NET	BEL	AUS	GRE	FIN	POR	IRE	**Contribution From Others**
GER	20.05	18.39	2.83	1.34	17.09	9.79	13.04	0.08	17.20	0.07	0.12	79.95
FRA	10.38	29.44	1.10	0.29	14.93	13.11	15.48	0.41	14.71	0.09	0.07	70.56
ITA	0.52	0.36	68.00	25.27	0.67	3.08	0.30	0.00	0.76	0.13	0.90	32.00
SPA	0.22	0.03	34.03	61.69	0.20	1.69	0.08	0.08	0.34	0.38	1.26	38.31
NET	12.24	18.85	2.74	0.50	20.64	12.72	14.75	0.01	17.38	0.16	0.02	79.36
BEL	4.89	10.26	12.36	4.91	8.97	41.10	8.48	0.34	8.41	0.10	0.16	58.90
AUS	9.13	20.03	1.06	0.19	15.11	14.00	23.83	0.55	15.93	0.16	0.01	76.17
GRE	0.10	0.23	2.89	2.13	0.10	0.12	0.01	92.66	0.03	1.05	0.67	7.34
FIN	12.09	18.65	3.23	1.04	17.09	11.55	15.74	0.10	20.39	0.09	0.03	79.61
POR	0.01	0.37	10.13	13.34	0.04	0.04	0.36	10.44	0.04	54.45	10.80	45.55
IRE	0.07	0.36	8.28	10.23	0.00	1.02	0.12	2.70	0.01	6.04	71.18	28.82
Contribution To Others	71.23	74.83	53.63	48.99	78.24	62.02	74.15	13.69	78.58	13.17	16.48	**Total connectedness =54.23**
Net Contribution (To –From) Others	**-8.72**	**4.27**	**21.63**	**10.68**	**-1.12**	**3.13**	**-2.02**	**6.34**	**-1.03**	**-2.37**	**-2.34**	

Note: GER, FRA, ITA, SPA, NET, BEL AUS, GRE, FIN, POR and IRE stand for Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Greece, Finland, Portugal and Ireland respectively.

Table 3: Full-sample connectedness before the breakpoint

	GER	FRA	ITA	SPA	NET	BEL	AUS	GRE	FIN	POR	IRE	Contribution From Others
GER	14.52	10.13	6.17	9.07	11.74	9.05	10.62	4.00	11.35	8.40	4.95	85.48
FRA	10.33	11.04	6.83	9.70	11.43	9.92	10.25	4.54	11.01	9.11	5.85	88.96
ITA	6.39	7.16	12.71	10.10	9.00	10.21	8.59	7.66	8.79	10.90	8.48	87.29
SPA	7.31	7.83	9.05	12.43	9.85	10.81	9.45	5.93	9.67	10.41	7.26	87.57
NET	9.64	9.28	7.04	10.01	12.57	10.33	10.03	4.41	11.03	9.39	6.28	87.43
BEL	7.37	8.12	8.65	11.14	10.30	12.24	9.31	5.42	9.91	10.45	7.09	87.76
AUS	9.25	8.85	7.51	10.39	10.79	10.20	11.99	4.54	10.89	9.69	5.91	88.01
GRE	5.97	6.48	9.12	7.70	7.31	8.12	7.61	19.30	7.81	9.03	11.54	80.70
FIN	9.46	9.06	7.00	9.87	11.12	10.12	10.28	4.49	12.94	9.53	6.15	87.06
POR	6.95	7.40	9.51	10.43	9.31	10.17	9.14	6.60	9.46	12.89	8.14	87.11
IRE	5.79	6.16	8.27	8.27	8.44	9.40	7.49	10.83	8.62	9.22	17.51	82.49
Contribution To Others	84.38	87.93	86.16	88.61	88.76	88.93	88.56	75.17	88.40	88.18	80.36	**Total connectedness =86.35**
Net Contribution (To –From) Others	**-1.10**	**-1.03**	**-1.12**	**1.04**	**1.33**	**1.17**	**0.54**	**-5.53**	**1.33**	**1.07**	**-2.13**	

Table 4: Full-sample connectedness after the breakpoint

	GER	FRA	ITA	SPA	NET	BEL	AUS	GRE	FIN	POR	IRE	Contribution From Others
GER	31.71	7.81	0.25	0.08	24.55	1.06	9.05	0.36	24.25	0.02	0.86	68.29
FRA	11.12	28.40	0.10	0.06	13.39	12.68	21.46	0.11	12.19	0.38	0.14	71.60
ITA	0.83	0.99	58.75	28.71	0.08	5.02	1.06	0.26	0.20	2.17	1.92	41.25
SPA	1.11	2.13	26.01	60.96	0.31	3.80	2.46	0.17	0.79	0.40	1.87	39.04
NET	20.83	9.78	0.21	0.02	29.76	3.01	11.40	0.47	24.04	0.04	0.43	70.24
BEL	3.30	15.41	2.83	2.31	4.29	50.75	16.12	0.03	3.71	0.84	0.41	49.25
AUS	10.42	19.07	0.01	0.02	12.93	11.71	31.05	0.10	13.91	0.63	0.15	68.95
GRE	2.65	0.15	6.23	3.40	1.67	0.63	0.38	79.83	1.12	3.14	0.80	20.17
FIN	20.00	9.94	0.12	0.03	22.88	3.86	13.68	0.36	28.83	0.13	0.17	71.17
POR	0.66	0.02	8.81	5.67	0.66	0.93	0.19	3.65	1.03	70.26	8.13	29.74
IRE	0.05	0.34	1.59	3.44	0.26	2.88	0.62	1.05	0.00	4.25	85.51	14.49
Contribution To Others	69.11	69.80	44.00	41.78	73.14	47.32	71.11	7.59	73.81	14.58	14.83	**Total connectedness =49.47**
Net Contribution (To –From) Others	**0.82**	**-1.80**	**2.74**	**2.74**	**2.90**	**-1.93**	**2.16**	**-12.6**	**2.64**	**-15.2**	**0.34**	

Note: GER, FRA, ITA, SPA, NET, BEL AUS, GRE, FIN, POR and IRE stand for Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Greece, Finland, Portugal and Ireland respectively.

Table 5. Panel regression: All countries

	Without dummy	With dummy
Constant	2.5705* (3.8189)	2.8238* (3.4237)
DCRISIS		-0.7563* (-4.2693)
Macrofundamentals		
DEF	-0.2132* (-3.8710)	-0.2009* (-3.4541)
DCRISIS*DEF		-0.0056* (-3. 2530)
DEB	-0.0146* (-6.8134)	-0.0122* (-5.4660)
DCRISIS*DEB		-0.0041* (-3.1127)
Market sentiments		
CCI	0.3078* (7.1324)	0.2809* (7.1762)
DCRISIS*CCI		0.0079* (5.7277)
VOL	-0.0085* (-8.1645)	-0.0080* (-8.3530)
DCRISIS*VOL		-0.0001* (-4.3770)
R^2	0.8512	0.8497
Observations	1694	

Notes: RE regression results. In the ordinary brackets below the parameter estimates are the corresponding *z*-statistics, computed using White heteroskedasticity-robust standard errors. In the square brackets below the specification tests are the associated *p*-values. * indicates significance at 1% level.

Table 6. Panel regression: Central countries

	Without dummy	**With dummy**
Constant	1.9715* (6.8140)	1.8426* (6.1825)
DCRISIS		-0.1288* (-3.8916)
Macrofundamentals		
INF	-1.0207* (4.2092)	-1.0624* (3.9951)
DCRISIS*INF		-0.0303* (-3.7634)
DEB	-0.1357* (-6.4410)	-0.1301* (-6.4372)
DCRISIS*DEB		-0.0066* (-3.6941)
CAC	0.2327* (3.7058)	0.2431* (4.1258)
DCRISIS*CAC		0.0012* (2.9584)
Market sentiments		
CCI	0.2201* (6.4104)	0.2139* (6.4615)
DCRISIS*CCI		0.0053* (3.7134)
VOL	-0.0068* (-6.0229)	-0.0066* (-5.7843)
DCRISIS*VOL		-0.0003* (-4.1013)
R^2 Within Between Overall	 0.5726 0.7146 0.4415	 0.7394 0.7349 0.7472
Observations	924	

Notes: FE regression results. In the ordinary brackets below the parameter estimates are the corresponding *z*-statistics, computed using Arellano (1987)'s White heteroskedasticity-robust standard errors adjusted to account for the possible correlation within a cluster. In the square brackets below the specification tests are the associated *p*-values. * indicates significance at 1% level.

Table 7. Panel regression: Peripheral countries.

	Without dummy	With dummy
Constant	11.4278* (12.0155)	10.2377* (10.3152)
DCRISIS		-0.5198* (-13.3843)
Macrofundamentals		
DEF	-0.4408* (-3.8791)	-0.4130* (-3.7687)
DCRISIS*DEF		-0.0105* (-3.7596)
Market sentiments		
CCI	0.7817* (12.3218)	0.8152* (11.1011)
DCRISIS*CCI		0.0130* (10.9831)
VOL	-0.0004* (-8.2425)	-0.0005* (-7.1149)
DCRISIS*VOL		-0.0002* (-3.8954)
R^2	0.8572	0.8674
Observations	780	

Notes: RE regression results. In the ordinary brackets below the parameter estimates are the corresponding *z*-statistics, computed using White heteroskedasticity-robust standard errors. In the square brackets below the specification tests are the associated *p*-values. * indicates significance at 1% level.

Figure 1: Daily 10-year sovereign yields in EMU countries and rolling total connectedness:

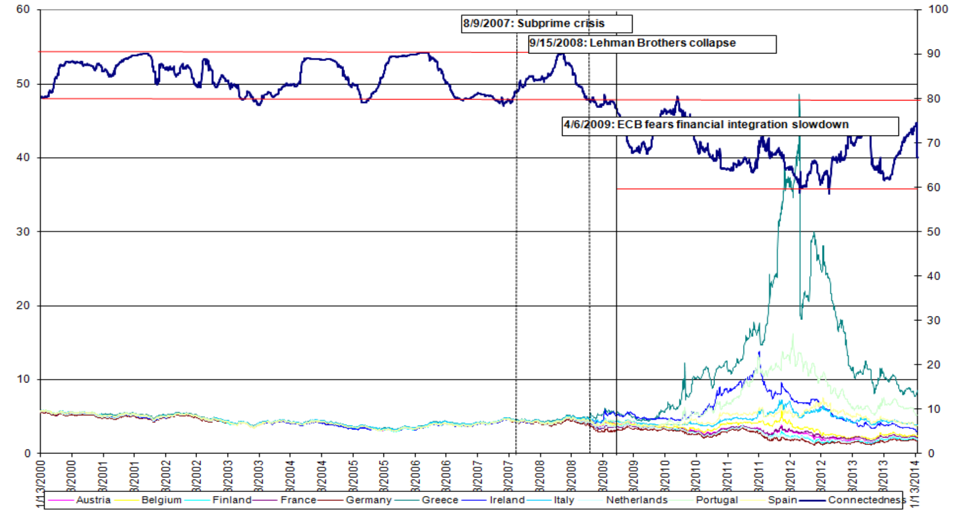


Figure 2: Rolling total connectedness throughout the period (1/13/2000-1/27/2014)

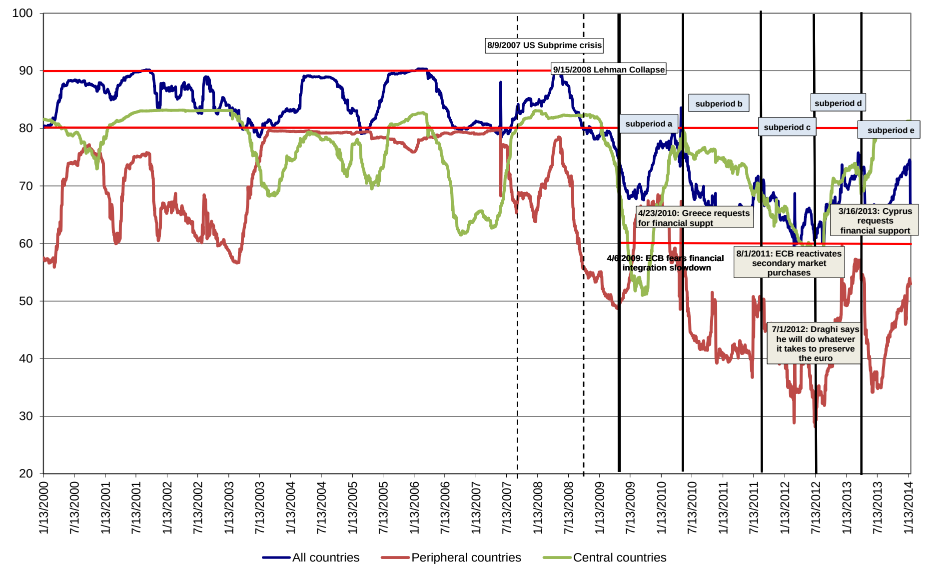


Figure 3: Rolling total connectedness after the breakpoint (6/4/2009-1/27/2014)

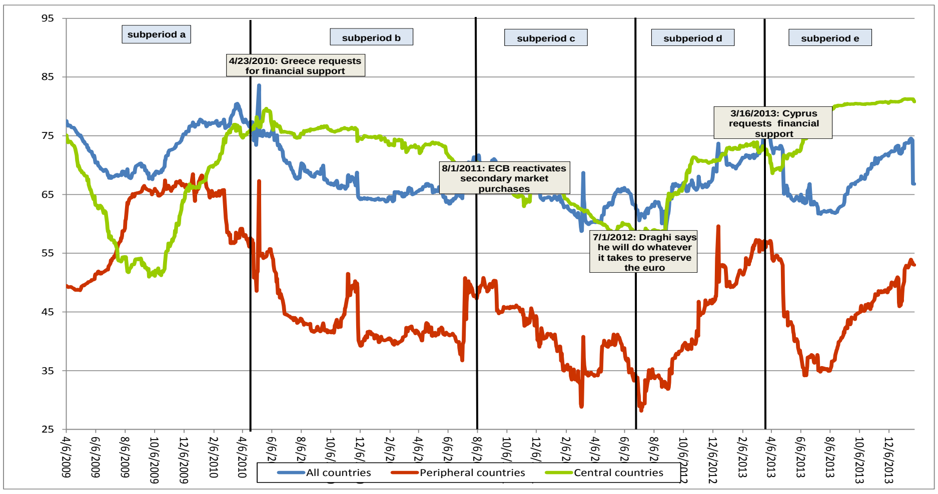
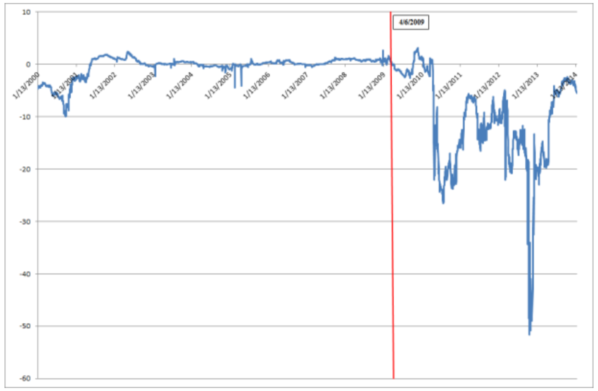
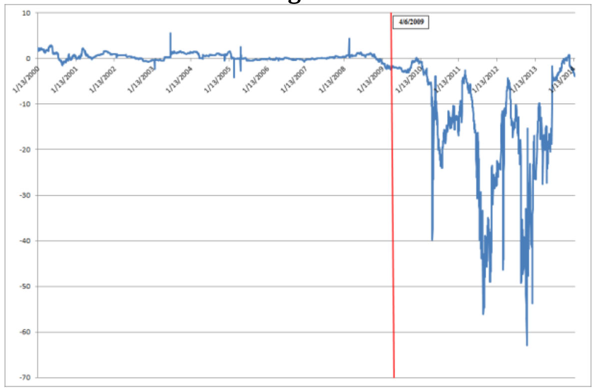


Figure 4a: Net directional connectedness-EMU Central countries

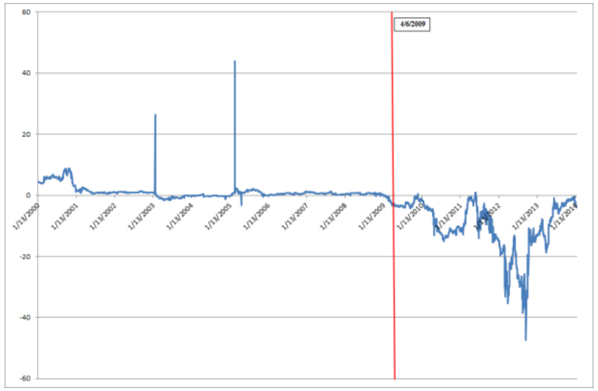
Austria



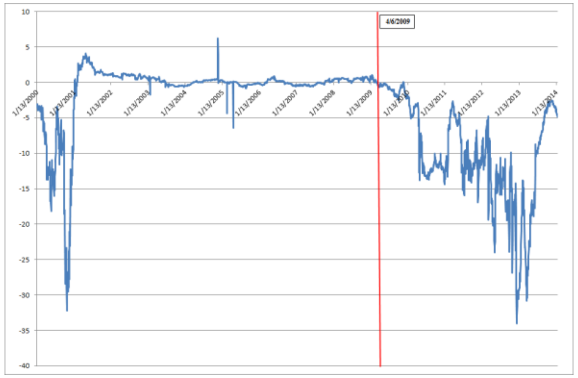
Belgium



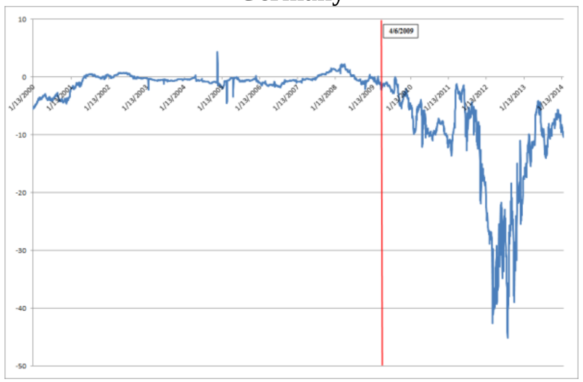
Finland



France



Germany



Netherlands

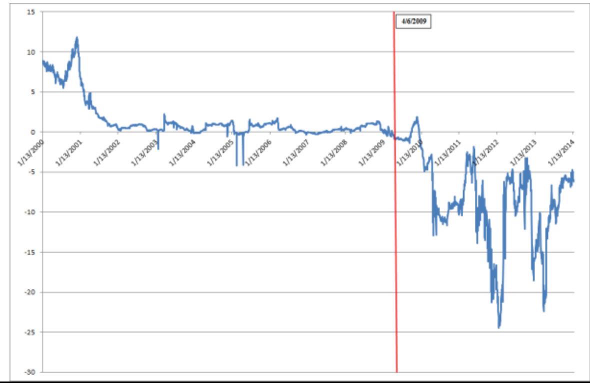


Figure 4b: Net directional connectedness- EMU Peripheral countries

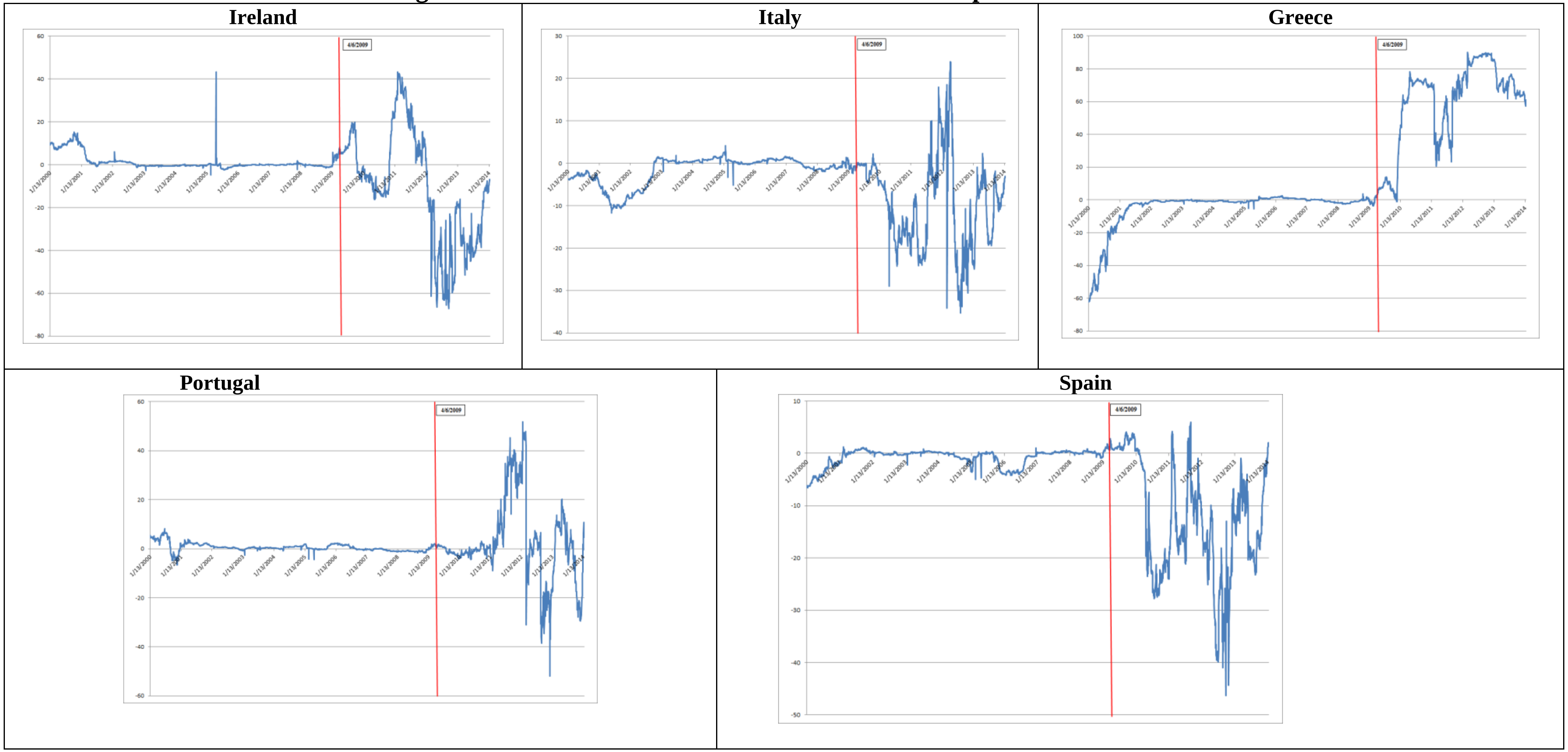
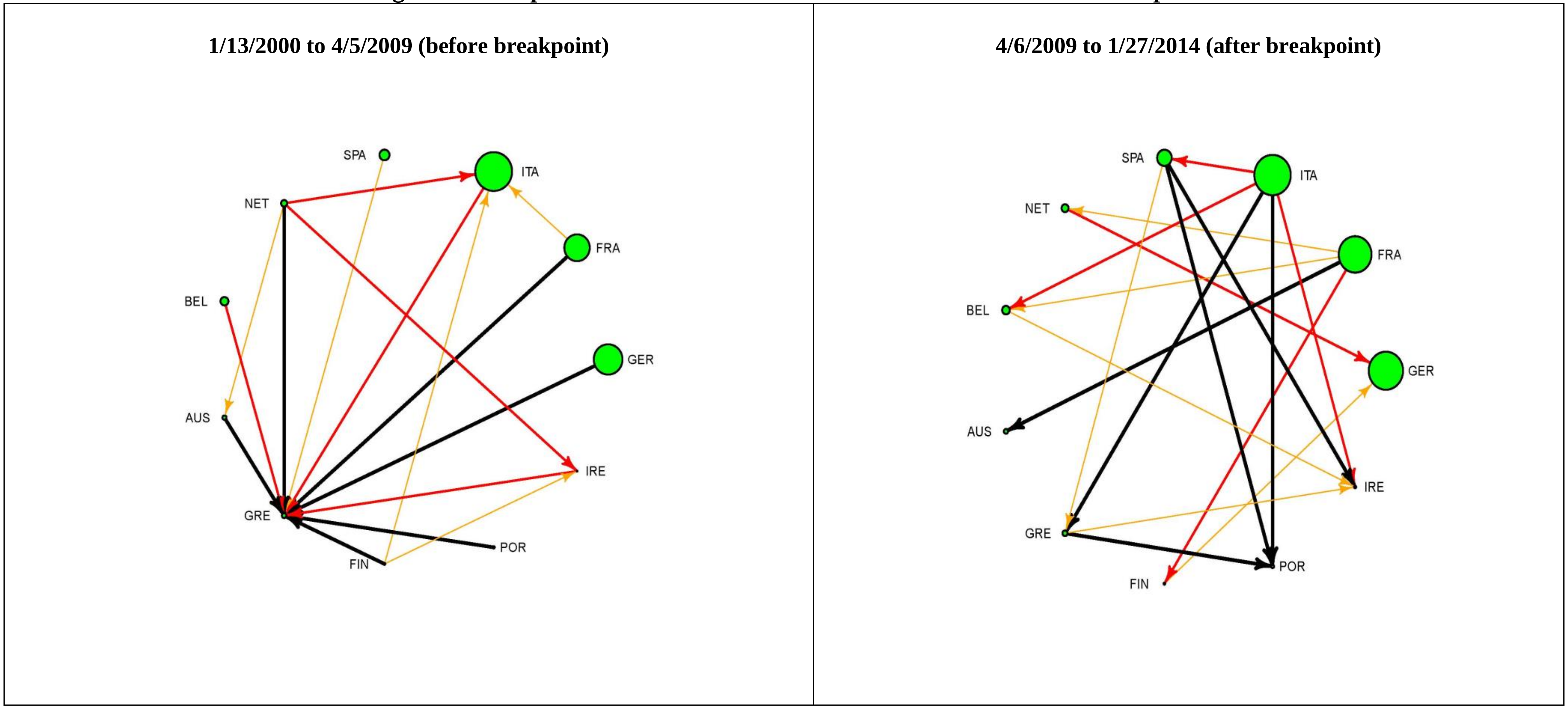
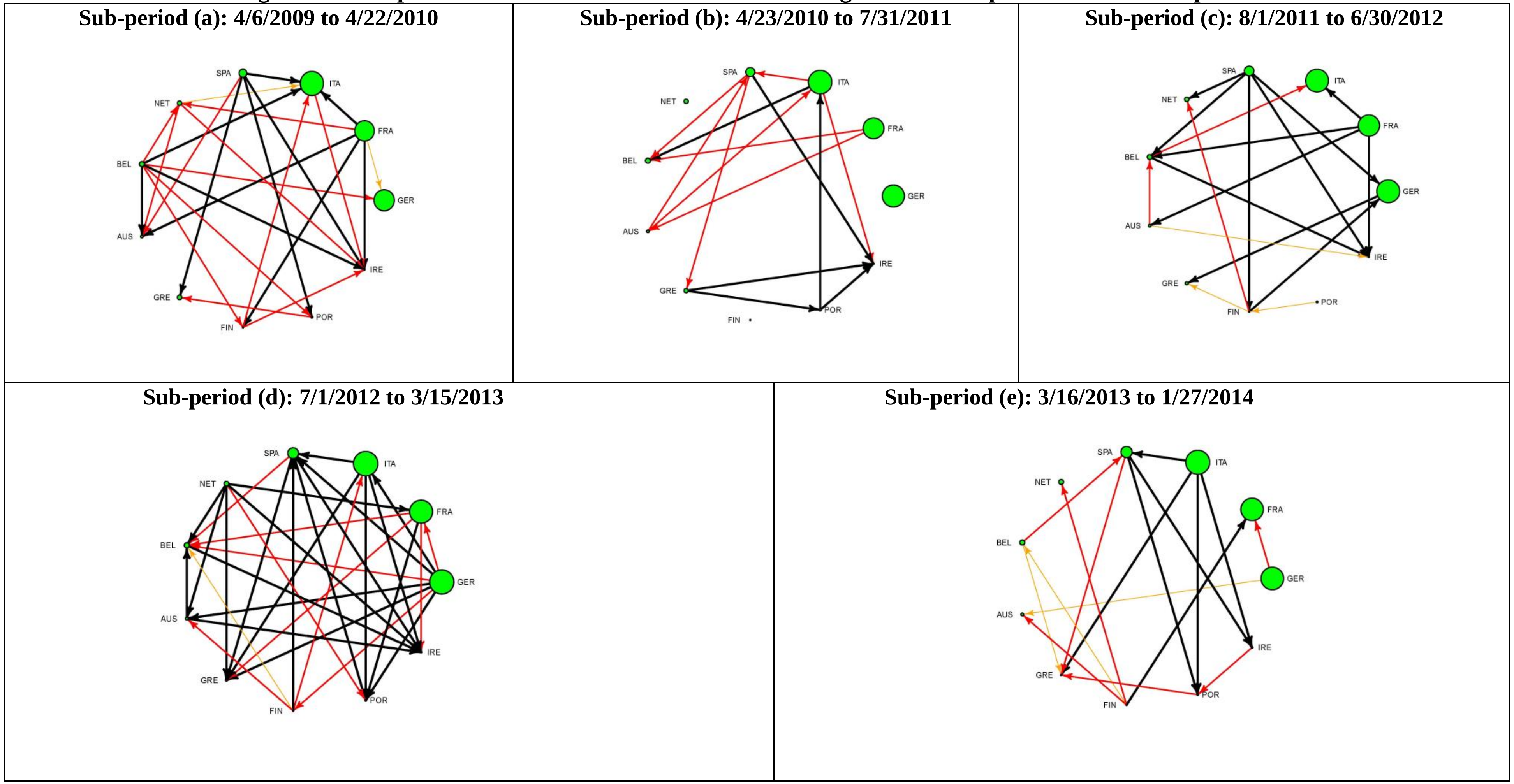


Figure 5a: Net pair-wise directional connectedness before and after breakpoint



Notes: We show the most important directional connections among the 55 pairs of the 10-year bond yields under study. Black, red and orange links (black, grey and light grey when viewed in grayscale) correspond to the tenth, twentieth and thirtieth percentiles of all net pair-wise directional connections. Node size indicates sovereign debt market size. GER, FRA, ITA, SPA, NET, BEL AUS, GRE, FIN, POR and IRE stand for Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Greece, Finland, Portugal and Ireland respectively.

Figure 5b: Net pair-wise directional connectedness during the five sub-periods after breakpoint



Notes: We show the most important directional connections among the 55 pairs of the 10-year bond yields under study. Black, red and orange links (black, grey and light grey when viewed in grayscale) correspond to the tenth, twentieth and thirtieth percentiles of all net pair-wise directional connections. Node size indicates sovereign debt market size. GER, FRA, ITA, SPA, NET, BEL AUS, GRE, FIN, POR and IRE stand for Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Greece, Finland, Portugal and Ireland respectively.