# DOCUMENTOS DE ECONOMÍA Y FINANZAS INTERNACIONALES

## Working Papers on International Economics and Finance

**DEFI 15-02**
**February 2015**


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Asociación Española de Economía y Finanzas Internacionales
www.aeefi.com
ISSN: 1696-6376

# Financial stress transmission in EMU sovereign bond market volatility: a connectedness analysis.

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January 2015

## Abstract

This paper measures the connectedness in 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, Market Linkages, Vector Autoregression, Variance Decomposition.

JEL Classification Codes: C53, E44, F36, G15

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## 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).

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 twice, but Ireland, Portugal and Cyprus also needed bailouts to stay afloat.

[Insert Figure 1 here]

[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 subsequently 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.

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. 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?

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)[4]: 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.

This literature includes two groups of theories 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). In this context, the measures of connectedness proposed by Diebold and Yilmaz (2014)

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

can be considered as a bridge between the two visions mentioned above, since they examine volatility spillovers using useful information on agents' expectations[5], and sidestep the contentious issues associated with the definition and existence of episodes of "fundamentals-based" or "pure" contagion.

A substantial amount of literature uses 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. 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. However, few papers to date have looked at the connectedness and spillover effects within euro area sovereign debt markets, even though quantifying the spillover risk is a very important tool in order to assess whether the benefits of a sovereign bailout may outweigh its costs.

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.

However, to our knowledge, no empirical analyses have been performed of the connectedness in sovereigns' market volatility, in spite of its profound importance. 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

[5] Since uncertainty is based on how much of the forecasting error variance cannot be explained by shocks in the variable, expectations gauge the evolution of both fundamental and market sentiment variables.

to obtain a better understanding of yield evolution over time, providing a barometer for the vulnerability of these markets.

Moreover, since volatility tracks investor fear, by measuring and analyzing the dynamic connectedness in volatility we are able to examine the “fear of connectedness” expressed by market participants as they trade. So, given that volatility tracks investors’ perceived risk and is a crisis-sensitive variable which can induce “volatility surprise” (Engle 1993), this paper centres 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.

Moreover, Diebold and Yilmaz (2014) showed that the connectedness framework was 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*., 2014). The degree of connectedness, on the other hand, measures the contribution of individual units to systemic network events, in a fashion very similar to the CoVaR of this unit (see, e. g., Adrian and Brunnermeier, 2008).

This paper explores this challenging avenue of research, focusing our study on connectedness in EMU sovereign bond market volatility during the period from April 1999 to January 2014. However, 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.

After explaining the methodology that will be used in the empirical analysis, we will proceed in four stages. First, in order to estimate system-wide connectedness, we will undertake a full-sample (static analysis) that is not only of intrinsic interest, but will also prepare the way for the second stage: the performance of a dynamic (rolling-sample) analysis of conditional connectedness. In the third stage, we will “zoom in” on the evolution of net directional connectedness in each market and assess whether their determinants differ between EMU central and peripheral countries. Finally, in the last stage we will examine how net pair-wise connectedness changes over the sample period.

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. 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: $x_t = \Theta(L)u_t$, $\Theta(L) = \Theta_0 + \Theta_1 L + \Theta_2 L^2 + \ldots$, $E(u_t, u_t') = I$. Note that $\Theta_0$ need not be diagonal. All aspects of connectedness are contained in this very general representation. Contemporaneous aspects of connectedness are summarized in $\Theta_0$ and dynamic aspects in $\{\Theta_1, \Theta_2, \ldots\}$. Transformation of $\{\Theta_1, \Theta_2, \ldots\}$ 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* to others from $i$ is defined as

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

We can also define *net total directional connectedness* as

$$C^H_i = C^H_{\bullet \leftarrow i} - C^H_{i \leftarrow \bullet}.$$

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*:

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

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 $D^{gH} = \left[ d^{gH}_{ij} \right]$, where

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

In this case, $e_j$ is a vector with $j$th element unity and zeros elsewhere, $\Theta_h$ is the coefficient matrix in the infinite moving-average representation from VAR, $\Sigma$ is the covariance matrix of the shock vector in the non-orthogonalized-VAR, $\sigma_{jj}$ 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 volatility built on data 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)[6], 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.

### *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.

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

[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 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.

### *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.

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 is plotted along with the evolution of daily 10-year sovereign yields, while in Figures 2 and 3 it is plotted separately.

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 of the EMU sovereign debt market 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 and their high level of connectedness.

However, 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)[7], sovereign yields begin to spiral and total connectedness began a downturn trend. From then on, in parallel with the increase in sovereign yields, connectedness decreased and entered a different regime. These results are in concordance with Gómez-Puig and Sosvilla-Rivero (2014) who, by applying the Quandt–Andrews and Bai and Perron tests (1998, 2003), allowed the data to select when regime shifts occur in each potential causal relationship. Their results suggest that 69 out of the 110 breakpoints (i.e., 63%) occurred after November 2009, after Papandreou's government had revealed that its finances were far worse than previously announced.

[Insert Figure 2 here]

[7] 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.

Moreover, the existence of two different regimes in the evolution of connectedness[8] 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. 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 23 April 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 suddenly reversed. However, during sub-periods (b) and (c) this downtrend deepens. 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, 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) [9]. In November 2011 and March 2012, the ECB provided banks with a sum close to 500 billion Euros for a three-

[8] 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.

[9] 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.

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 EMU sovereign debt markets. Nonetheless, our indicator definitely registered a new slowdown 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).

## 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, we use panel model techniques to analyse their determinants. We adopt an eclectic approach and apply a general-to-specific modelling strategy 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.

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*

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 debt-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)[10], 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

[10] 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.

monthly standard deviation of equity returns (EVOL) in each country to capture local stock market volatility[11]. A summary with the definition and sources of all the explanatory variables used is presented in Appendix A.

### *3.1.3. Empirical results*

Our empirical analysis starts with a general unrestricted statistical model including all explanatory variables to capture the essential characteristics of the underlying dataset. We use standard testing procedures to reduce its complexity by eliminating statistically insignificant variables. We check the validity of the reductions at each stage in order to ensure the congruence of the finally selected model and thus to identify the variables that best explain the developments.

Tables 3 to 5 show the final results for three groups of countries: all 11 EMU countries under study, EMU central countries, and EMU peripheral countries throughout the sample period: 2000:01-2014:01. 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. Therefore, this division[12] 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[13]: 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.

[Insert Tables 3 to 5 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).

[11] 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 EVOL.

[12] This classification of EMU central and peripheral countries follows the standard division presented in the literature.

[13]

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 marginal effects of each variable are:

$\beta = \beta_1 + \beta_2$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 $\beta_2$ 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 3 to 5 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 3) we find a negative and significant effect for the stock-market volatility (EVOL), 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 marginal effects 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, 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 4), three variables gauging macroeconomic fundamentals are significant with the expected sign (the loss of competitiveness (INF), the Government deficit-to-GDP (DEB) and the net position towards the rest of the word (CAC)); whilst in the former (see Table 5) 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 (EVOL), whereas, as expected, the consumer confidence indicator (CCI) presents a positive sign[14]. Again, without exception, for the two groups of countries all marginal effects 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, we have also examined their net pair-wise directional connectedness.

[Insert Figures 5a and 5b here]

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

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 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.

Our analysis, which has focused on the study of connectedness in EMU sovereign bond yields volatility during the period April 1999 to January 2014, may enhance the understanding of cross-market volatility dynamics in times of both turbulence and calm, and may help to assess the risk of crisis transmission. We stress the paper's important methodological contribution: that is, the use of the 'volatility surprise' component (along with other traditional measures of volatility) to fully apprehend the sensitivity of financial markets to volatility shocks.

The main contributions of our research can be summarized as follows. In the first step, we found a system-wide value of 54.23% for the total connectedness between the eleven countries under study for the full sample period. This level is much lower than that obtained by Diebold and Yilmaz (2012, 2014) for international financial markets and US financial institutions respectively. However, it should be understood in the context of the results obtained in the second step, in which we analyse the dynamic nature of total net connectedness.

In Figures 1 to 3, which plot total volatility connectedness, we clearly identify two distinct periods in its evolution which coincide with the evolution of 10-year yields. Indeed, the existence of these two different regimes in the evolution of connectedness has been empirically tested and corroborated. In the first period, the level of connectedness of EMU sovereign debt markets is very high, closely matching the evolution of 10-year yields. However, in the second period, which begins only a few months before Papandreou's government announced Greece's distressed debt position (November 2009), connectedness began a downturn trend. Consequently, the substantial decrease in the level of connectedness in EMU sovereign debt markets, along with the unfolding of the crisis, may explain its low average value in the static analysis for the whole sample period.

In the third step, we calculated the net directional connectedness index which provides information about how much each country's sovereign bond yield volatility contributes in net terms to other countries' sovereign bond yield volatilities. Our empirical evidence shows that, for the whole sample, in three cases (the Netherlands, Finland and Portugal), their bond yield volatility influenced that of the rest of EMU countries, whereas the remaining countries are net receivers. The empirical evidence also suggests that during the stability period, the triggers of the net connectedness relationships are mainly central countries, but during the crisis, they are mostly peripheral countries.

In a further step, we used panel data techniques to analyse the drivers of net directional connectedness in each country. Our results once again highlight 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 appear to play a greater role in relationships where central countries are the triggers. Moreover, without exception, all marginal effects register an increase in the crisis compared to the pre-crisis period.

Finally, in the last step we examined net pair-wise directional connectedness among the 11 EMU countries, both in the two regimes detected and during the five sub-periods in which the crisis period has been divided. Our findings corroborate the conclusions drawn from the third step regarding the direction of net connectedness and provide further insights into both their intensity and their behaviour during the five sub-periods of the crisis.

Overall, 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.

To sum up, the analysis in this paper suggests 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.

## 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 (DEF and DEB) | 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 (EVOL) | 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 Maria del Carmen Ramos-Herrera and Manish K. Singh for their excellent research assistance. This paper is based upon work supported by the Government of Spain and FEDER under grant numbers ECO2011-23189 and ECO2013-48326. Simón Sosvilla-Rivero thanks the Universitat de Barcelona and RFA-IREA for their hospitality. Responsibility for any remaining errors rests with the authors.

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## Table 1: Schematic connectedness table

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

## 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 | **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. Panel regression: All countries

| | Without dummy | With dummy |
|---|---|---|
| Constant | 2.5705*<br>(3.8189) | 2.8238*<br>(3.4237) |
| DCRISIS | | -0.7563*<br>(-4.2693) |
| **Macrofundamentals** | | |
| DEF | -0.2132*<br>(-3.8710) | -0.2009*<br>(-3.4541) |
| DCRISIS*DEF | | -0.0056*<br>(-3. 2530) |
| DEB | -0.0146*<br>(-6.8134) | -0.0122*<br>(-5.4660) |
| DCRISIS*DEB | | -0.0041*<br>(-3.1127) |
| **Market sentiments** | | |
| CCI | 0.3078*<br>(7.1324) | 0.2809*<br>(7.1762) |
| DCRISIS*CCI | | 0.0079*<br>(5.7277) |
| EVOL | -0.0085*<br>(-8.1645) | -0.0080*<br>(-8.3530) |
| DCRISIS*EVOL | | -0.0001*<br>(-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 (1980)'s heteroskedasticity-robust standard errors. In the square brackets below the specification tests are the associated *p*-values. * indicates significance at 1% level.

## Table 4. Panel regression: Central countries

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

Notes: FE regression results. In the ordinary brackets below the parameter estimates are the corresponding *z*-statistics, computed using White (1980)'s heteroskedasticity-robust standard errors. In the square brackets below the specification tests are the associated *p*-values. * indicates significance at 1% level.

## Table 5. Panel regression: Peripheral countries.

| | Without dummy | With dummy |
|---|---|---|
| Constant | 11.4278*<br>(12.0155) | 10.2377*<br>(10.3152) |
| DCRISIS | | -0.5198*<br>(-13.3843) |
| **Macrofundamentals** | | |
| DEF | -0.4408*<br>(-3.8791) | -0.4130*<br>(-3.7687) |
| DCRISIS*DEF | | -0.0105*<br>(-3.7596) |
| **Market sentiments** | | |
| CCI | 0.7817*<br>(12.3218) | 0.8152*<br>(11.1011) |
| DCRISIS*CCI | | 0.0130*<br>(10.9831) |
| EVOL | -0.0004*<br>(-8.2425) | -0.0005*<br>(-7.1149) |
| DCRISIS*EVOL | | -0.0002*<br>(-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 (1980)'s 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:**

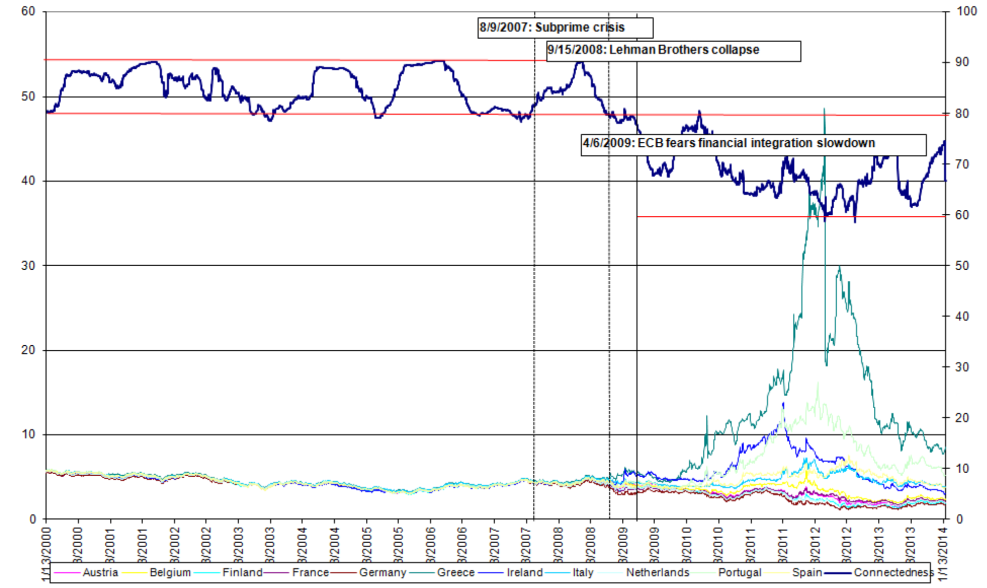



**Figure 2: Rolling total connectedness throughout the period (1/13/2000-1/27/2014)**

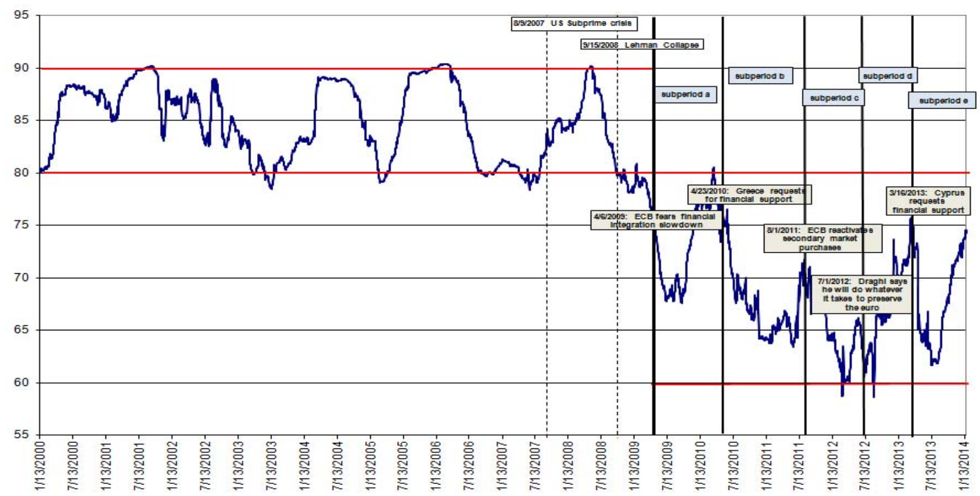
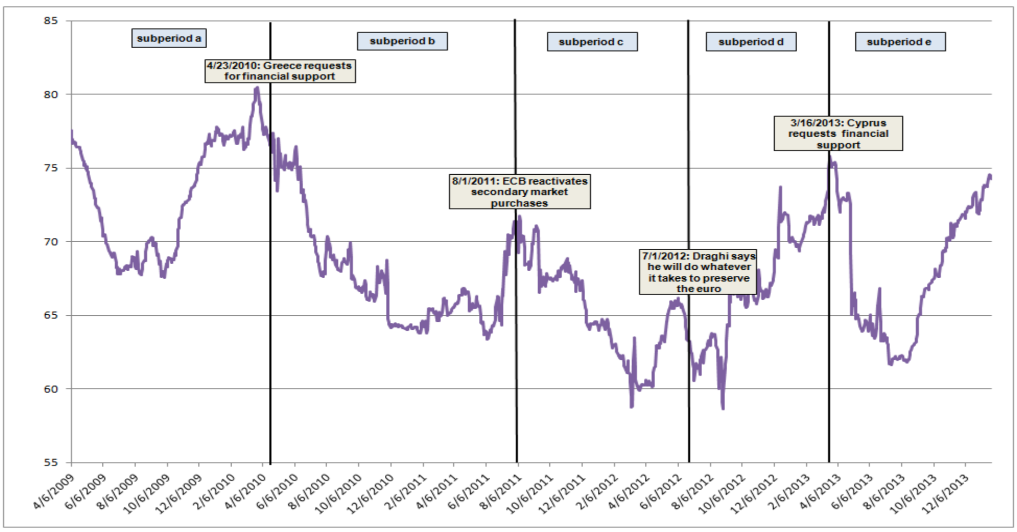
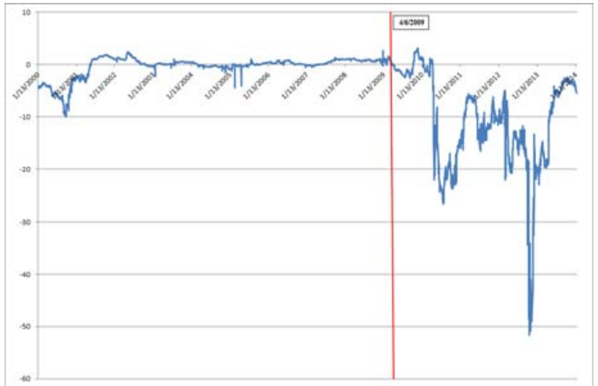



**Figure 3: Rolling total connectedness after the breakpoint (6/4/2009-1/27/2014)**

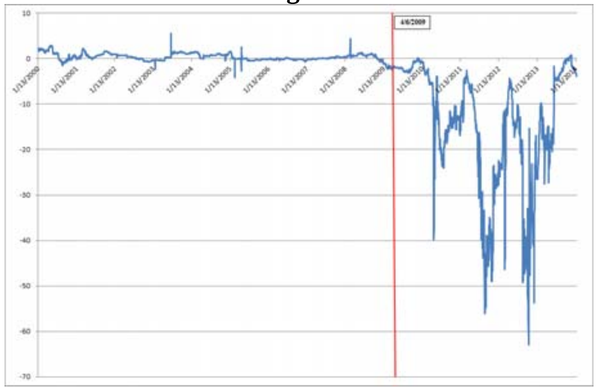


## Figure 4a: Net directional connectedness-EMU Central countries

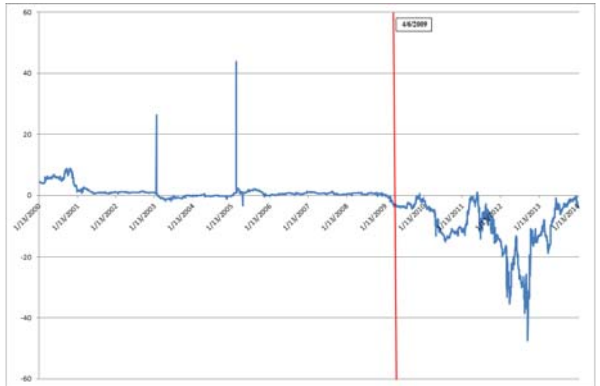
**Austria**



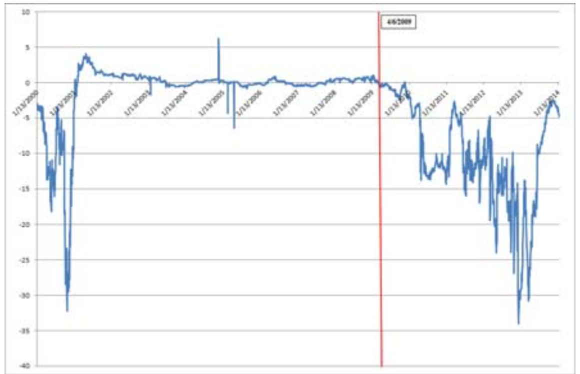
**Belgium**



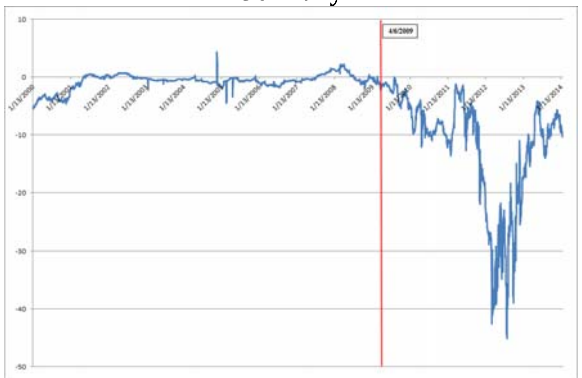
**Finland**



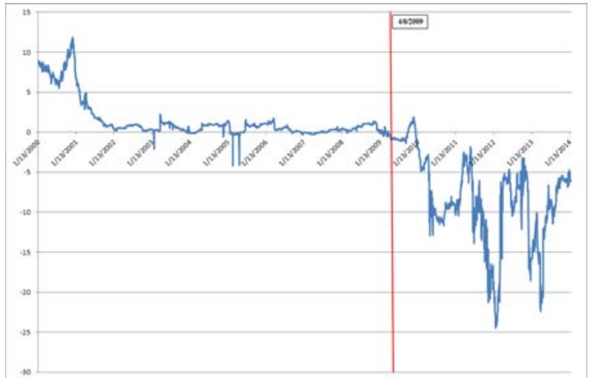
**France**



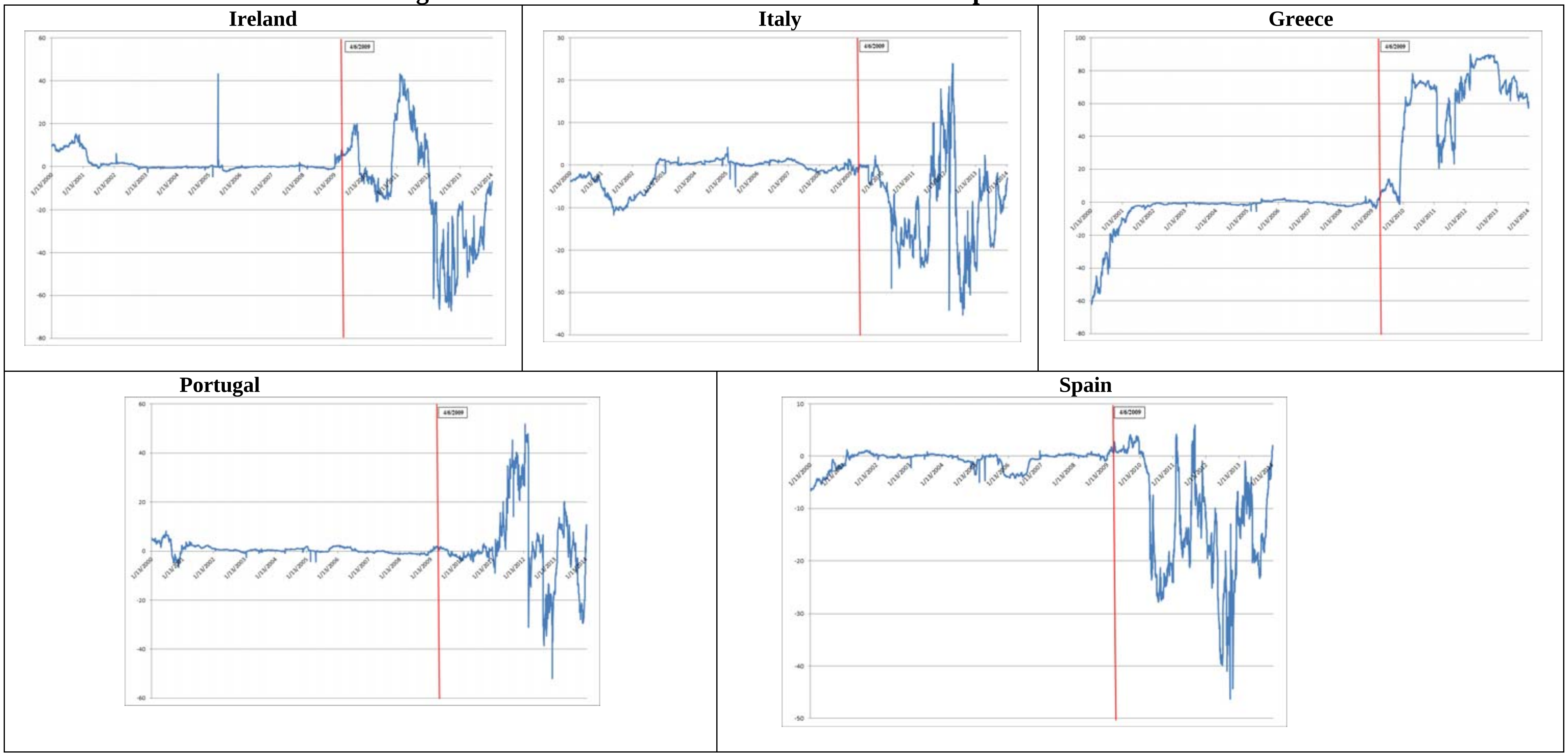
**Germany**



**Netherlands**

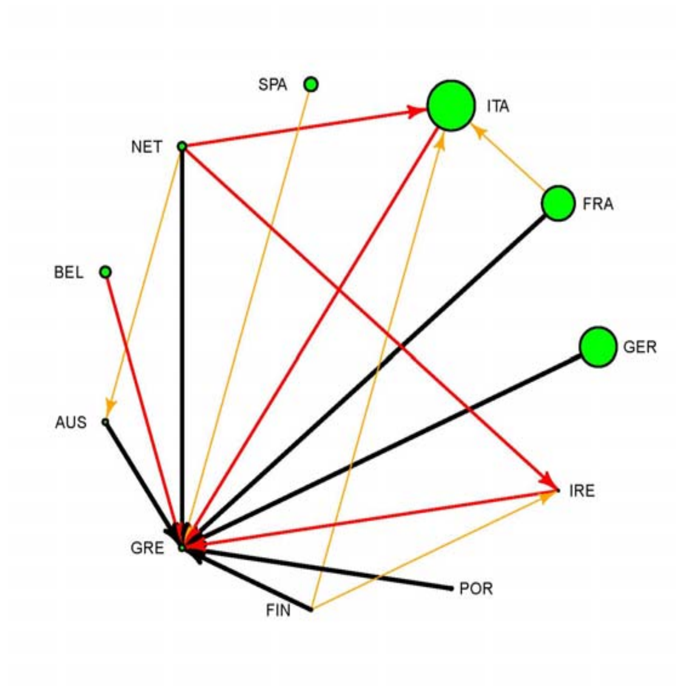


## Figure 4b: Net directional connectedness- EMU Peripheral countries

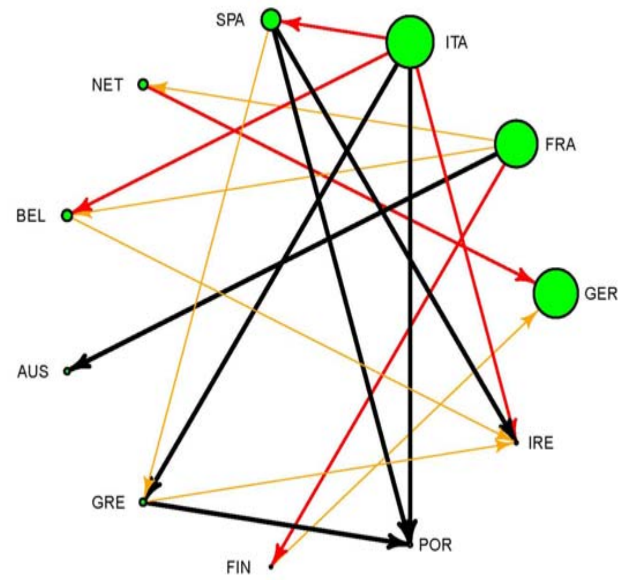


## Figure 5a: Net pair-wise directional connectedness before and after breakpoint

**1/13/2000 to 4/5/2009 (before breakpoint)**



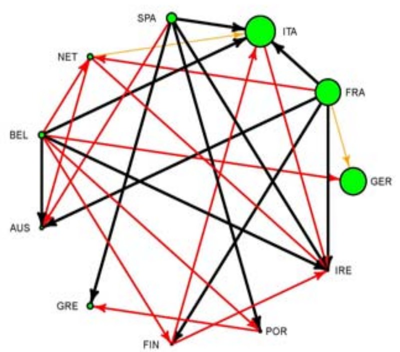

**4/6/2009 to 1/27/2014 (after breakpoint)**



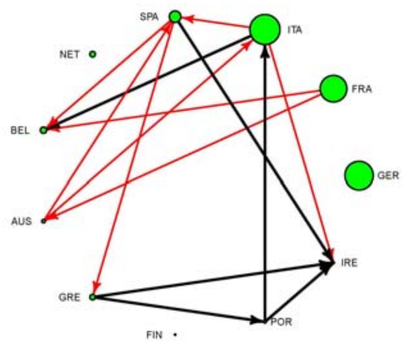

Notes: We show the most important directional connections among the 55 pairs of the 10-year bond yields under study. Black, red and orange links (black, grey and light grey when viewed in grayscale) correspond to the tenth, twentieth and thirtieth percentiles of all net pair-wise directional connections. 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

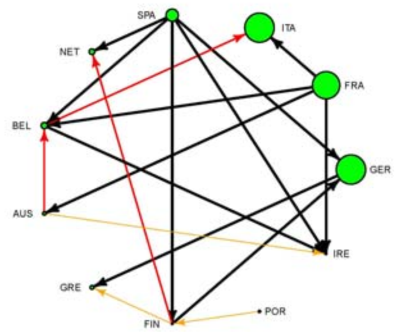
**Sub-period (a): 4/6/2009 to 4/22/2010**



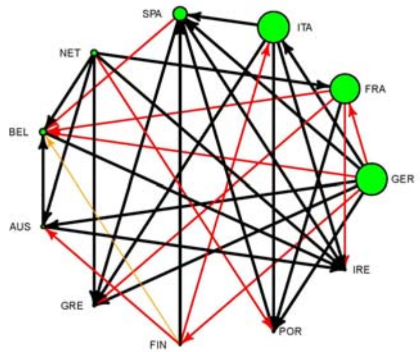

**Sub-period (b): 4/23/2010 to 7/31/2011**



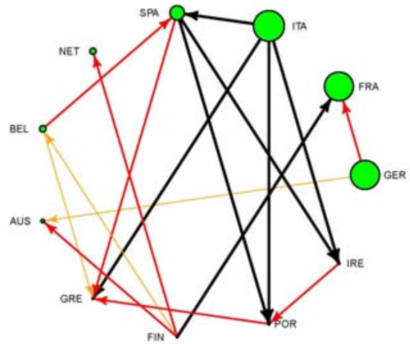

**Sub-period (c): 8/1/2011 to 6/30/2012**




**Sub-period (d): 7/1/2012 to 3/15/2013**




**Sub-period (e): 3/16/2013 to 1/27/2014**




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.