Financial stress transmission in EMU sovereign bond markets' volatility: a connectedness analysis.

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Abstract

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

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

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1. Introduction

The elimination of currency risk and regulatory convergence[1] are some 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 was even stronger for some of the EMU peripheral countries[2]. However, even though cross-border banking had clearly benefited risk diversification in business' portfolios and was considered a hallmark of successful financial integration by monetary authorities; it also presents some drawbacks. First, foreign capital is likely to be much more mobile than domestic one and, in a crisis situation, foreign banks may simply decide to "cut and run". Moreover, in an integrated banking system, financial or sovereign crisis in a country can quickly spill over to other countries. In this sense, it is worth to remark that given the high degree of interconnectedness in European financial markets, one important 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 (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 "fear" of contagion (see, for instance, Constâncio, 2012), not only because there was a sudden loss of investors' confidence 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 high exposure to Greece (see Gómez-Puig and Sosvilla-Rivero, 2013).

Indeed, from late 2009 onwards, in parallel with the higher demand for the German bund which benefited from its safe haven status, 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 also Ireland, Portugal and Cyprus needed bailouts to stay afloat.

[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 an excessive degree may not be.

[Insert Figure 1 here]

In this scenario, where we have witnessed how crisis episodes in a given EMU sovereign market affected other markets almost instantaneously, some important questions have been raised for economists, policymakers, and practitioners. 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 the sovereign risk premium increase?

Some researchers have already studied transmission and/or contagion between sovereigns in the euro area context using different 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 still scarcely explored methodology in this area. In particular, we will make use of Dielbold and Yilmaz (2014)'s measures of connectedness (both system-wide and pair-wise) in order to be able to contribute to the literature on international transmission mechanisms that the sovereign debt crisis in the euro area has rekindled with the aim to be able to answer some of the previously posed questions.

This literature includes two groups of theories that, even though they are not necessarily mutually exclusive (see Dungey and Gajurel, 2013), have fostered an important 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 among 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, financial crises in one country may conceivably trigger a crisis elsewhere for reasons unexplained by macroeconomic fundamentals – perhaps because they lead to shifts in market sentiment, changes the

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

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) can be considered as a bridge between the two abovementioned visions, since they examine volatility spillovers using useful information on agents’ expectations[5], sidestepping the contentious issues associated with the definition and existence of episodes of ‘‘fundamentals-based” or “pure contagion’’.

While there is a substantial amount of literature using 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) or 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 their analysis on Asian countries; Apostolakisa and Papadopoulos (2014) and Tsai (2014) examine G-7 economies; whilst Duncan and Kabundi (2013) center their analysis in South African markets; few papers to date have looked at the connectedness and spillovers effects within euro area sovereign debt markets, although quantifying the spillover’s risk is a very important tool in order to assess whether the benefits of a sovereign bailout may outweigh their 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; or Alter and Beyer (2014), who quantify spillovers between sovereign credit markets and banks in the euro area. Whilst the former authors apply Diebold and Yilmaz methodology, Favero (2013) proposes an extension to Global Vector Autoregressive (GVAR) models to capture time-varying interdependence among EMU sovereign yield spreads.

However, to our knowledge, there is no empirical analysis on the study of connectedness in sovereigns’ markets volatility, even though it is a highly relevant issue. As volatility reflects the extent to which the market evaluates and assimilates the

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

arrival of new information, the analysis of its transmission pattern might provide an insight concerning the characteristics and dynamics of sovereign debt markets, and such information can be used to obtain a better understanding of yields' 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 that it is a crisis-sensitive variable that can induce "volatility surprise" (Engle 1993), this paper is centered on the analysis of connectedness in EMU sovereign debt markets volatility using Diebold and Yilmaz (2014)'s methodology filling the existing gap in the literature.

Moreover, Diebold and Yilmaz (2014) showed that the connectedness framework was closely linked with both the modern network theory (see Glover and Richards-Shubik, 2014) and the modern measures of systemic risk (see Ang and Longstaff, 2013 or Acemoglu *et al*., 2014). The connectedness degree, on the other hand, measures the contribution of individual units to systemic network events, in a fashion very similar to CoVaR of such unit (see, e. g., Adrian and Brunnermeier, 2008).

Therefore, the main objective of this paper is to make some contributions to this challenging avenue of research, focusing our study on connectedness in EMU sovereign bond markets volatility during the period April 1999 to January 2014. However, unlike previous studies, we will only include in the analysis 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.

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

All in all, our results suggest that the positive influence that core and sound countries had over peripheral ones in the stability period, suddenly faded with the crisis outbreak when investors disregarded the shelter that they could give to peripheral countries and focused their attention in the important imbalances in some of the latters. Consequently, whilst in the stability period, alongside the slight differences in yield's behaviour (all followed the German bund evolution and spreads moved in a very narrow range) central countries where the triggers in net connectedness relationships; in the crisis one, an important shift occurred and this role was played by peripheral ones. Therefore, according to our results, in a context of increased cross-border financial activity in the euro-area, the risk that, in turbulent times, a shock in one country might have spillover effects over the others might have solid grounds, risking global financial stability.

The rest of the paper is organized as follows. Section 2 presents the Diebold and Yılmaz (2014)'s methodology for assessing connectedness in financial markets volatility and the empirical results (both static and dynamic) obtained for our sample of EMU sovereign markets (system-wide measure of connectedness). In Section 3 we present the empirical results regarding the evolution of net directional connectedness in each market and carry out the exploration of their determinants. Section 4 examines the time-varying behaviour of net pair-wise directional connectedness during 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 to measure the amount of connectedness is based on a decomposition of the forecast error variance, which will be briefly described next.

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 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 $\{\Theta_1, \Theta_2, \ldots\}$. Transformation of $\{\Theta_1, \Theta_2, \ldots\}$ via variance decompositions in needed to reveal and compactly summarize connectedness. In this sense, 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, that contains the variance decompositions, is called the "variance decomposition matrix," and is denoted it by $D^H = [d_{ij}]$. The connectedness table augments 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:

$$C_{ij}^{H} = C_{j\leftarrow i}^{H} - C_{i\leftarrow j}^{H}.$$

Regarding 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 other, 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, labeled “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

$$C_{i\leftarrow \bullet}^{H} = \sum_{\substack{j=1 \\ j\neq i}}^{N} d_{ij}^{H},$$

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

$$C_{\bullet\leftarrow i}^{H} = \sum_{\substack{j=1 \\ j\neq i}}^{N} d_{ji}^{H}.$$

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 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 employed. 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 *jth* 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-ortogonalized-VAR, σ_{jj} being its jth diagonal element. In this GVD framework, the lack of orthogonality makes it so that the rows of d_{ij}^{gH} do not have sum unity and, in order to get 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 yields volatility built on data collected from 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, specially the euro area sovereign debt crisis from 2009 onwards.

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

2.3. Static (full-sample, unconditional) analysis

The full-sample connectedness table appears as Table 2. As mentioned before, its *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's) are the largest individual elements of 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 more 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 Spain to Italy (25.27%) is the second-highest. The highest value of pair-wise directional connectedness among EMU central is from France to Austria (20.03%), followed by that from France to the Netherlands (18.85%). With respect to total directional connectedness from others that measures the share of volatility shocks received from other bond yields in the total variance of the forecast error for each bond yield, it 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 the connectedness to others, lower than the range of 72.61 points found for the connectedness from others. Finally, we obtain a value of 54.23% for the total connectedness among 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 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 understand the connectedness dynamics. The appeal of the connectedness methodology lies with its use as a measure of how quickly return or volatility shocks spread across countries as well as within a country. This section presents the dynamic connectedness analysis which relies on rolling estimation windows.

The dynamic connectedness analysis starts with the total connectedness, to then move 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, whilst in Figure 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 are coincident with the evolution of 10-year yields. In the first period (that will be denoted as stability period), the level of connectedness of EMU sovereign's debt market is high matching the close evolution of 10-year yields (spreads moved in a narrow range and reached values close to zero). Neither the US subprime crisis on August 2007 nor the Lehman Brothers Collapse on September 2008 seemed to hit, substantially, euro area sovereign debt markets and their high level of connectedness.

However, from April 2009 coinciding with one statement by the European Central Bank (ECB) in which it expressed its fears of slowdown in financial market integration and only some months before Papandreou's government disclosed the 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

[7] In November 2009, Papandreou's government disclosed that its finances were far worse than 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 December 8th. These episodes marked the beginning of the euro area sovereign debt crisis.

sovereign yields, connectedness decreased and entered in 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), let the data select when regime shifts occur in each potential causal relationship. Their results suggest that 69 out of the 110 breakpoints (i.e., 63%) occur after November 2009, after Papandreou's government had revealed that its finances were far worse than previously announced.

[Insert Figure 2 here]

Moreover, the existence of two different regimes in the evolution of connectedness, which has been empirically tested (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 6th April 2009, supporting their existence) along with 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), among the eleven countries under study for the full sample. Therefore, since the second regime matches the euro area sovereign debt crisis period, we will focus our analysis on this period (denoted as 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 23rd 2010 (when Greece requested financial support), can still be defined as a pre-crisis period, since the downtrend that was registering the total level of connectedness in euro area sovereign debt markets is suddenly reverted. However, during sub-period (b) and (c) this downtrend deepens. Indeed, sub-period (b) –from April 2010 to August 2011- is a phase of very high turmoil in EMU sovereign debt markets. We should recall that during this period 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, uncertainty continued in European debt markets during sub-period (c) (it begins in August 2011 and ends in 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 also of Austria and France. In this context of financial distress and huge liquidity problems, the ECB responded forcefully by implementing (along with other central banks) nonstandard monetary policies, i.e., policies beyond setting the refinancing rate. In particular, the ECB's principal means of intervention were the so-called long term refinancing operations (LTRO) [8]. In November 2011 and March 2012, the ECB allotted to banks an amount 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. It was in that scenario, that the ECB's President Mario Draghi made the statement that he would do "whatever it takes to preserve the euro". So, sub-period (d), which starts after that statement in July 2012, clearly reflects the healing effects of Draghi's words since an important increase in the level of total connectedness can be observed in EMU sovereign debt markets. Nonetheless, our indicator definitely registered a new slowdown in Mars 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, as 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 EMU Central and Peripheral 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 than during most of the sample period, their bond yields' volatility influence that of the rest of EMU countries, whereas for the

[8] 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. Then, the Fed 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 was notably different 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 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.

remainder 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 are 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 bet receivers, with a percentage of negative values of 100%, 99%, 98%, 95% and 92% for the France, Finland, Belgium, Netherlands and Austria, respectively. In this second period, Germany also appears as net receiver with a 100% of negative values. Regarding peripheral countries (Figure 4b), four of the five studied countries are net received during the stability period, with a percentage of negative values of 78%, 57%, 55% and 52% for the Greece, Ireland, Spain and Italy, respectively; whilst during the crisis period, Greece and Portugal became net triggers, with a percentage of positive values of 99% and 52%, respectively.

3.1 Determinants of net directional connectedness

3.1.1 Econometric methodology

Once we have evaluated net directional connectedness, we use panel model techniques to analyse their determinants. In particular, 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 in monthly or quarterly frequency, we generate a new dependent variable computing for each country the monthly average of the daily net directional connectedness.

3.1.2. Instruments to model 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)[9], 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 (EVOL) in each country to capture local stock market volatility[10]. A summary with the definition and sources of all the explanatory variables that have been 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, using standard testing procedures to reduce its complexity by eliminating statistically insignificant variables, and checking the validity of the reductions at each stage in order to ensure congruence of the finally selected model in order to find what variables explain developments best.

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 during the whole sample period: 2000:01-2014:01. The reason to split the sample in 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 two categories can be detected within them. Therefore, this division[11] allows differentiating the impact of potential determinants on bond spreads in core and peripheral countries. We only report the results obtained using

[9] 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 among markets. Indeed, some literature supports the importance of market size 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.

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

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

the relevant model in each case[12]: the Random Effects (RE) model in the case of all EMU countries and EMU Peripheral countries; and the Fixed Effects (FE) model for the EMU Central 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 to be used 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 of coefficients' significance over time (i.e., during the stability and the crisis periods).

Therefore, in addition to the chosen independent variables 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: $\beta_1 = \beta_1 + \beta_2$, in order to assess whether the impact of independent variables on net directional connectedness changed significantly with the start of the sovereign debt crisis, is not necessary 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)

[12] 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 and Pagan (1980)'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.

The second column in Tables 3 to 5 shows the re-estimation results with the DCRISIS dummy. Looking across the columns in these Tables, it can be observed that, when examining all eleven countries (Table 3), with regard to the variables measuring market sentiment, 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 net directional connectedness of variables measuring the fiscal position (both the debt and the deficit-to-GDP). Moreover, without exceptions, 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 sentiments during the crisis period compared with the pre-crisis one is in line with the previous empirical literature (see Gómez-Puig *et al.*, 2014, among others).

Besides, it is worth to note that our analysis 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 relative higher relevance, while macroeconomic fundamentals seemed to play a major 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 the stock-market volatility (EVOL), whereas, as expected, the consumer confidence indicator (CCI) presents a positive sign[13]. Again, without exceptions, for the two groups of countries, all marginal effects register an increase in the crisis period compared to the pre-crisis one.

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 financial crisis might spread from one country to another due

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

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 informed 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 in favour of this "wake-up call" contagion, though for other countries there is much less of such evidence since macroeconomic fundamentals' relevance is higher.

4. Net pair-wise directional connectedness

So far we have discussed the behavior 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]

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

Both Figures present very relevant results. In Figure 5a, it can be observed that while in the stability period, central countries are the triggers in the connectedness relationships, in the crisis regime, these relationships are higher when the trigger is a peripheral country. These results are in concordance with those presented in Figures 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 account for 75% of the total and in the tenth and twentieth percentile all 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, we only detect three relationships departing from central countries), whilst although receiver's are mainly peripheral, central countries still account for 41% of the total.

These results are very clarifying 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 central and sound countries might have on the rest of the Eurozone. However, the situation radically changed with the crisis when suddenly market’s participants focused their attention in the important macroeconomic imbalances that some peripheral countries presented which not only were eventually able to lead them to a default, but also might affect central countries that held important positions in 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), which can be defined as the period just before the beginning of the euro-area sovereign debt crisis (the disclosure of the distressed public finance position by Papandreou in November 2009 market its beginning), we not only detect an important number (25) of net pair-wise relationships but in 72% of the cases central countries are still the triggers. However, an important difference with the pre-crisis period is that peripheral countries register a decrease in its weight as receivers’. In this sub-period, they account for 60% of the total, whilst the rest (40%) are central countries. Thus, the extension of the crisis’ effects to central countries begins to be a fact.

Nonetheless, the situation radically changes in sub-period (b), which includes the rescue to Greece, Ireland and Portugal. In this phase not only the number of connectedness relationships decreases from 25 to 14, but also their direction changes. In this second sub-period of the crisis regime, net pair-wise connectedness relationships mainly occur between peripheral countries, which weight is the highest (around 71%) both as triggers and as receivers. Besides, it is worth to note 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 and, as it is displayed in Figure 3, 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%). Besides, it is also important to note that central countries recover their role in the relationships both as 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 the role of central countries as triggers is stressed (they represent 76% of the total), but also peripheral countries recover the receiver role they registered in the pre-crisis period (64%). Finally, in the last sub-period (which begins with the rescue to Cyprus), we observe again a decrease in the number of pair-wise connectedness relationships, however the majority of them take place between peripheral countries, both as a triggers (53% of the total) and as a receivers (65%).

5. Concluding remarks.

We think that our analysis, which has focused on the study of connectedness in EMU sovereign bond yields volatility during the period April 1999 to January 2014, might enhance the understanding of cross-market volatility dynamics, both in turbulent and calm times, helping to assess the risk of crisis transmission. Additionally, one central methodological contribution is brought to the attention of practitioners: it is related to the use of the 'volatility surprise' component (alongside other traditional measures of volatility) to apprehend fully 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 among the eleven countries under study for the full sample. 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 much be understood in the context of the results obtained in the second step where we analyze the dynamic nature of total net connectedness.

In this sense, in Figures 1 to 3, where total volatility connectedness is plotted, we can clearly identify two distinct periods in its evolution which are coincident 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's debt market is very high matching the close evolution of 10-year yields. However in the second one, which begins only some months before Papandreou's government disclosed the 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 crisis unfolding, might explain its low average value in the static analysis for the whole sample period.

In the third step, we have 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 points out that, for the whole sample, in three cases (the Netherlands, Finland and Portugal), their bond yields' volatility influence that of the rest of EMU countries, whereas the remainder countries are net receivers. Besides, the empirical evidence also suggests that while in the stability period, the triggers of the net connectedness relationships are mainly central countries, during the crisis regime, they are mostly peripheral countries.

In a further step, we have 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 relative higher relevance, while macroeconomic fundamentals appeared to play a major role in relationships where central countries are the triggers. Moreover, without exceptions, all marginal effects register an increase in the crisis period compared to the pre-crisis one.

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

All in all, our results give support to the hypothesis that, during the first ten years of EMU, peripheral countries imported credibility from central countries. Nevertheless, with the crisis outbreak, a sudden shift in the sentiment of market participants took place, paying 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 developed in this paper might suggest that 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 along with the crisis unfolding, mostly departed from peripheral countries. In that context, where cross-border financial activity was very important and market sentiments' indicators played an important 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 might not be disregarded by financial authorities and policymakers who have a responsibility of 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)

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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	**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* (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)
EVOL	-0.0085* (-8.1645)	-0.0080* (-8.3530)
DCRISIS*EVOL		-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 (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* (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)
EVOL	-0.0068* (-6.0229)	-0.0066* (-5.7843)
DCRISIS*EVOL		-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 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* (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)
EVOL	-0.0004* (-8.2425)	-0.0005* (-7.1149)
DCRISIS*EVOL		-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 (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:

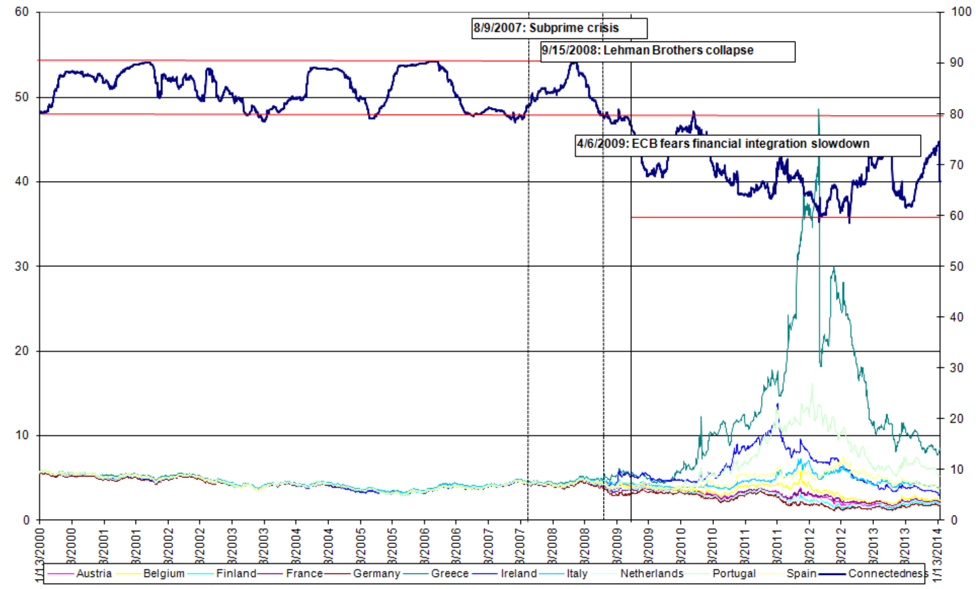


Figure 2: Rolling total connectedness during all the period (1/13/2000-1/27/2014)

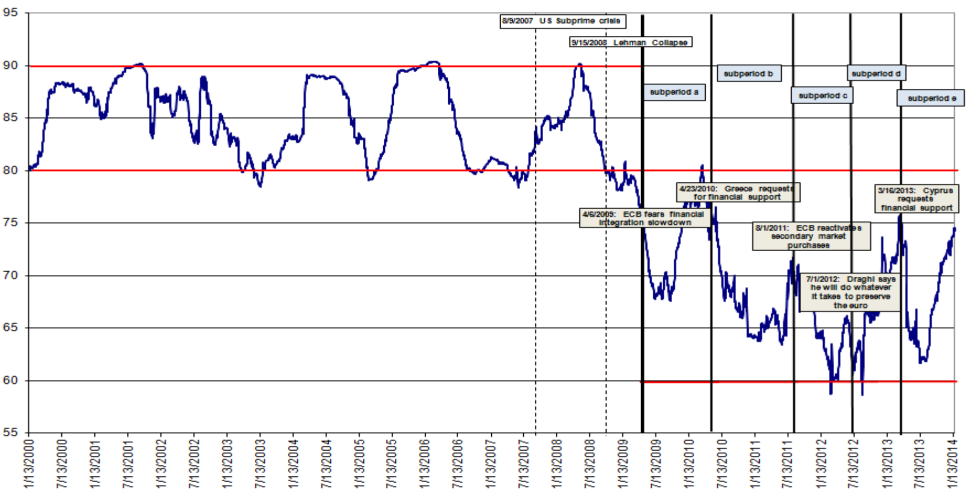


Figure 3: Rolling total connectedness after the breakpoint (6/4/2009-1/27/2014)

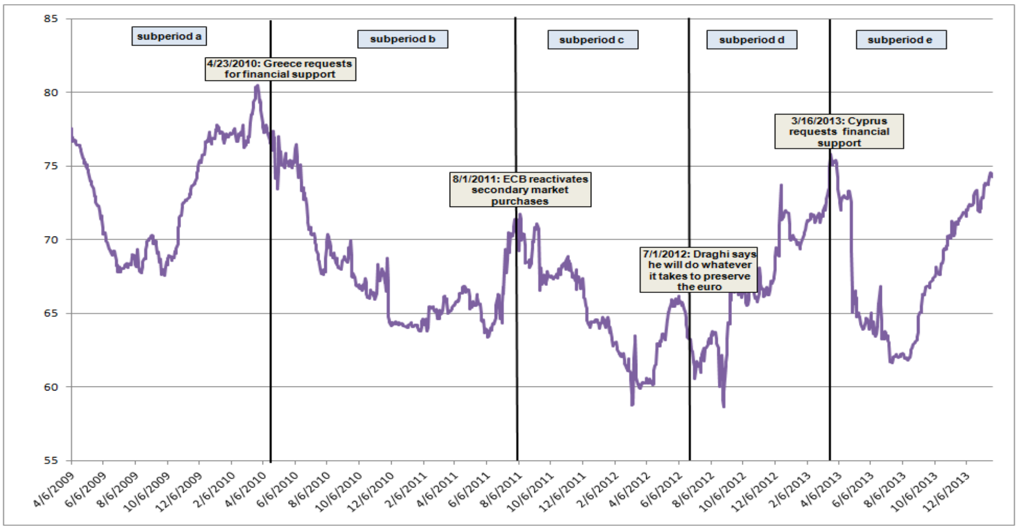
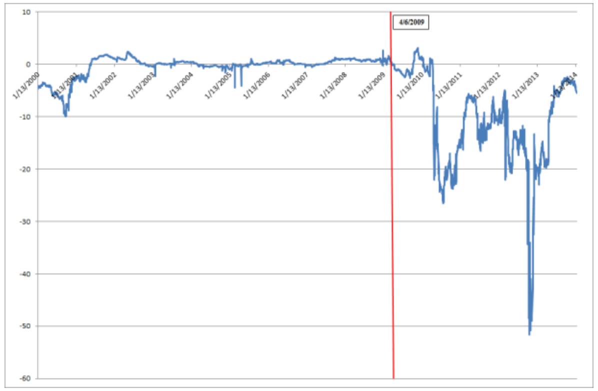
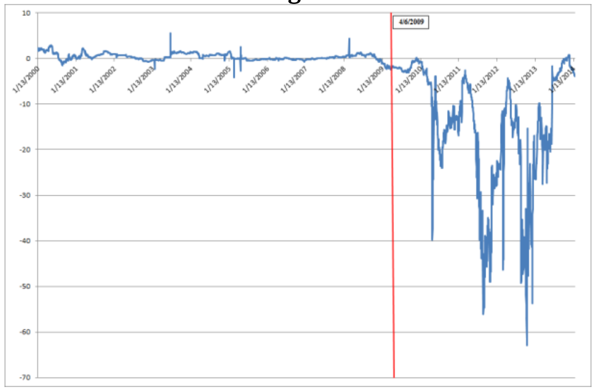


Figure 4a: Net directional connectedness-EMU Central countries

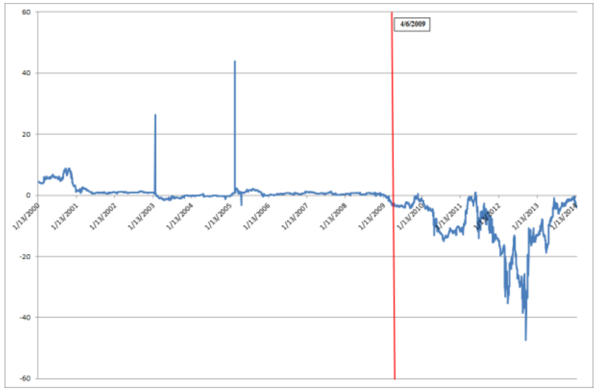
Austria



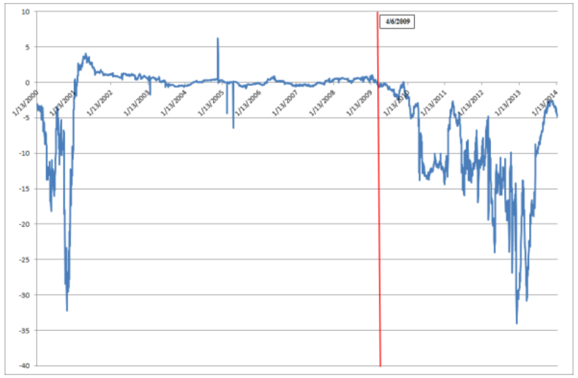
Belgium



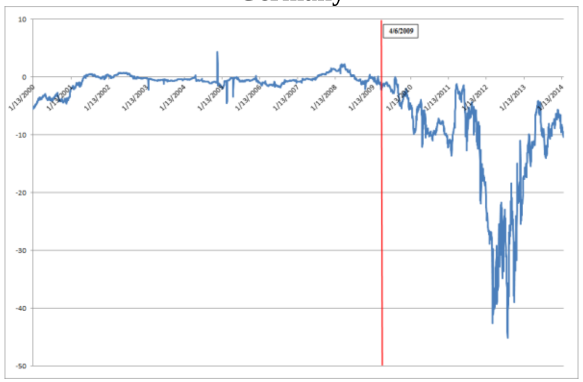
Finland



France



Germany



Netherlands

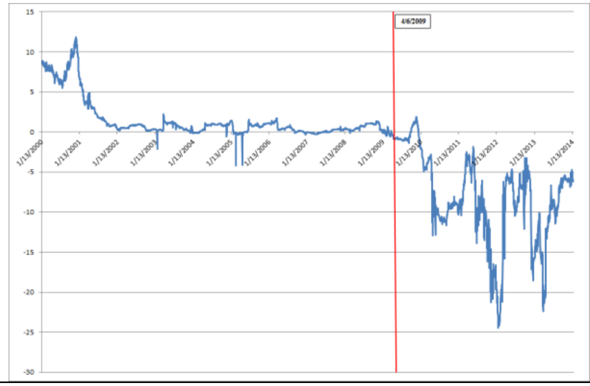


Figure 4b: Net directional connectedness- EMU Peripheral countries

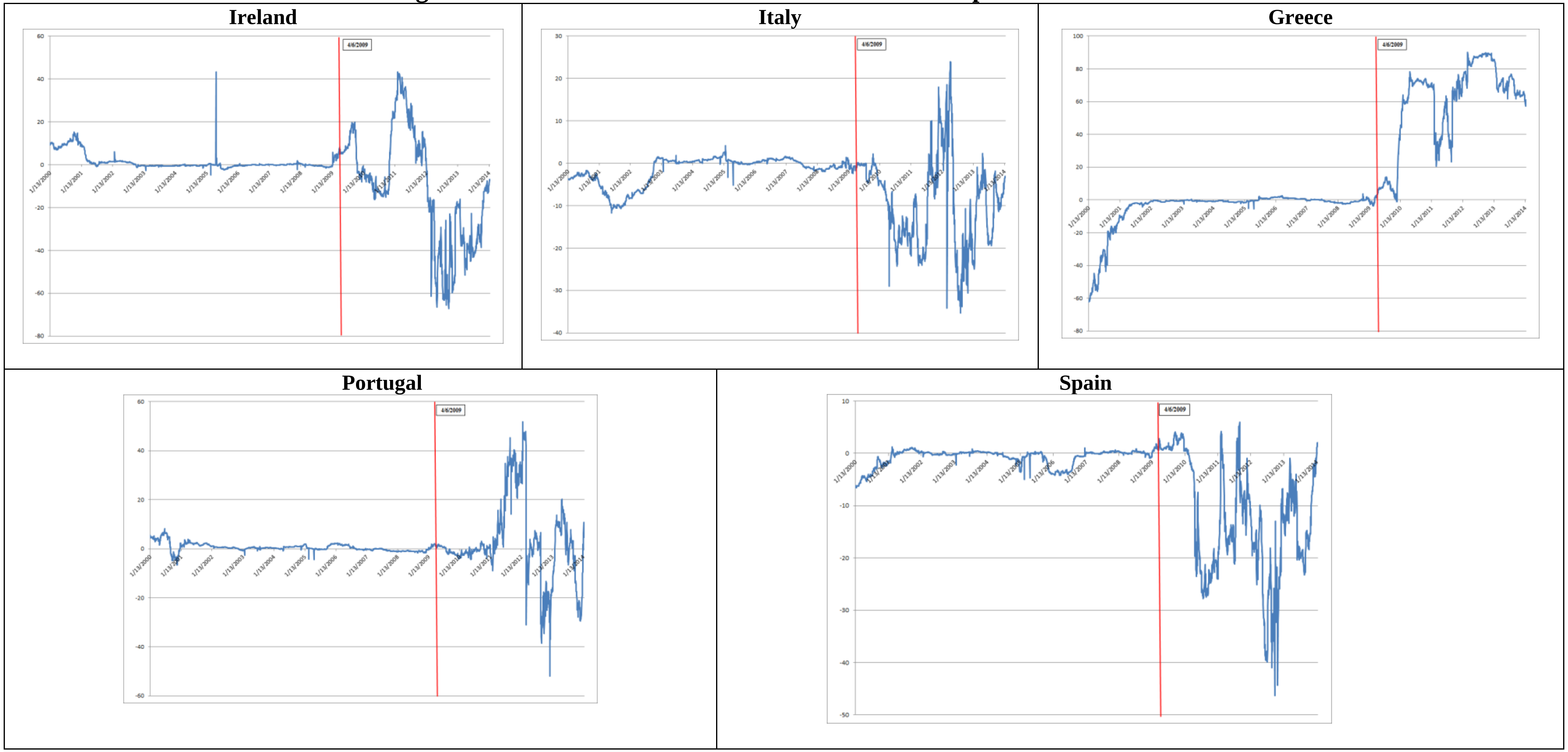
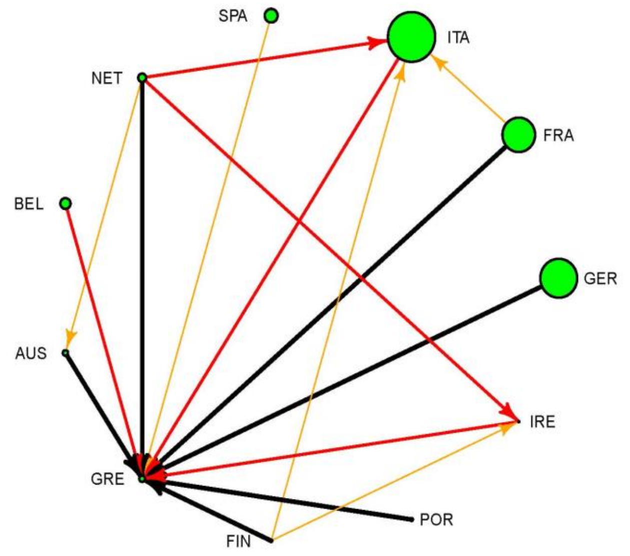
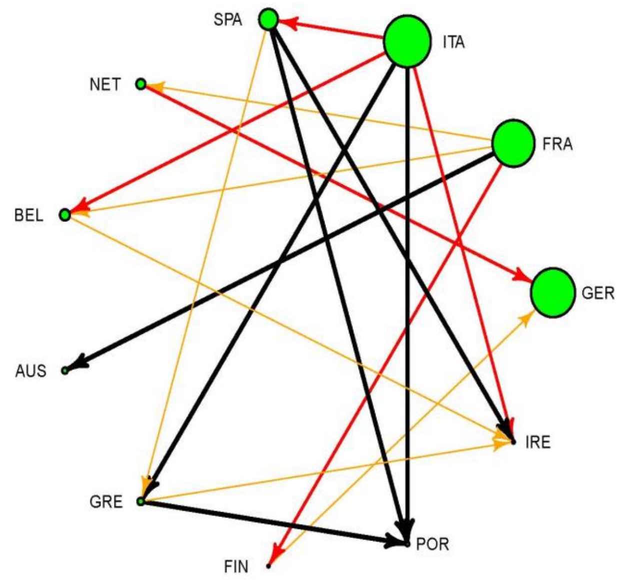


Figure 5a: Net pair-wise directional connectedness before and after breakpoint

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

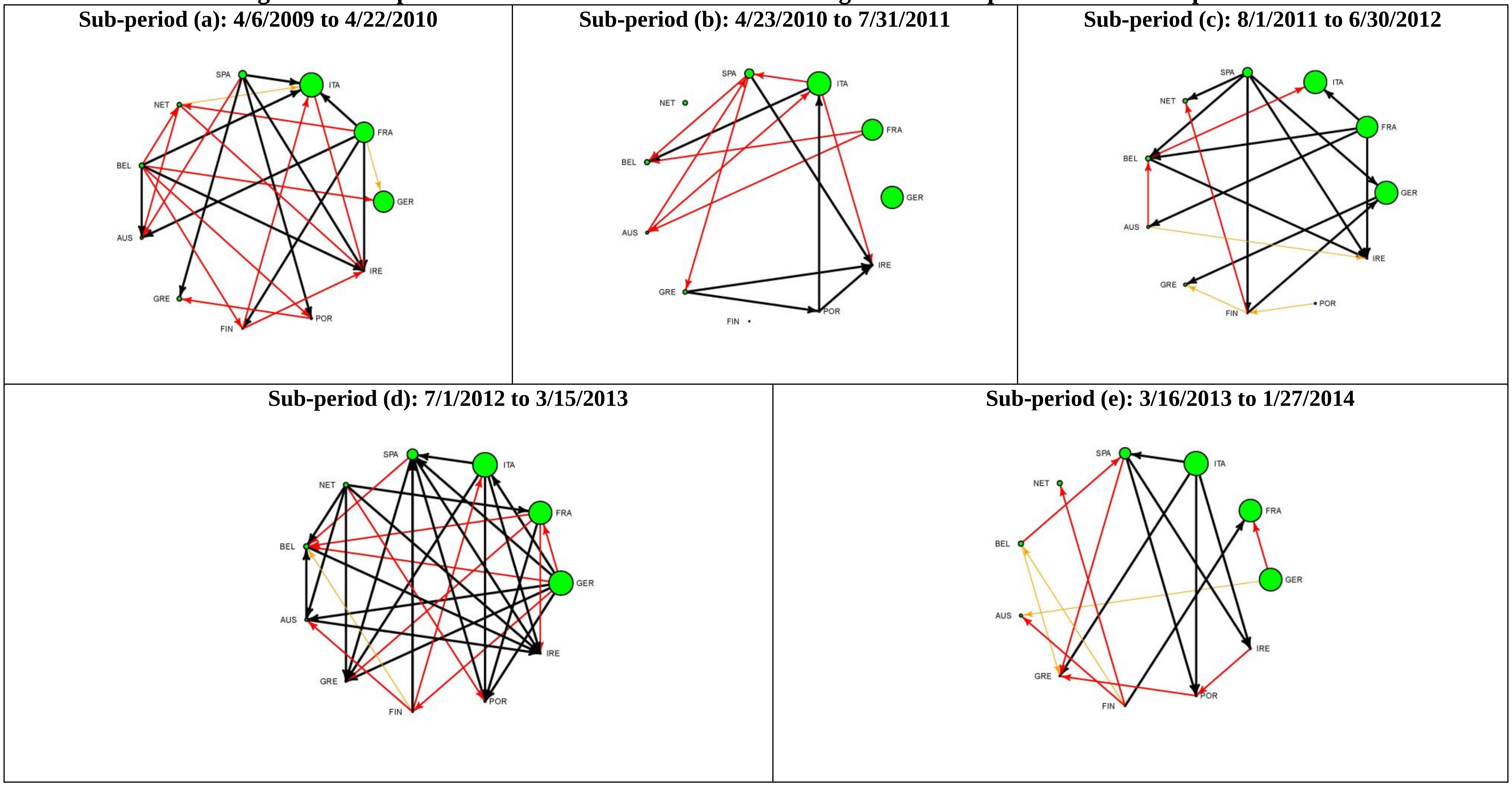


4/6/2009 to 1/27/2014 (after breakpoint)



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, gray and light gray 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, gray and light gray 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.