CAUSALITY AND CONTAGION IN EMU SOVEREIGN DEBT MARKETS*

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Abstract

This paper contributes to the existing literature by applying the Granger-causality approach and endogenous breakpoint test to offer an operational definition of contagion with which to examine the behaviour of public debt issued by central and peripheral member countries of the European Economic and Monetary Union (EMU). To this end, we make use of a database of the daily frequency of yields on 10-year government bonds issued by 11 EMU countries covering fourteen years of monetary union, from its inception on January 1st 1999 to December 31st 2012. The main results of the analysis suggest that the 41 new causality patterns, which appeared for the first time in the crisis period, and the intensification of causality recorded in 70% of the cases, provide clear evidence of contagion in euro area sovereign debt markets in the aftermath of the current crisis.

JEL Classification: E44, F36, G15, C58

Keywords: Sovereign bond yields, Granger-Causality, Contagion, Euro area EMU countries.

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1. Introduction

From the introduction of the euro in January 1999 until the collapse of the US financial institution Lehman Brothers in September 2008, sovereign yields of euro area issues moved in a narrow range with only very slight differences across countries (see Figures 1 and 2). Nevertheless, following the Lehman Brothers collapse severe tensions emerged in financial markets worldwide, including the euro zone bond market. In fact, not only did the period of financial turmoil turn into a global financial crisis but it also began to spread to the real sector, with a rapid, synchronized deterioration in most major economies. This financial crisis put the spotlight on the macroeconomic and fiscal imbalances within European Economic and Monetary Union (EMU) countries which had largely been ignored during the period of stability when markets had seemed to underestimate the possibility that governments might default. Furthermore, in some EMU countries, problems in the banking sector spread to sovereign states because of their excessive debt issues made in order to save the financial industry; eventually, the global financial crisis grew into a full-blown sovereign debt crisis. Indeed, since 2010, Greece has been bailed out twice and Ireland, Portugal and Cyprus have also needed bailouts to stay afloat. These events brought to light the fact that the origin of sovereign debt crises in the euro area varies according to the country and reflects the strong interconnection between public and private debt (see Gómez-Puig and Sosvilla-Rivero, 2013).

In this scenario, some of the research to date has focused on the analysis of interactions between the sovereign market and the financial sector [see Mody (2009), Ejsing and Lemke (2009), Gennaioli *et al.* (2013), Broner *et al.* (2011), Bolton and Jeanne (2011) and Andenmatten and Brill (2011)]. Other researchers have discussed transmission and/or contagion between sovereigns in the euro area context [see Kalbaska and Gatkowski (2012), Metiu (2012), Caporin *et al.* (2013) and Beirne and Fratzscher (2013) to name a few].

The aim of this paper is to contribute to this second branch of the literature by examining not only the transmission of sovereign risk, but also the contagion in euro area public debt markets. In the literature there is a considerable amount of ambiguity concerning the precise definition of contagion. There is no theoretical or empirical definition on which researchers agree and, consequently, the debate on exactly how to define contagion is not just academic, but also has important implications for measuring the concept and for evaluating policy responses. Pericoli and Sbracia (2003) note five definitions of contagion used in the literature. Two of them have been predominantly used in empirical studies to analyze contagion in financial markets and have been adopted in common usage by governments, citizens and policymakers. The first defines contagion depending on the channels of transmission that are used to spread the effects of the crisis, whilst the second defines it depending on whether the transmission mechanisms are stable through time.

Masson (1998) and Kaminsky and Reinhart (2000) apply the first definition, which argues that contagion arises when common shocks and all channels of potential interconnection are either not present or have been controlled for. So, the term contagion will only be applied when a crisis in one country may conceivably trigger a crisis elsewhere for reasons unexplained by macroeconomic fundamentals[1] – perhaps because it leads to shifts in market sentiment, or changes the interpretation given to existing information. According to the second definition, which was proposed in a seminal paper by Forbes and Rigobon (2002), contagion is a significant increase in cross-market linkages after a shock to one country (or group of countries)[2]. Therefore, if two markets show a high degree of co-movement during periods of stability, even if they continue to be highly correlated after a

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[1] The theory of "monsoonal effects" suggests that financial crises appear to be contagious because underlying macroeconomic variables are correlated. In this context, several important papers have focused on the macroeconomic causes of crises, for example, Eichengreen, Rose, and Wyplosz (1996).

[2] The distinction between contagion which occurs at times of crisis, and interdependence which is a result of normal market interaction, has become the focal point of many contagion studies: see for example Corsetti *et al.* (2005) or Bae *et al.* (2003).

shock to one market, this may not constitute contagion. This definition implies the presence of a tranquil, pre-crisis period.

In this paper, in order to capture the phenomenon of contagion quantitatively we will use an operational approach based on the second of these definitions. Besides, among the five general strategies[3] that have been used in the literature, our analysis will be related to one of the most conventional methodologies for testing for contagion: the analysis of cross-market correlations. However, we not only investigate changes in cross-market interdependencies via cointegration analysis, but also explore changes in the existence and direction of causality by means of a Granger-causality approach[4] before and after endogenously identified crises. Hence, the definition of contagion that we will explore in the remainder of this paper is the following: an abnormal increase in the number or in the intensity of causal relationships, compared with that of tranquil periods, triggered by an endogenously detected shock.

Most studies in the literature investigate changes in cross-market correlations; very few explore changes in the existence and direction of causality. Exceptions are studies by Edwards (2000) who focuses on Chile, Baig and Goldfajn (2001) who investigate contagion from Russia to Brazil, Gray (2009) who examines spillovers in Central and Eastern European countries, and both Granger *et al.* (2000) and Sander *et al.* (2003) who investigate spillovers during the Asian crisis. However, very few studies have applied a Granger-causality approach to the investigation of changes in the existence and direction of transmission in euro area debt markets. Among them, Kalbaska and Gatkowski (2012) analyze the dynamics of the credit default swap (CDS) market of peripheral EMU countries

[3] Probability analysis, cross-market correlations, VAR models, latent factor/GARCH models, and extreme value/co-exceedance/jump approach (see Forbes, 2012).

[4] Forbes and Rigobon (2002) suggest the use of this methodology when they point out that, if the source of the crisis is not well identified and endogeneity may be severe, it may be useful to utilize Granger-causality tests to determine the extent of any feedback from each country in the sample to the initial crisis country.

along with three central European countries (France, Germany and the UK) for the period of 2008–2010, and Gómez-Puig and Sosvilla-Rivero (2013) focus on the existence of possible Granger-causal relationships between the evolution of the yield of bonds issued solely by peripheral EMU countries during the period 1999-2010.

Therefore, our study extends this literature by applying a Granger-causality approach to 10-year sovereign yields[5] of both peripheral and central EMU countries[6] on an extended time period spanning from the inception of the euro in January 1999, well before the global financial and sovereign debt crises, until December 2012. But, unlike previous studies in the literature (see Sander *et al.*, 2003 o Kalbaska and Gatkowski, 2012), we do not set a specific breakpoint based on *a priori* knowledge of the potential break date. In our analysis, we use two techniques that take into consideration that the timing of the break is unknown and allow the data to select when regime shifts occur. Thus, break dates that identify the shock triggering contagion are determined endogenously by the model in each of the potential pair-wise causal relationships.

The most important results that emerge from our analysis are the following: (1) Around two thirds out of the total breakpoints, which are endogenously identified, occur after November 2009, when Papandreou's government revealed that its finances were far worse than previous announcements, suggesting that regional rather than global factors are behind the euro area crisis. (2) The number of causal relationships increases as the financial and sovereign debt crisis develops in the euro area, and causality patterns after the break

[5] Our analysis focuses on 10-year yields instead of CDS since CDS data are not available for all the countries in the study until late 2008 - only one year before the onset of the euro sovereign debt crisis.

[6] Gómez-Puig and Sosvilla-Rivero (2013) report data of consolidated claims on an immediate borrower basis provided by the Bank for International Settlements by nationality of reporting banks as a proportion of total foreign claims on each country. These data suggest that the problems of peripheral countries can trigger contagion which may affect not only other peripheral countries but also central EMU countries, since some of these banks (mostly German and French banks) are highly exposed to the debt of peripheral countries.

dates are more frequent when EMU peripheral countries are the triggers. (3) In the crisis period we find evidence of 101 causal relationships: 41 represent new causality linkages, and 60 are patterns that already existed in the tranquil period. However, we find an intensification of the causal relationship in 42 out of the 60 cases. In our opinion, these 41 new causality patterns, together with the intensification of the causal relationship in 70% of the cases, can be considered an important operative measure of contagion that is consistent with the definition we have proposed.

The rest of the paper is organized as follows. The next section explains the econometric methodology. The dataset used to analyze causality is described in Section 3. Section 4 presents the empirical findings, whilst Section 5 offers some concluding remarks.

2. Econometric methodology

2.1 Testing for causality

Granger's (1969) causality test is widely used to test for the relationship between two variables. A variable X is said to Granger-cause another variable Y if past values of X help predict the current level of Y better than past values of Y alone, indicating that past values of X have some informational content that is not present in past values of Y. This definition is based on the concept of causal ordering: two variables X and Y may be contemporaneously correlated by chance, but it is unlikely that the past values of X will be useful in predicting Y, giving all past values of Y[7].

7 Granger causality is not identical to causation in the classical philosophical sense, but it demonstrates the likelihood of this causation more forcefully than contemporaneous correlation (Geweke, 1984).

Granger-causality tests are sensitive to lag length and, therefore, it is important to select the appropriate lengths[8]. Otherwise, the model estimates will be inconsistent and the inferences drawn may be misleading (see Thornton and Batten, 1985). In this paper, we use Hsiao's (1981) generalization of the Granger notion of causality. Hsiao proposed a sequential method to test for causality, which combines Akaike (1974)'s final predictive error (FPE, from now on) and the definition of Granger-causality (Canova 1995, 62-63). Essentially, the FPE criterion trades off the bias that arises from the underparameterization of a model against the loss in efficiency that results from the overparameterization of the model.

Consider the following models,

$$Y_t = \alpha_0 + \sum_{i=1}^{m} \delta_i Y_{t-i} + \varepsilon_t \qquad (1)$$

$$Y_t = \alpha_0 + \sum_{i=1}^{m} \delta_i Y_{t-i} + \sum_{j=1}^{n} \gamma_j X_{t-j} + \varepsilon_t \qquad (2)$$

where X_t and Y_t are covariance-stationary variables [i.e., they are I(0) variables]. The following steps are used to apply Hsiao's procedure for testing causality:

i) Treat Y_t as a one-dimensional autoregressive process (1), and compute its FPE with the order of lags m_i varying from 1 to M. Examine the FPE

$$FPE_Y(m_i, 0) = \frac{T + m_i + 1}{T - m_i - 1} \cdot \frac{SSR}{T}$$

where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (1). Choose m_i for the value of m that minimizes the FPE, say m, and denote the corresponding value as FPE_Y (m, 0).

ii) Treat Y_t as a controlled variable with m number of lags, and treat X_t as a manipulated variable as in (2). Compute again the FPE of (2) by varying the order of lags n_i of X_t from 1 to N. Examine the FPE

8 The general principle is that the smaller lag length has smaller variance but runs a risk of bias, while larger lags will reduce the bias problem but may lead to inefficiency.

$$FPE_Y(m_i, n_i) = \frac{T + m_i + n_i + 1}{T - m_i - n_i - 1} \cdot \frac{SSR}{T}$$

Choose the order n_i which gives the smallest FPE, say n, and denote the corresponding FPE as FPE_Y (m,n).

iii) Compare FPE_Y (m, 0) with FPE_Y (m,n) [i.e., compare the smallest FPE in step (i) with the smallest FPE in step (ii)]. If FPE_Y (m,0)-FPE_Y (m,n)>0, then X_t is said to cause Y_t. If FPE_Y (m,0)-FPE_Y (m,n)<0, then Y_t is an independent process.

iv) Repeat steps i) to iii) for the X_t variable, treating Y_t as the manipulated variable.

When X_t and Y_t are not stationary variables, but are first-difference stationary [i.e., they are I(1) variables] and cointegrated (see Dolado *et al.*, 1990), it is possible to investigate the causal relationships from ΔX_t to ΔY_t and from ΔY_t to ΔX_t, using the following error correction models:

$$\Delta Y_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta Y_{t-i} + \varepsilon_t \qquad (3)$$

$$\Delta Y_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta Y_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta X_{t-j} + \varepsilon_t \qquad (4)$$

where Z_t is the OLS residual of the cointegrating regression ($Y_t = \mu + \lambda X_t$), known as the error-correction term. Note that, if X_t and Y_t are I(1) variables but are not cointegrated, then β in (3) and (4) is assumed to be equal to zero.

In both cases [i.e., X_t and Y_t are I(1) variables, and they are or they are not cointegrated], we can use Hsiao's sequential procedure substituting Y_t with ΔY_t and X_t with ΔX_t in steps (i) to (iv), as well as substituting expressions (1) and (2) with equations (3) and (4).

2.2 Stability Diagnostics

In the conventional Granger-causality analysis, the relationship between two variables is assumed to exist at all times. However, in a context of financial crisis, parameter non-constancy may occur and may generate misleading inferences if left undetected (see, Bai and Perron, 1998, 2003; Perron, 1989; Zivot and Andrews, 1992). Furthermore, the pre-testing issue in early studies may induce a size distortion of the resulting test procedures (Bai, 1997). Thus, it is desirable to let the data select when and where regime shifts occur. To this end, we first identify a single structural change using the Quandt–Andrews one-time unknown structural break test. We then use the procedure suggested by Bai (1997) and Bai and Perron (1998, 2003) to detect multiple unknown breakpoints in order to obtain further evidence of the existence of the breakpoints previously detected endogenously. These breakpoints allow the identification of pre-crisis and crisis periods for each pair-wise causal relationship, which are needed for the detection of a possible contagion episode.

2.2.1 Quandt-Andrews Breakpoint Test

A particular challenge in empirical time series analysis is to determine the appropriate timing of the structural test. In a traditional Chow (1960) test, we have to set a specific breakpoint based on *a priori* knowledge about the potential break date. In our analysis, however, we do not assume any prior knowledge about potential break dates. We use the heteroskedasticity-robust Quandt–Andrews unknown breakpoint test, originally introduced by Quandt (1960) and later developed by Andrews (1993) and Andrews and Ploberger (1994). The idea behind the Quandt-Andrews test is that a single Chow breakpoint test is performed at every observation between two dates, or observations (τ_1 and τ_2). The k test statistics from those Chow tests are then summarized into one test statistic for a test against the null hypothesis of no breakpoints between τ_1 and τ_2.

From each individual Chow breakpoint test, the Likelihood Ratio F-statistic (based on the comparison of the restricted and unrestricted sums of squared residuals) is retained. The individual test statistics can be summarized in three different statistics; the Sup or Maximum statistic, the Exp statistic, and the Ave statistic (see Andrews, 1993 and Andrews and Ploberger, 1994). The Maximum statistic is simply the maximum of the individual Chow F-statistics:

$$MaxF = \max_{\tau_1 \le \tau \le \tau_2} (F(\tau))$$

The Exp statistic takes the form:

$$ExpF = \ln\left(\frac{1}{k}\sum_{\tau=\tau_1}^{\tau_2} \exp\left(\frac{1}{2}F(\tau)\right)\right)$$

Finally, the Ave statistic is the simple average of the individual F-statistics:

$$AveF = \frac{1}{k}\sum_{\tau=\tau_1}^{\tau_2} F(\tau)$$

We set a search interval $\tau \in [0.15, 0.75]$ for the full sample T to allow a minimum of 15% of effective observations contained in both pre- and post-break periods.

2.2.2 Multiple Breakpoint Tests

For a specific set of unknown breakpoints $(T_1, ..., T_m)$, we use the following set of tests developed by Bai and Perron (1998, 2003) to detect multiple structural breaks: the sup F type test, the double maximum tests, and the test for ℓ versus $\ell + 1$ breaks. First, we consider the sup F type test of no structural breaks ($m = 0$) versus the alternative hypothesis that there are $m = k$ breaks. Second, we use the double maximum tests, *UD*max and *WD*max. They contrast the null hypothesis of no structural breaks against an unknown number of breaks given some upper bound *m**. Finally, we use the test for ℓ versus $\ell + 1$ breaks, the labelled sup $F_T(\ell + 1/\ell)$ test. The method involves the application of the $(\ell+1)$ test of the null hypothesis of no structural change versus the alternative hypothesis of a single change. The test is applied to each segment containing the observations $\hat{T}_{i-1}$ to $\hat{T}_i$ $i=1,\dots,(\ell+1)$. To run these tests it is necessary to decide the minimum distance between two consecutive breaks, *h*, which is obtained as the integer part of a trimming parameter, ε, multiplied by the number of observations *T* (we use $\varepsilon = 0.15$ and allow up to four breaks).

To select the dimension of the models, we follow the method suggested by Bai and Perron (1998) based on the sequential application of the sup $F_T(\ell+1/\ell)$ test, the sequential procedure.

2.3 Testing for Causality Intensification

As stated above, Granger causality measures precedence and information content. Therefore, the statement "*X* Granger causes *Y*" implies that past values of *X* provide relevant and valuable information about the future behaviour of *Y* that is not present in past values of *Y*.

Since the statistic we use to detect Granger-causality is FPE_Y (m,0)-FPE_Y (m,n), we can compute this statistic before and after the endogenously identified breakpoint, and thus assess the intensification or reduction in the causal relationship for those pairs in which we have found Granger-causality in both periods.

To this end, for each pair-wise relationship where we find causality both in the tranquil and in the crisis periods, we compare FPE_Y (m,0)-FPE_Y (m,n) in these periods. If this statistic is higher in the crisis than in the tranquil period, we can conclude that an intensification in the causal relationship has taken place. Indeed, this result shows that in the crisis period, even though the uncertainty is by definition higher, the X_t (or ΔX_t) in equation (2) [or in equation (4)] contains relatively more useful information for forecasting the Y_t (or ΔY_t) which is not contained in past values of Y_t (or ΔY_t), than during the pre-crisis period. Conversely, if this statistic is lower in the crisis period than in the tranquil one, we can infer a reduction in the causal relationship, since the extra lagged variables are less useful now for providing information about the future behaviour of the yield under study during the crisis period than during the pre-crisis period.

In doing so, we are first evaluating the "forecast conditional efficiency" in the terminology of Granger and Newbold (1973, 1986) [or "forecast encompassing" according to Chong and Hendry (1986) and Clements and Hendry (1993)] of the manipulated variable X_t (or ΔX_t) in equation (2) [or equation (4)] for each period, by examining whether X_t (or ΔX_t) contains useful information for forecasting the Y_t (or ΔY_t) which is not contained in past values of Y_t (or ΔY_t), and then comparing them and assessing the relative gains in forecast accuracy in each period.

3. Data

We use daily data of 10-year bond yields from January 1st 1999 to December 31st 2012 collected from Thomson Reuters Datastream for EMU-11 countries: both central (Austria, Belgium, Finland, France, Germany and the Netherlands) and peripheral countries (Greece, Ireland, Italy, Portugal and Spain).

[Insert Figure 1 and Figure 2 here]

Figure 1 plots the evolution of daily 10-year bond yields for each country in our sample, whilst Figure 2 displays the evolution of their spread against the German bund. A simple look at these figures allows us to identify two periods, although the breakpoint is not the same in all countries. Between January 1999 and summer 2008, the 10-year bond yields of different countries were evolving simultaneously, and spreads presented only small differences across countries. Only at the end of this period, following the collapse of Lehman Brothers in September 2008, did the major tensions emerging in the financial markets worldwide affect the euro area sovereign debt market since, in a context in which the crisis had already reached the real sector, the problems in the banking sector began to spread to euro area sovereign states.

[Insert Table 1 here]

The descriptive statistics of the dependent variable in our model, the 10-year government bond yield in EMU countries during the sample period, are presented in Table 1. As can be seen, the mean is not significantly different from zero for the first differences. Normality is tested with the Jarque-Bera test (which is distributed as $\chi 2(2)$ under the null) and strongly rejected for both the levels and first differences. Since rejection could be due to either excess of kurtosis or skewness, we report these statistics separately in Table 1. Given that the kurtosis of the normal distribution is 3, our results suggest that the distribution of the yields of Greece, Ireland, Italy and Portugal, as well as all the first differences, are peaked relative to the normal, while the distribution of the yields in the remainder cases are flat relative to the normal. Finally, regarding the asymmetry of the distribution of the series around their mean, we find positive skewness for the yields of Belgium, Greece, Ireland, Italy, Portugal and Spain, and for the first difference in the case of Austria, Belgium, Finland, France, Germany, the Netherlands and Portugal, suggesting that their distributions have long right tails; whilst in the cases of the levels of Austria, Finland, France, Germany, and the Netherlands and for the first differences of yields for Greece, Ireland, Italy and Spain there is evidence of negative skewness and therefore of distributions with long left tails.

4. Empirical results

4.1 Preliminary analysis

As a first step, we tested for the order of integration of the 10-year bond yields by means of the Augmented Dickey-Fuller (ADF) tests. The results, shown in Table 2, decisively reject the null hypothesis of nonstationarity, suggesting that both variables could be treated as first-difference stationary.

[Insert Table 2 here]

We also compute the Kwiatkowski *et al.* (1992) (KPSS) tests, where the null is a stationary process against the alternative of a unit root. As argued by Cheung and Chinn (1997), the ADF and KPSS tests can be viewed as complementary, rather than in competition with one another; therefore, we can use the KPSS tests to confirm the results obtained by the ADF tests. As can be seen in Table 3, the results fail to reject the null hypothesis of stationarity in first-difference but strongly reject it in levels.

[Insert Table 3 here]

As a second step, we tested for cointegration between each of the 55 pair combinations[9] of EMU-11 yields using Johansen (1991, 1995)'s approach. An important decision in this approach is whether to include deterministic terms in the cointegrating VAR. Deterministic terms, such as the intercept, linear trend, and indicator variables, play a crucial role in both data behaviour and limiting distributions of estimators and tests in integrated processes. Results in Banerjee *et al.* (1993), Johansen (1994) and Nielsen and Rahbek (2000) show the statistical properties of this commonly used test, namely that its size cannot be controlled in some cases, and that there is substantial power loss in other cases. Depending on their presence or absence, the system may manifest drift, linear trends in cointegration vectors, or even quadratic trends. In practical work, there seem to be only two relevant model

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[9] Recall that the number of possible pairs between our sample of EMU-11 yields is given by the following formula $\frac{n!}{r!(n-r)!} = \frac{11!}{2!(11-2)!} = 55$

representations for the analysis of cointegration between most economic time series variables:

i. the level data have no deterministic trend and the cointegrating equations have intercepts, and
ii. the level and the cointegrating equations have linear trends.

Table 1 shows that the hypothesis of the expected values of the first differences of the series is equal to zero cannot be rejected; hence there is no evidence of linear deterministic trends in the data. The graphs in Figure 1 support this conclusion. Therefore, we conclude that the cointegrated VAR model should be formulated according to i) with the constant term restricted to the cointegration space, and no deterministic trend terms. This implies that some of the equilibrium means are different from zero.

As can be seen in Table 4, only for the Austria-Finland, Austria-France, Finland-France, Finland-Netherlands, Greece-Ireland, Greece-Portugal, Ireland-Italy, Ireland-Portugal, Italy-Netherlands and Italy-Portugal cases does the trace test indicate the existence of one cointegrating equation at least at the 0.05 level. Therefore, for these pairs we test for Granger-causality in the first difference of the variables, with an error-correction term added [i. e., equations (3) and (4)], whereas for the remaining cases, we test for Granger-causality in first difference of the variables, with no error-correction term added [i. e., equations (3) and (4) with $\beta=0$]

[Insert Table 4 here]

4. 2. Detecting structural breakpoints

As we explained above, in order to detect contagion in the euro area sovereign debt markets, we need to identify a tranquil or pre-crisis period. To do so, unlike previous studies, we do not set a specific breakpoint based on *a priori* knowledge about the potential break date; first we use the Quandt-Andrews breakpoint test and let the data select when regime shifts occur in each potential causal relationship, and later we confirm the identified breakpoint by using one of the tests developed by Bai and Perron (1998, 2003) to detect multiple structural breaks. Table 5 shows that 70% of the total break dates (77 out of the 110 cases analysed) can be explained by some of the following five triggering events[10]: (1) the increase in the ECB interest rates by 25 basis points on July 3rd 2008; (2) the Lehman Brothers collapse on September 15th 2008; (3) the admission by Papandreou's government that its finances were far worse than in previous announcements in November 2009; (4) Greece's request for financial support on April 23rd 2010; and (5) Ireland's request of financial support on November 21st 2010.

[Insert Table 5 here]

These results suggest that not only can most of the breakpoints be explained by systemic shocks, but that half of them (54 out of 110) are directly connected to the euro sovereign debt crisis (triggering events 3 to 5). Besides, 69 out of the 110 breakpoints (i. e., 63%) occur after November 2009, after Papandreou's government had 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, and 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.

[10] In order to save space, the numerical results of Quandt-Andrews and Bai-Perron tests are not reported in Table 5, but they are available upon request.

Furthermore, it is also notable that all break dates, including the 30% which are not related to one of the five triggering events mentioned above[11], occur between January 2008 and December 2010, suggesting that systemic rather than idiosyncratic factors explain euro area sovereign debt market turmoil. However, since the precise regime shift date changes depending on the causal relationship, our analysis improves on previous studies by using in each relationship the breakpoint obtained from the Quandt–Andrews and Bai-Perron tests.

4. 3. Changes in the number of Granger-causal relationships

Given the evidence presented in the previous sub-section, in ten relationships (Austria-Finland, Austria-France, Finland-France, Finland-Netherlands, Greece-Ireland, Greece-Portugal, Ireland-Italy, Ireland-Portugal, Italy-Netherlands and Italy-Portugal) we test for Granger-causality in the first difference of the variables, with an error-correction term added. In all other cases, we test for Granger-causality in the first difference of the variables, with no error-correction term added. The causal relationships resulting from the estimated FPE statistics for the pre-crisis and crisis periods jointly with the break dates resulting from the Quandt–Andrews and Bai-Perron tests are shown in Tables 6 to 9[12].

[Insert Table 6 to Table 9 here]

The changes in causal relationships in the crisis period compared to the pre-crisis period are drawn in Figures 3 to 6 (red arrows represent relationships that did not exist before the breakpoint, whilst blue arrows reflect relationships that disappear with the crisis).

[Insert Figure 3 to Figure 6 here]

[11] We make use of equality tests to formally evaluate the null hypothesis that the mean and variance in the pre-crisis and crisis periods are equal against the alternative that they are different. The results (not shown here to save space, but available from the authors upon request) indicate strong evidence that they differ across periods.

[12] These results were confirmed using both Wald statistics to test the joint hypothesis $\hat{\gamma}_1 = \hat{\gamma}_2 = ... = \hat{\gamma}_n = 0,$ and the Williams-Kloot test for forecasting accuracy (Williams, 1959). These additional results are not shown here to save space, but are available from the authors upon request.

Specifically, Table 6 and Figure 3 present the evolution of the causality running from EMU central to EMU peripheral countries. The behaviour of causality running from EMU peripheral to EMU central countries is displayed in Table 7 and Figure 4. Table 8 and Figure 5 show the evolution of causality running within EMU central countries. Finally, Table 9 and Figure 6 report how causality running within EMU peripheral countries has evolved during the two periods.

As can be seen, for the four subsamples of countries, the number of causal relationships increases as the financial and sovereign debt crisis develops in the euro area. If we focus on the evolution of causality between EMU peripheral and EMU central countries (Tables 5 and 6 and Figures 3 and 4), it can be observed that in the pre-crisis period causality is higher if EMU central countries are triggers rather than EMU peripheral countries. In particular, our results indicate the existence of 19 causal relationships in the first case (Figure 3a) and 10 in the second (Figure 4a). Two interesting findings are worth pointing out: (1) in the pre-crisis period, the evolution of Greek sovereign yields does not Granger-cause that of other EMU central countries, and (2) the Netherlands' yield behaviour is not Granger-caused by the evolution of yields of any EMU peripheral country (see Figure 4a).

During the crisis period, even though the number of causal relationships detected increases in both directions, they are more frequent when EMU peripheral countries are the triggers. We find 24 out of 30 causal relationships when the EMU central countries are the triggers (Figure 3b), whilst the number of causality linkages rises from 10 to 27 if the triggers are EMU peripheral countries (Figure 4b). Interestingly, Greece now Granger-causes Austria, Belgium, Finland and France, whilst Netherlands' yield behaviour is caused by Spanish and Irish yield behaviour. Moreover, another relevant finding is that with the crisis, four causal relationships from central to peripheral countries disappear: Austria-Ireland, Belgium-

Greece, France-Portugal and Netherlands-Ireland, suggesting a temporal disconnection between them.

Table 8 and Figure 5 present the results regarding causality running within EMU central countries in the two periods. From these results it can be inferred that the number of causal relationships also increases in the crisis period, since we find evidence of bidirectional causality in all 15 relationships (Figure 5c). Hence, causality linkages increase from 21 to 30 during the crisis compared to the pre-crisis period.

Finally, Table 9 and Figure 6, which present the results regarding causal relationships running within EMU peripheral countries in the two periods of study, also suggest that their number is boosted as the financial and sovereign debt crises expand in the euro area. We find evidence of 14 relationships in the pre-crisis period (Figure 6a) and 20 in the crisis period. In the pre-crisis period the exceptions are: a) Greece-Ireland, where there is no evidence of Granger-causality in either direction, and b) some relationships where we do not find unidirectional Granger-causality: from Greece to Italy and Spain, and from Portugal and Spain to Ireland. Nevertheless, we find evidence of bidirectional causality in all the relationships during the crisis period.

4. 4. Changes in the intensity of Granger-causal relationships

As mentioned above, for each of the 60 cases where we find causality in both the tranquil and the crisis periods, we compare FPE_X (m,0)-FPE_X (m,n) in the two periods. If this statistic is higher in the crisis than in the tranquil period, we can conclude that the causal relationship has intensified. Conversely, if this statistic is lower in the crisis period than in the tranquil one, we can infer a reduction in the causal relationship.

In the last column in Tables 6 to 9, we report the results of this exploratory exercise. As can be seen, even though in the aftermath of the crisis there is an increase in volatility (see Figure 1), we obtain evidence of causality intensification with respect to the more stable pre-crisis period[13]. The causing yields improve the forecast accuracy of the caused yields during the crisis period compared with the tranquil period, indicating that after the detected breakpoint they carry even more useful informational content about the future behaviour of the caused yields.

Regarding the causal relationships running from EMU central to EMU peripheral countries, in 10 out of the 15 cases where we find causality both in the tranquil and in the crisis period, we find that the relationship intensifies (Table 6). As for the causality linkages going from EMU peripheral to EMU central countries, an increase in causality after the endogenously identified crisis is detected in six of the 10 possible cases (Table 7). With regard to the causal relationships within EMU central countries, we find evidence of significant relative rise in causality after the crisis in 14 out of the 21 possible cases (Table 8). Finally, when examining the causal relationships within EMU peripheral countries we conclude that they increase after the crisis in 12 of the 14 possible cases (Table 9).

4.5. Contagion assessment

From the above analysis we can conclude that, in the crisis period, not only do we find some new causality patterns which had been absent before its start, but also an intensification of causality in 70% of the cases which would allow us to establish that those linkages may be purely crisis-contingent.

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[13] Note that, in contrast to tests for contagion based on cross-market correlation measures, we do not need to adjust for the shift in volatility from the tranquil period to the crisis period.

Specifically, causal relationships running from EMU peripheral countries record an important increase in the crisis period: not only relationships within peripheral countries (Figure 6 shows six new linkages), but also causal relationships running from EMU peripheral to EMU central countries (Figure 4 displays 17 new causality patterns). This suggests that the problems of peripheral countries can spill over not only to other peripheral countries but also to EMU central countries since some of these banks (mostly German and French banks) are highly exposed to the debt of peripheral countries[14]. On the other hand, our results also suggest that tensions in sovereign debt markets spread to EMU central countries since nine new linkages appear (see Figures 3 and 5) both in the causal relationships running from EMU central to EMU peripheral countries and between EMU central countries.

In our view, these 41 new causality patterns out of the 101 causal relationships that exist in the crisis period within the 11 euro area countries analyzed (which were absent before the break date, determined endogenously for each causal relationship), together with the intensification of the causal relationship in 42 of the 60 cases in which we find causality both in the tranquil and in the crisis period, can be considered an important operative measure of contagion consistent with our definition and in line with the one proposed by Forbes and Rigobon (2002).

5. Conclusions

This paper has three main objectives: (1) to test for the existence of possible Granger-causal relationships between the evolution of the yield of bonds issued by both peripheral and central EMU countries; (2) to determine endogenously the breakpoints in the evolution of those relationships; and (3) to detect contagion episodes according to an

[14] See Gómez-Puig and Sosvilla-Rivero (2013)

operative definition: an abnormal increase in the number or in the intensity of causal relationships compared with that of tranquil periods, triggered by an endogenously detected shock.

The Quandt–Andrews and Bai-Perron tests identify around two thirds out of the total breakpoints after November 2009, suggesting that it is regional rather than global factors that are behind the euro area crisis. As expected, the number of causal relationships increases as the financial and sovereign debt crisis develops in the euro area and, after the break dates, causality patterns are more frequent when EMU peripheral countries are the triggers. In the crisis period we find 41 new causality patterns, and we also detect intensification of the causal relationship in 70% of the cases. Therefore, our results support the hypothesis of a systemic increase in the number and intensity of cross-market linkages after an endogenously identified shock in the market, consistent with our operational definition of contagion.

Regarding policy implications, our results seem to indicate that EMU has brought about strong interlinkages of the participating countries, which in good times exist as strong degrees of financial integration and in bad times are found in the transmission of negative effects across the euro area. We think that this is a very interesting and informative feature of the current sovereign debt crisis. Given that financial markets' conditions are cyclical (and as a result will eventually reverse, once again, to the positive side), this finding supports the interconnectedness of the euro area and, possibly, its irreversibility.

Acknowledgements

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Figure 1. Daily 10-year sovereign yields in EMU-11 countries: 1999-2012

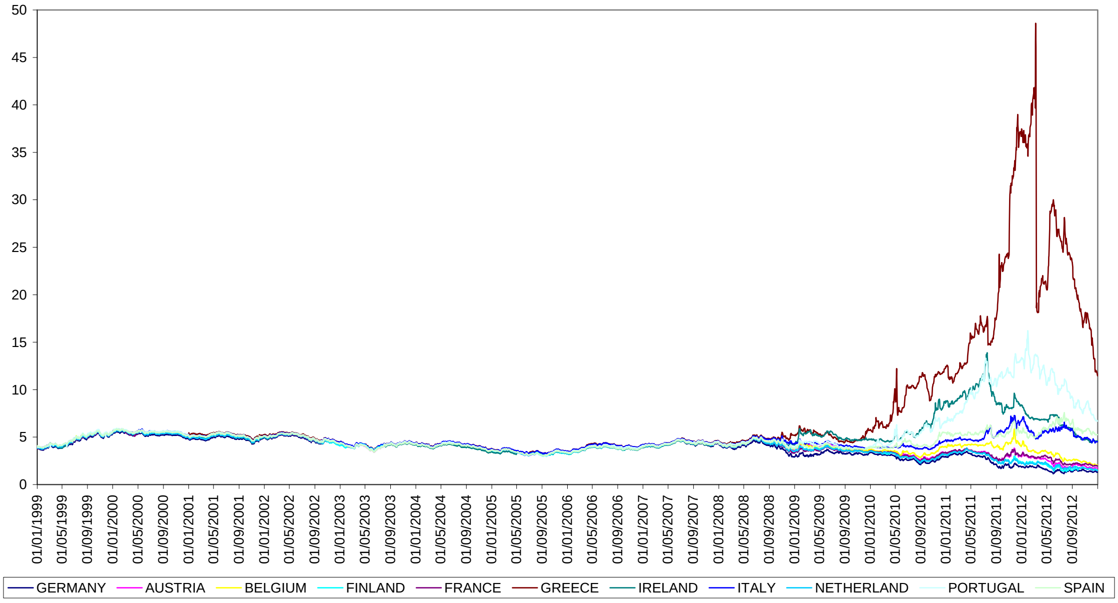

Figure 2. Daily 10-year sovereign yield spreads over Germany: 1999-2012

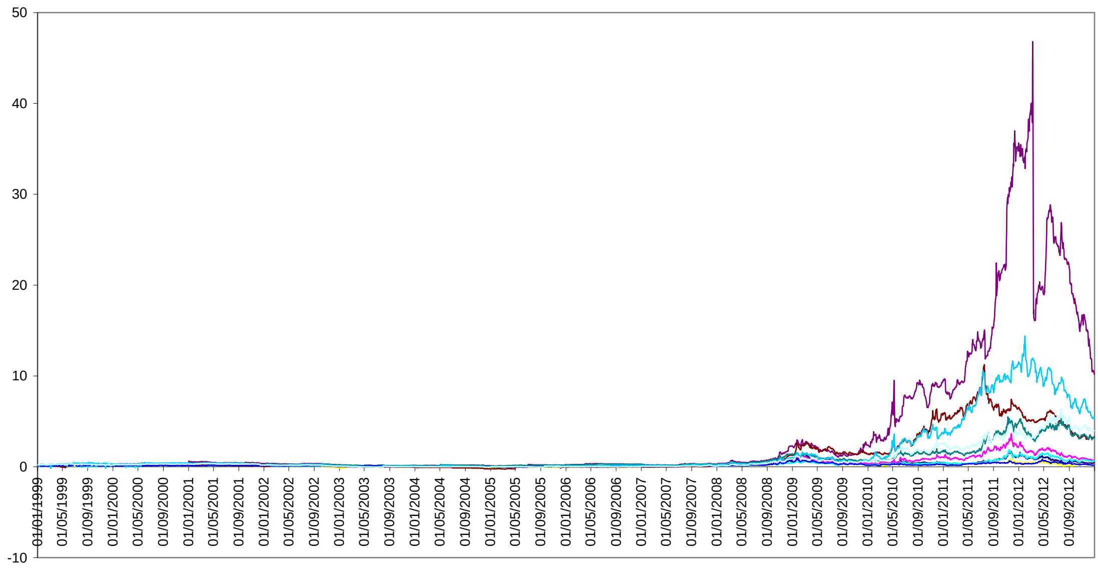

Figure 3: Causal relationships between EMU Central and EMU Peripheral countries.

Figure 3a: Pre-crisis period

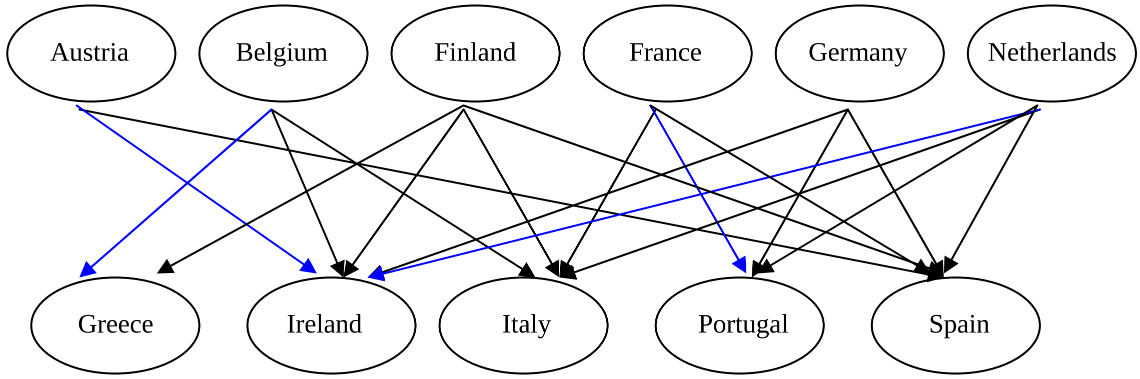

Figure 3b: Crisis period

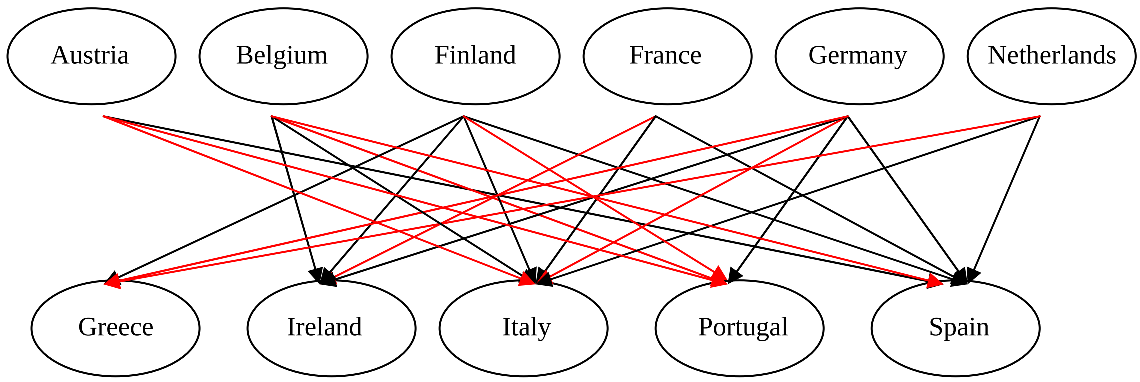

Figure 4: Causal relationships from EMU Peripheral to EMU Central countries.

Figure 4a: Pre-crisis period

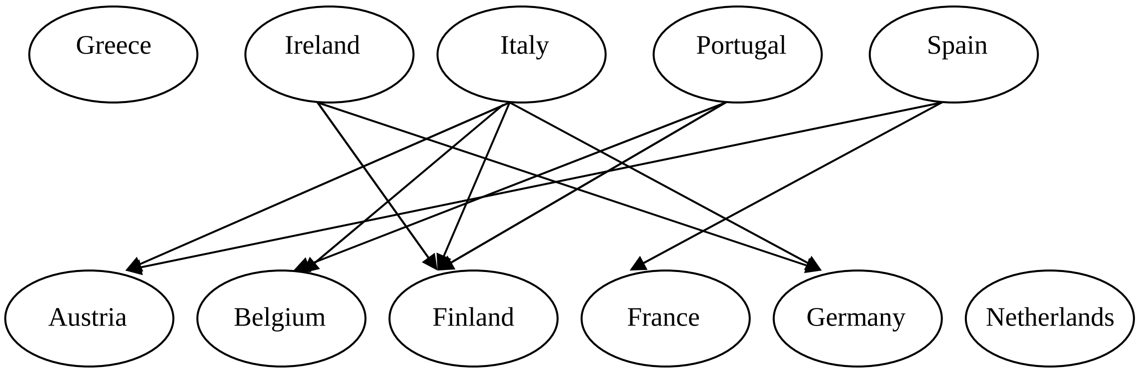

Figure 4b: Crisis Period

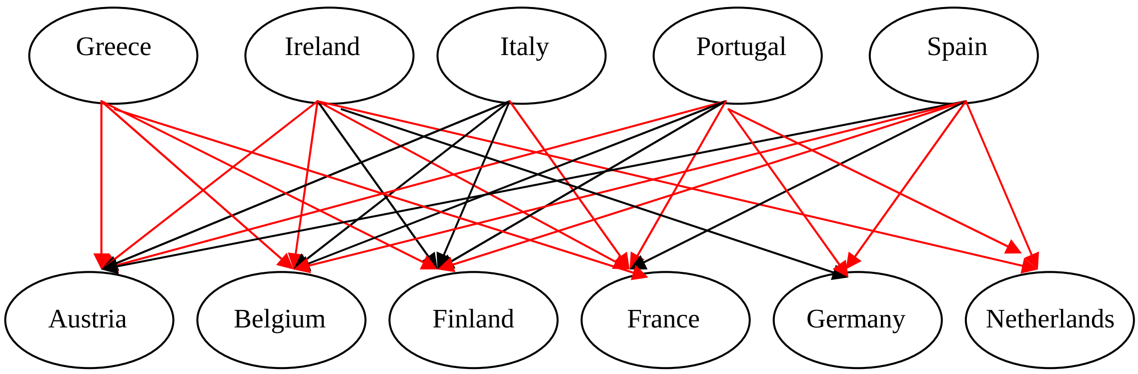

Figure 5: Causal relationships within EMU Central countries.

Figure 5a: Pre-crisis period

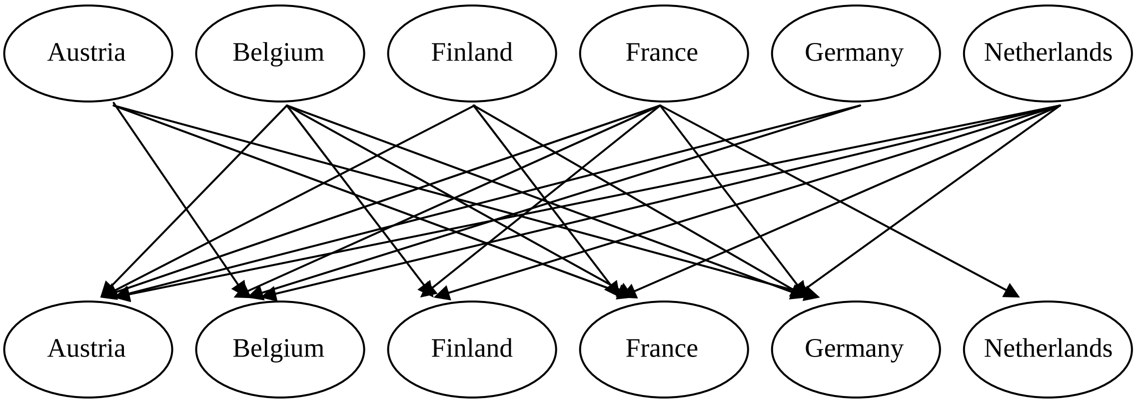

Figure 5b: Crisis Period

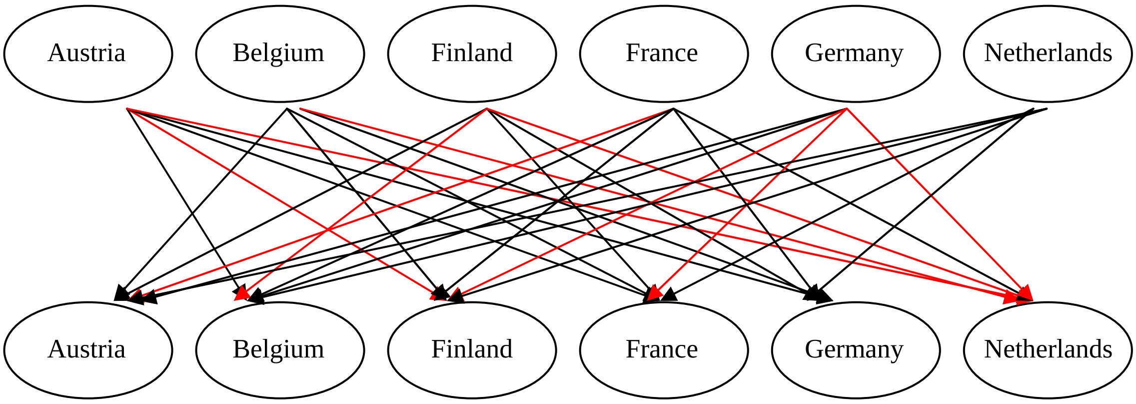

Figure 6: Causal relationships within EMU Peripheral countries.

Figure 6a: Pre-crisis period

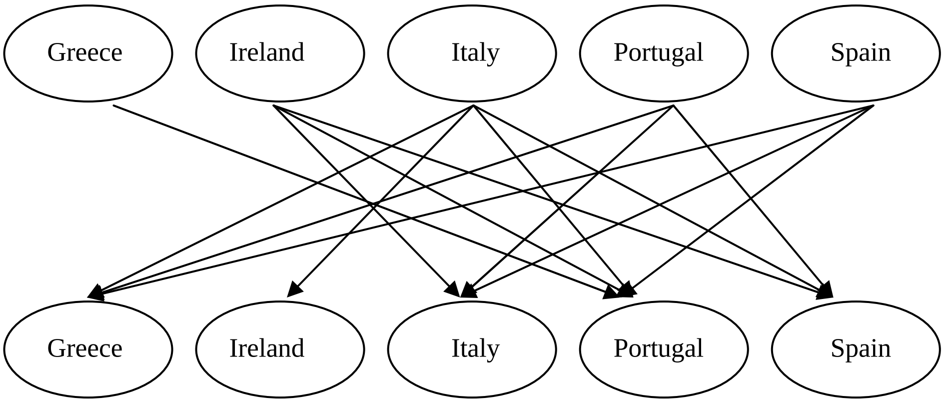

Figure 6b: Crisis period

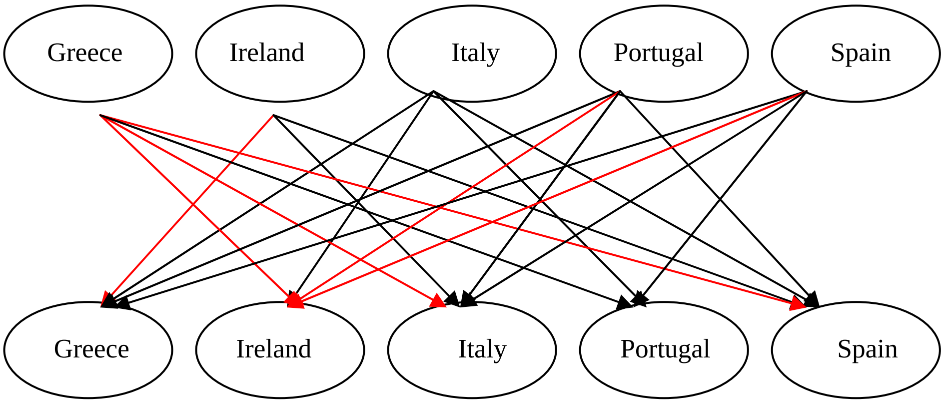

Table 1. Descriptive statistics

Panel A: Levels

	AT	BE	FI	FR	GE	GR	IE	IT	NL	PT	SP
Mean	4.057459	4.227579	3.950790	4.015918	3.792875	7.600870	5.005941	4.618034	3.956600	5.365012	4.564049
Median	4.062450	4.161400	3.990750	4.006900	3.946750	5.115850	4.658300	4.490400	4.016300	4.543150	4.346550
Maximum	5.868300	5.881300	5.840100	5.833400	5.646300	48.60200	13.89500	7.288000	5.780800	16.21100	7.590000
Minimum	1.706000	2.048700	1.359000	1.954000	1.149000	3.205600	3.037800	3.214600	1.491400	2.997000	3.025000
Std. Dev.	0.884764	0.758488	0.967157	0.821462	1.011153	6.855286	1.559646	0.697661	0.940227	2.271520	0.781025
Skewness	-0.221063	0.024054	-0.397247	-0.085694	-0.618475	2.820479	2.032843	0.551483	-0.454454	2.155841	0.503074
Kurtosis	2.877678	2.825848	2.912022	2.616165	2.933690	11.06645	7.851619	3.071409	2.870659	7.031252	2.745439
Jarque-Bera	32.02157	4.967221	97.22834	26.88835	233.4908	14484.76	6097.015	185.8916	128.2525	5301.730	163.9038
Probability	0.000000	0.083441	0.000000	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	14817.84	15439.12	14428.28	14666.13	13851.58	27271.92	18281.70	16865.06	14449.50	19593.02	16667.91
Sum Sq. Dev.	2858.030	2100.434	3415.116	2463.696	3732.894	168570.9	8881.045	1777.053	3227.584	18838.44	2227.112
Observations	3652	3652	3652	3652	3652	3588	3652	3652	3652	3652	3652

Panel B: First differences

	DAT	DBE	DFI	DFR	DGE	DGR	DIE	DIT	DNL	DPT	DSP
Mean	-0.000631	-0.000551	-0.000693	-0.000524	-0.000705	0.001537	0.000172	0.000123	-0.000672	0.000719	0.000322
Median	-0.000200	-0.000400	-0.000400	-0.000100	-0.001000	-0.000100	-0.000700	-0.000200	-0.000100	-0.000100	-0.000200
Maximum	0.254000	0.344000	0.246100	0.250100	0.193100	7.028000	0.750000	0.509000	0.177100	1.686000	0.373000
Minimum	-0.217000	-0.302000	-0.239000	-0.262900	-0.256000	-27.47500	-1.027900	-0.780000	-0.224000	-1.469800	-0.883000
Std. Dev.	0.044269	0.046034	0.043890	0.045503	0.043450	0.524679	0.074384	0.057705	0.042549	0.103013	0.059495
Skewness	0.314611	0.130930	0.186139	0.087682	0.100390	-39.36020	-0.231766	-1.089643	0.144703	1.213480	-1.262756
Kurtosis	5.202142	7.639839	4.677189	5.766810	4.471790	21.10096	32.86899	27.80910	4.196888	62.51168	24.15220
Jarque-Bera	797.9487	3285.394	449.0052	1169.231	335.6605	6.64E+08	135752.0	94354.09	230.6665	539668.1	69033.38
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	-2.305600	-2.009900	-2.530100	-1.912000	-2.574400	5.512700	0.626300	0.450300	-2.451700	2.625800	1.175100
Sum Sq. Dev.	7.153120	7.734751	7.031203	7.557317	6.890938	987.1846	20.19561	12.15390	6.607870	38.73229	12.91954
Observations	3651	3651	3651	3651	3651	3587	3651	3651	3651	3651	3651

AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.

Table 2. Augmented Dickey- Fuller tests for unit roots.

Panel A: I (2) versus I (1)			
	τ_τ	τ_μ	τ
DAT	-56.7020*	-56.6721*	-56.6704*
DBE	-51.7753*	-51.7534*	-51.7548*
DFI	-57.8975*	-57.8669*	-57.8619*
DFR	-59.1308*	-59.1061*	-59.1077*
DGE	-56.7370*	-56.7036*	-56.6987*
DGR	-22.5230*	-22.5258*	-22.5280*
DIE	-35.5228*	-35.5240*	-35.5286*
DIT	-36.6792*	-36.6815*	-36.6861*
DNL	-56.5094*	-56.4727*	-56.4686*
DPT	-20.8407*	-20.8436*	-20.8404*
DSP	-32.4944*	-32.4988*	-32.5010*
Panel B: I (1) versus I (0)			
	τ_τ	τ_μ	τ
AT	-2.8613	-0.5504	-0.8558
BE	-2.8894	-1.1936	-0.7846
FI	-2.5708	-0.2092	-0.9764
FR	-3.1388	-0.7678	-0.8351
GE	-2.9983	-0.2832	-0.9178
GR	-2.6803	-2.1530	-1.2963
IE	-1.9652	-1.9674	-0.4612
IT	-2.6669	-2.6201	-0.2387
NL	-2.8488	-0.2945	-0.8901
PT	-1.4804	-1.3073	-0.0698
SP	-2.3831	-2.3817	-0.0633

Notes:
The ADF statistic is a test for the null hypothesis of a unit root.
τ_τ. τ_μ and τ denote the ADF statistics with drift and trend, with drift, and without drift, respectively.
* denotes significance at the 1% level. Critical values based on MacKinnon (1996)
AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.

Table 3. KPSS tests for stationarity

Panel A: I (2) versus I (1)		
	τ_τ	τ_μ
DAT	0.0647	0.2191
DBE	0.0758	0.1897
DFI	0.0592	0.1969
DFR	0.0757	0.1190
DGE	0.0478	0.2448
DGR	0.0345	0.0398
DIE	0.0879	0.0835
DIT	0.0599	0.0568
DNL	0.0588	0.2526
DPT	0.0716	0.0718
DSP	0.0530	0.0584
Panel B: I (1) versus I (0)		
	τ_τ	τ_μ
AT	0.3996*	4.9550*
BE	0.4150*	4.0166*
FI	0.4447*	5.2529*
FR	0.3248*	5.1893*
GE	0.5365*	5.6121*
GR	1.1743*	3.0363*
IE	1.0815*	2.2581*
IT	1.0165*	1.1198*
NL	0.4570*	5.2661*
PT	1.2315*	2.4834*
SP	1.3217*	1.3123*

Notes:
The KPSS statistic is a test for the null hypothesis of stationarity.
τ_τ and τ_μ denote the KPSS statistics with drift and trend, and with drift, respectively.
* denotes significance at the 1% level. Asymptotic critical values based on Kwiatkowski *et al.* (1992. Table 1)
AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.

Table 4. Cointegration tests

	Hypothesized numbers of cointegrating relations	Trace statistic[a]	p-value[b]
AT. BE	None At most one	11.9479 1.0321	0.4534 0.9474
AT. FI	None At most one	20.2618* 9.1645	0.0065 0.9600
AT. FR	None At most one	22.3931** 0.8805	0.0251 0.9657
AT. GE	None At most one	9.5054 0.8924	0.6882 0.9644
AT. GR	None At most one	9.0425 1.1372	0.7323 0.9328
AT. IE	None At most one	6.3485 1.2095	0.9340 0.9219
AT. IT	None At most one	8.3411 1.2653	0.7957 0.9132
AT. NL	None At most one	17.8997 0.8453	0.1024 0.9694
AT. PT	None At most one	7.9545 1.5432	0.8280 0.8656
AT. SP	None At most one	8.7303 1.9609	0.7611 0.7855
BE. FI	None At most one	12.7795 1.1536	0.3817 0.9303
BE. FR	None At most one	11.8958 1.2328	0.4582 0.9183
BE. GE	None At most one	9.4260 1.0545	0.6958 0.9444
BE. GR	None At most one	12.8454 3.4545	0.3763 0.4994
BE. IE	None At most one	5.5265 1.2324	0.9674 0.9184
BE. IT	None At most one	9.8880 1.2737	0.6508 0.9119
BE. NL	None At most one	10.2220 0.9798	0.6180 0.9541
BE. PT	None At most one	8.7857 3.0979	0.7561 0.5626
BE. SP	None At most one	8.8834 1.9915	0.7471 0.7794
FI. FR	None At most one	24.7092** 0.9305	0.0114 0.9590
FI. GE	None At most one	6.8434 0.8368	0.9069 0.9703
FI. GR	None At most one	8.8404 1.0307	0.7511 0.9475
FI. IE	None At most one	7.0084 1.2193	0.8967 0.9204
FI. IT	None At most one	8.7980 1.2620	0.7550 0.9137

FI. NL	None At most one	30.1779* 0.9600	0.0016 0.9565
FI. PT	None At most one	8.1555 1.3697	0.8114 0.8961
FI. SP	None At most one	8.5333 1.8702	0.7789 0.8034
FR. GE	None At most one	13.5117 0.9111	0.3244 0.9623
FR. GR	None At most one	9.0245 1.2562	0.7340 0.9146
FR. IE	None At most one	6.0276 1.1843	0.9488 0.9258
FR. IT	None At most one	8.3984 1.1284	0.7907 0.9340
FR. NL	None At most one	17.6169 0.8660	0.1111 0.9673
FR. PT	None At most one	6.8323 1.4282	0.9075 0.8861
FR. SP	None At most one	8.3855 1.5201	0.7918 0.8698
GE. GR	None At most one	9.3212 0.9575	0.7059 0.9568
GE. IE	None At most one	6.9969 1.1413	0.8974 0.9322
GE. IT	None At most one	8.2820 1.2034	0.8007 0.9229
GE. NL	None At most one	12.3399 0.9987	0.4188 0.9517
GE. PT	None At most one	7.8258 1.1658	0.8383 0.9285
GE. SP	None At most one	8.4601 1.5887	0.7853 0.8572
GR. IE	None At most one	21.8905** 4.7395	0.0296 0.3132
GR. IT	None At most one	17.1477 4.8966	0.1271 0.2949
GR. NL	None At most one	8.9244 0.9596	0.7433 0.9566
GR. PT	None At most one	53.0634* 2.0624	0.0000 0.7652
GR. SP	None At most one	15.1575 3.3759	0.2175 0.5129
IE. IT	None At most one	22.4423** 7.4435	0.0247 0.1049
IE. NL	None At most one	6.6633 1.1204	0.9173 0.9352
IE. PT	None At most one	28.1766* 6.4209	0.0033 0.1606
IE. SP	None At most one	16.1657 5.2525	0.1668 0.2569
IT. NL	None At most one	22.4428** 7.4435	0.0247 0.1049

IT. PT	None At most one	22.4428** 7.4435	0.0247 0.1049
IT. SP	None At most one	17.4499 5.8882	0.1166 0.1995
NL. PT	None At most one	7.4056 1.1992	0.8699 0.9235
NL. SP	None At most one	8.7692 2.0050	0.7576 0.7767
PT. SP	None At most one	16.9398 2.9291	0.1348 0.5940

Notes:
[a] * and ** denote rejection of the hypothesis at the 1% and 5% levels respectively.
[b] MacKinnon *et al.* (1999)'s p-values
AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.

Table 5: Causal relationships' break dates

Causal relationship	Break date
(1) 07/03/2008: ECB increases interest rates by 25 basis points	
PT → NL	07/04/2008
SP → NL	07/04/2008
FR → NL	07/04/2008
GE → FI	07/04/2008
GE → NL	07/04/2008
NL → GE	07/04/2008
IE → NL	07/04/2008
IT → GE	07/04/2008
GR → GE	07/04/2008
GR → NL	07/04/2008
FR → PT	07/04/2008
FR→ SP	07/04/2008
IE → GE	07/04/2008
BE → NL	07/24/2008
(2) 09/15/2008: Lehman Brothers files for bankruptcy	
PT → IT	09/15/2008
PT → GE	10/08/2008
SP → GE	10/08/2008
FR → FI	10/08/2008
SP → IT	10/08/2008
NL → FI	10/28/2008
BE → GE	11/04/2008
IE → IT	11/14/2008
GR → IT	11/28/2008
(3) November 2009: Papandreou's government reveals that its finances were far worse than previous announcements	
BE → PT	11/30/2009
IT → PT	12/03/2009
IT→ SP	12/03/2009
GR → AT	12/21/2009
PT → FR	12/21/2009
SP → FR	12/21/2009
(4) 04/23/2010: Greece seeks financial support	
IT → AT	05/05/2010
FR → IT	05/07/2010
GE → IT	05/10/2010
GR→ SP	05/10/2010
NL → IT	05/10/2010
IT → NL	05/10/2010
SP → AT	05/10/2010
FR → AT	05/10/2010
FR → BE	05/11/2010
FI → IT	05/11/2010
FI → GR	05/11/2010
AT → GR	05/11/2010
AT → PT	05/11/2010

BE → IT	05/11/2010
BE → GR	05/11/2010
IE → BE	05/11/2010
IE → GR	05/12/2010
IT → GR	05/12/2010
SP → GR	05/12/2010
(5) 11/21/2010: Ireland seeks financial support	
FI → PT	11/21/2010
FI→ SP	11/21/2010
BE → SP	11/21/2010
FI → IE	11/21/2010
BE → IE	11/21/2010
NL → IE	11/21/2010
AT → BE	11/21/2010
AT → NL	11/21/2010
BE → FR	11/21/2010
FI → FR	11/21/2010
IT → IE	11/21/2010
PT → IE	11/21/2010
SP → IE	11/21/2010
SP→ PT	11/21/2010
GE → IE	11/22/2010
AT → SP	11/23/2010
AT → IT	11/23/2010
GE → BE	11/24/2010
NL → BE	11/24/2010
NL → FR	11/24/2010
FI → BE	11/24/2010
SP → BE	11/24/2010
GR → BE	11/24/2010
IT → BE	11/24/2010
PT → BE	11/24/2010
AT → FI	11/25/2010
NL→ SP	11/25/2010
GE → GR	12/10/2010
NL → GR	12/10/2010

Notes: Five triggering events explain 70% of total break dates.
AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.

Table 6: Causality running from EMU Central to EMU Peripheral countries

	Pre-crisis period	Crisis period	Break date	Causality changes
AT → IE	Yes	**No**	07/05/2010	-
AT → IT	**No**	Yes	11/23/2010	New
AT → GR	**No**	**No**	05/11/2010	-
AT → PT	**No**	Yes	05/11/2010	New
AT → SP	Yes	Yes	11/23/2010	Intensification
BE → IE	Yes	Yes	11/21/2010	Intensification
BE → IT	Yes	Yes	05/11/2010	Intensification
BE → GR	Yes	**No**	05/11/2010	-
BE → PT	**No**	Yes	11/30/2009	New
BE → SP	**No**	Yes	11/21/2010	New
FI → IE	Yes	Yes	11/21/2010	Intensification
FI → IT	Yes	Yes	05/11/2010	Intensification
FI → GR	Yes	Yes	05/11/2010	Intensification
FI → PT	**No**	Yes	11/21/2010	New
FI→ SP	Yes	Yes	11/21/2010	Intensification
FR → IE	**No**	Yes	07/05/2010	New
FR → IT	Yes	Yes	05/07/2010	Intensification
FR → GR	**No**	**No**	05/03/2010	-
FR → PT	Yes	**No**	07/04/2008	-
FR→ SP	Yes	Yes	07/04/2008	Intensification
GE → IE	Yes	Yes	11/22/2010	Reduction
GE → IT	**No**	Yes	05/10/2010	New
GE → GR	**No**	Yes	12/10/2010	New
GE → PT	Yes	Yes	01/08/2008	Reduction
GE→ SP	Yes	Yes	01/14/2010	Intensification
NL → IE	Yes	**No**	11/21/2010	-
NL → IT	Yes	Yes	05/10/2010	Reduction
NL → GR	**No**	Yes	12/10/2010	New
NL → PT	Yes	Yes	08/18/2008	Reduction
NL→ SP	Yes	Yes	11/25/2010	Reduction

Notes: AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.
Bold values indicate absence of Granger-causality.

Table 7: Causality running from EMU Peripheral to EMU Central countries

	Pre-crisis period	Crisis period	Break date	Causality Changes
IE → AT	**No**	Yes	09/18/2009	New
IE → BE	**No**	Yes	05/11/2010	New
IE → FI	Yes	Yes	01/29/2009	Intensification
IE → FR	**No**	Yes	03/23/2010	New
IE → GE	Yes	Yes	07/04/2008	Reduction
IE → NL	**No**	Yes	07/04/2008	New
IT → AT	Yes	Yes	05/05/2010	Reduction
IT → BE	Yes	Yes	11/24/2010	Intensification
IT → FI	Yes	Yes	07/04/2010	Intensification
IT → FR	**No**	Yes	01/05/2009	New
IT → GE	Yes	Yes	07/04/2008	Reduction
IT → NL	**No**	**No**	05/10/2010	-
GR → AT	**No**	Yes	12/21/2009	New
GR → BE	**No**	Yes	11/24/2010	New
GR → FI	**No**	Yes	07/04/2010	New
GR → FR	**No**	Yes	01/06/2009	New
GR → GE	**No**	**No**	07/04/2008	-
GR → NL	**No**	**No**	07/04/2008	-
PT → AT	**No**	Yes	01/06/2009	New
PT → BE	Yes	Yes	11/24/2010	Intensification
PT → FI	Yes	Yes	07/04/2010	Reduction
PT → FR	**No**	Yes	12/21/2009	New
PT → GE	**No**	Yes	10/08/2008	New
PT → NL	**No**	Yes	07/04/2008	New
SP → AT	Yes	Yes	05/10/2010	Intensification
SP → BE	**No**	Yes	11/24/2010	New
SP → FI	**No**	Yes	07/04/2010	New
SP → FR	Yes	Yes	12/21/2009	Intensification
SP → GE	**No**	Yes	10/08/2008	New
SP → NL	**No**	Yes	07/04/2008	New

Notes: AT, BE, FI, FR, GE, GR, IE, IT, NL, PT, and SP stand for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain, respectively.
Bold values indicate absence of Granger-causality.

Table 8: Causality running within EMU Central countries

	Pre-crisis period	Crisis period	Break date	Causality changes
AT → BE	Yes	Yes	11/21/2010	Intensification
AT → FI	**No**	Yes	11/25/2010	New
AT → FR	Yes	Yes	06/10/2008	Intensification
AT → GE	Yes	Yes	07/01/2008	Intensification
AT → NL	**No**	Yes	11/21/2010	New
BE → AT	Yes	Yes	06/01/2009	Reduction
BE → FI	Yes	Yes	06/04/2010	Intensification
BE → FR	Yes	Yes	11/21/2010	Intensification
BE → GE	Yes	Yes	11/04/2008	Reduction
BE → NL	**No**	Yes	07/24/2008	New
FI → AT	Yes	Yes	05/01/2009	Intensification
FI → BE	**No**	Yes	11/24/2010	New
FI → FR	Yes	Yes	11/21/2010	Intensification
FI → GE	Yes	Yes	07/01/2008	Intensification
FI → NL	**No**	Yes	06/04/2010	New
FR → AT	**No**	Yes	05/10/2010	New
FR → BE	Yes	Yes	05/11/2010	Reduction
FR → FI	Yes	Yes	10/08/2008	Reduction
FR → GE	Yes	Yes	07/01/2008	Intensification
FR → NL	Yes	Yes	07/04/2008	Intensification
GE → AT	Yes	Yes	06/06/2009	Intensification
GE → BE	Yes	Yes	11/24/2010	Intensification
GE → FI	**No**	Yes	07/04/2008	New
GE → FR	**No**	Yes	02/19/2008	New
GE → NL	**No**	Yes	07/04/2008	New
NL → AT	Yes	Yes	01/06/2009	Intensification
NL → BE	Yes	Yes	11/24/2010	Intensification
NL → FI	Yes	Yes	10/28/2008	Reduction
NL → FR	Yes	Yes	11/24/2010	Reduction
NL → GE	Yes	Yes	07/04/2008	Intensification

Notes: AT, BE, FI, FR, GE, and NL stand for Austria, Belgium, Finland, France, Germany and the Netherlands, respectively.
Bold values indicate absence of Granger-causality.

Table 9: Causality running within EMU Peripheral countries

	Pre-crisis period	Crisis period	Break date	Causality changes
IE → IT	Yes	Yes	11/14/2008	Intensification
IE → GR	**No**	Yes	05/12/2010	New
IE → PT	Yes	Yes	06/22/2009	Intensification
IE→ SP	Yes	Yes	03/02/2009	Intensification
IT → IE	Yes	Yes	11/21/2010	Intensification
IT → GR	Yes	Yes	05/12/2010	Intensification
IT → PT	Yes	Yes	12/03/2009	Reduction
IT→ SP	Yes	Yes	12/03/2009	Intensification
GR → IE	**No**	Yes	07/05/2010	New
GR → IT	**No**	Yes	11/28/2008	New
GR → PT	Yes	Yes	02/02/2010	Intensification
GR→ SP	**No**	Yes	05/10/2010	New
PT → IE	**No**	Yes	11/21/2010	New
PT → IT	Yes	Yes	09/15/2008	Reduction
PT → GR	Yes	Yes	08/05/2010	Intensification
PT→ SP	Yes	Yes	15/01/2010	Intensification
SP → IE	**No**	Yes	11/21/2010	New
SP → IT	Yes	Yes	10/08/2008	Intensification
SP → GR	Yes	Yes	05/12/2010	Intensification
SP→ PT	Yes	Yes	11/21/2010	Intensification

Notes: GR, IE, IT, PT, and SP stand for Greece, Ireland, Italy, Portugal and Spain respectively.
Bold values indicate absence of Granger-causality.