Sovereign-Bank linkages: Quantifying directional intensity of risk transfers in EMU countries

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Abstract

This study attempts to identify and trace inter-linkages between sovereign and banking risk for each country in the euro area. To this end, we use an indicator of banking sector risk in each country based on the *Contingent Claim Analysis* literature, and 10-year government yield spreads over Germany as a measure of sovereign risk. We apply a dynamic approach to testing for Granger causality between the two measures of risk in each country, allowing us to check for episodes of significant and abrupt increase in short-run causal linkages. The empirical results indicate that episodes of causality intensification vary considerably in both directions over time and across the different EMU countries. The directionality suggests the presence of causality intensification, mainly from banks to sovereigns in crisis periods.

Keywords: sovereign debt crisis, banking crisis, distance-to-default, Granger causality, time-varying approach
JEL: C22, E44, G01, G13, G21

1. Introduction

Today, six years since the outbreak of the European Economic and Monetary Union (EMU) sovereign debt crisis in late 2009 - when the newly elected Greek government announced that the country's budget deficit was much larger than previously reported - we can see that its origin goes deeper than the fiscal imbalances in euro countries. The interconnection between private and public debt, and thus between banking and sovereign crises, is obvious. However, whether it was private debt that ultimately bankrupted sovereigns, or whether, conversely, it was excessive public debt that undermined the banking sector is a question that is not easily answered.

An extensive review of the channels through which sovereign risk can affect bank risk (and vice versa) suggest that the drivers of this relationship can be divided into two broad

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categories:[1] (i) Those who work via the assets side of banks' balance sheets; and (ii) Ones who work through the liability side. According to the former category: (i) A deterioration/improvement in a government's creditworthiness, as perceived by the markets, may cause losses/gains on banks' portfolios of sovereign securities and may also affect banks' standing in relation to their loans to the government; and (ii) Since government bonds are typically used as collateral, e.g. in repos, a fall in their price can trigger margin calls or larger haircuts, thus reducing the liquidity that can be obtained via a given nominal amount of sovereign paper. Regarding the latter category (sovereign-bank dependence via mechanisms that work on banks' liabilities side) (i) Governments explicitly/implicitly guarantee schemes on bank bonds during crisis periods whose effects are strongly linked with the creditworthiness of the sovereign; (ii) Sovereign rating usually put a ceiling on bank rating and sovereign downgrade often leads to downgrade of domestic banks; and (iii) Changes in sovereign yields tend to affect the availability and cost of bank funding.

On the reverse, a banking crisis can also trigger a surge in sovereign risk. The impact on the public finances typically comes from the recession and the fiscal expansion typically implemented to deal with it. A comprehensive analysis of the transmission channels of financial instability (or crisis) on a country's fiscal stance is presented by Eschenbach and Schuknecht (2002). These authors identify three major transmission channels of financial instability on a country's fiscal stance, namely (i) Direct bailout costs; (ii) Direct revenue effects; and (iii) Indirect effect via the impact on the real economy. Direct bailout costs focuses on the direct government support provided to distressed financial institutions in order to avoid a systemic financial crisis. The impact depends strongly on the form of government interventions. The revenue effect impacts through the downward changes in asset prices driven by financial instability causing reduction in tax paid (household on wealth, corporate and sales taxes etc.). A reduction in real estate transactions (price and volume), slowdown in equity market and decrease in dividends also negatively impacts the fiscal revenue. The indirect effect works through the real economy where lower wages and higher unemployment triggers a reduction in personal income tax and social contributions while simultaneously increasing the unemployment payments. Subsequent increase in government debt and higher interest payments both exacerbates the effect.

Based on these linkages, some authors (Brunnermeier et al. (2011) and Reichlin (2013), among them) have described the development of a 'diabolic loop' as the major cause of the crisis in EMU countries. European banks, encouraged by the absence of any regulatory discrimination between bonds, held an excessive part of the national debt, which - far from being safe - fed never-ending speculation on the banks' solvency. In turn, sovereigns were in constant danger of having to rescue their banks, which, combined with the uncertainty regarding the kind of fiscal support they would receive from their European partners, increased the riskiness of their bonds. However, banks' exposure to the domestic sovereign debt had declined steadily for all EMU countries between the mid-1990s till the end of 2008 (see Figure 4(a) in Angelini et al. (2014)). In most EMU countries, end 2008 marks an inversion in this trend, where the banks began to increase their domestic sovereign debt

[1]For a recent survey, see Angelini et al. (2014).

holdings. This suggests that the increasing exposure was a consequence not the cause of the crisis although it may have contributed to exacerbating the crisis by intensifying the bank-sovereign nexus. As most of these authors[2] try to establish or assume the existence of a diabolic loop between bank and sovereign risk, to our knowledge there is a lack of empirical support to identify, trace and quantify the asymmetrical directional intensity of risk transfer. This paper tries to fill this gap in the literature where direction and intensity of risk transfer between banking and sovereign risk is being evaluated for individual countries for each quarter between 2005Q1-2013Q2.

In a parallel development, some authors (see, e.g. Shambaugh (2012)) have pointed out that the euro area is currently facing three interlocking crises (banking, sovereign debt, and economic growth) which together challenged the viability of the currency union. According to this line of thought, these crises connected with one another in several ways: the problems of weak banks and high sovereign debt were mutually reinforcing, and both were exacerbated by weak, constrained growth. An analysis of the interrelationship between debt and growth - an unresolved issue of great importance, on which there is no consensus in the literature (see Krugman (2011), Delong and Summers (2012), Cochrane (2011) or Reinhart and Rogoff (2010), to name just a few) - is beyond the scope of this paper. Rather, we will focus on the interconnection between banking and sovereign risks in EMU countries.

While there is a substantial amount of empirical literature exploring the determinants of either bank risk or sovereign risk in isolation, few papers to date have tried to empirically quantify the interdependence or even contagion between the sovereign and banking sectors. Exceptions are Alter and Schüler (2012), Gross and Kok (2013) and Alter and Beyer (2014), who applied different extensions of vector autoregressive (VAR) models; and De Bruyckere et al. (2013) who investigated the presence of contagion by computing excess correlation (over and above what one would expect from fundamental factors). However, though they use different methodologies, all these papers apply the same measure of banking and sovereign risk: credit default swap[3] (CDS) spreads on 5-year senior debt contracts, since these are known to be the most actively traded and therefore the most liquid. In this context, our paper makes the first major contribution to this branch of the literature by applying indicators of bank and sovereign risk that differ considerably from the ones used in previous literature. As far as we know, this is the first paper to use measures other than CDS

[2]Angelini et al. (2014) point out that once a shock has set in motion a weakening of the sovereign, or of the banking system, a self-reinforcing feedback loop can easily develop. According to them, there is ample evidence that tensions in the sovereign debt market affect banks' funding conditions, and hence lending to domestic households and firms; a credit squeeze weakens the economy, leading to a decline in borrowers' creditworthiness and to further tensions in the sovereign's situation, due to falling fiscal revenues and the need for further fiscal tightening; finally, supply and demand factors contribute to depress credit growth, with negative effects on banks' interest margin and profitability.

[3]The theoretical use of a CDS contract is to provide insurance against unexpected losses due to a default by a corporate or sovereign entity. The debt issuer is known as the reference entity, and a default or restructuring on the predefined debt contract is known as a credit event. In the most general terms, it is a bilateral deal in which a 'protection buyer' pays a periodic fixed premium, usually expressed in basis points of the reference asset's nominal value, to a counterpart known by convention as the 'protection seller'. The total amount paid per year as a percentage of the notional principal is known as the CDS spread.

spreads to quantify the directional intensity of risk transfer between banks and sovereigns in the euro area. Our selection offers three major advantages: (1) It extends the sample period of analysis incorporating a few pre-crisis years; (2) It allows the inclusion of countries for which CDS spreads are thinly traded or not available; and (3) It measures the relative creditworthiness of the banking sector of different countries based on the same parameters.

Our indicator of banking risk in each country is based on the contingent claim analysis (CCA) framework. Specifically, the average 'distance-to-default' (DtD) based on the simple average DtD of all banks headquartered in a particular country will be the proxy of banking risk used in the analysis.[4] This indicator, which is based on Merton's model (1974), is calculated and broadly explained in a companion paper: Singh et al. (2015). On the other hand, 10-year government yield spreads over Germany will be our measure of sovereign risk,[5] since they reflect the premium that investors demand in order to bear the sovereign risk.

A second contribution of this paper is the directional quantification of significant, short-run abrupt increases in the causal linkages which might be associated with contagion periods (see Forbes and Rigobon (2002), Constâncio (2012)) using dynamic Granger-causality tests between the selected measures of banking and sovereign risk. As direct quantification of possible bailout costs and effects are extremely discretionary and heavily disputed, we avoid taking stand on the causal effect of different bailout strategy. Our econometric methodology has several advantages over the alternative approach of focusing on contemporaneous correlations (corrected or not for volatility). First, while correlation is a symmetrical measure, Granger-causality is an asymmetrical one, so our procedure provides information on the direction and magnitude of the risk transmission (from sovereign to banking risk, from banking to sovereign risk, or both). Second, the lag structure offers valuable insights for understanding the information flow between the two types of risk. Third, by investigating dynamic causal linkages through a rolling window, we examine how the strength of the relationships evolves over time, allowing us to detect episodes of sudden and temporary increases in these relationships. Fourth, we establish an approximate periodization for causality intensification by looking directly into the data (i.e., without making a priori conjectures on the time periods during which the risk transmission process might have started to spread). Additionally, like the VAR approach, our methodology enables us to capture the dynamic structure of the variables and offers a convenient framework for separating long-run and short-run components of the data generation process.

Our results suggest that in the pre-crisis period, from early 2005 till the collapse of

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[4]Hoque et al. (2015) also use the distance-to-default as a measure of banking risk. However, the construction of their indicator differs from ours. Concretely, they follow Laeven and Levine (2009) to capture default risk and their index is estimated as the average ROA plus the capital-to-asset ratio divided by the standard deviation of the ROA.

[5]Some authors contend that past CDS spreads improve the forecast quality of bond yield spreads (Palladini and Portes (2011), Fontana and Scheicher (2010)). However, CDS markets (in both the sovereign and the banking sectors) have been quite illiquid since late 2008, only one year before the onset of the euro sovereign debt crisis. This is one of the reasons we decided to make use of 10-year yield spreads over euro-denominated German government bonds instead of CDS (see Section 3.2), even though the 10-year yield is used in the case of Germany in order to include Germany in our analysis.

Lehman Brothers, 77% of the total episodes of causality intensification detected were from sovereigns to banks and coincided with a period of economic stagnation in EMU countries or with the beginning of a downturn in GDP growth in the euro area. After the last quarter of 2008, coinciding with the beginning of the financial crisis and the implementation of government measures to support financial institutions, the direction of the causality intensification underwent a change. In this crisis period the majority of the causality intensification episodes (around 63% of the total) ran from banks to sovereigns. This finding is noticeable in the cases of France, Greece, Ireland where episodes of causality intensification are detected only in this direction. For the case of Germany, Portugal and the Netherlands they account for more than 70% of the episodes. Conversely, in Belgium and Finland causality intensification was mainly from sovereigns to banks, while in Spain, Italy and Austria there were similar numbers of episodes of causality intensification in both directions.

The rest of the paper is organized as follows. Section 2 reviews the linkages between sovereign and banking risk in EMU countries. Section 3 briefly explains the selection and creation of our banking and sovereign risk indicators. Section 4 explains our data selection methodology. The econometric methodology used in our analysis is presented in Section 5. Section 6 summarizes the main results and, finally, Section 7 offers some concluding remarks.

2. Sovereign/bank linkages

The major focus of the sovereign and banking risk literature were the development of diverse range of risk indicators to understand and measure different dimensions of risk in isolation. However recently, the rapidly deteriorating outlook in the Eurozone gave rise to a new strand of literature focusing on the joint dynamics between sovereign and banking risk. Papers looking on this topic have gained importance during the recent European debt crisis. Here we will touch upon the major contributions made in this area by Acharya et al. (2014), Alter and Schüler (2012), Alter and Beyer (2014), Ejsing and Lemke (2011), Gross and Kok (2013) and Dieckmann and Plank (2011).

Acharya et al. (2014) finds empirical evidence to support the bi-directional negative feedback loop between banking and sovereign credit risk during the recent crisis. Using CDS rates on European sovereigns and banks for 2007-11, they show that bailouts triggered the rise of sovereign credit risk and find evidence for widening sovereign spreads and narrowing banking spreads after a bailout.

Alter and Schüler (2012) study the relationship between the sovereign CDS of seven European Union (EU) countries and the CDS of their banks. The authors analyze the period between June 2007 and May 2010 and look at differences in the market before and after government interventions. They find that before the government rescue interventions contagion spills over from the banking sector to the sovereign CDS market, whereas after the interventions sovereign CDS spreads largely determine the price of banks' CDS series. The authors also highlight the short-term impact of the financial sector on sovereign CDS spreads and its insignificance in the long run.

Alter and Beyer (2014) show that the contagion between banking and sovereign fluctuates within a stable interval over the period October 2009-July 2012. It is high around important policy events in April 2010, August 2011, and June 2012 and its components (banks-to-sovereigns and sovereigns-to-banks) increase during the period of analysis, which suggests intensifying feedback loops between euro area banks and sovereigns.

Ejsing and Lemke (2011) examine co-movements between sovereign CDS spreads of ten Euro area countries and CDS of their banks for the period from January 2008 to June 2009. The authors find that the government rescue packages led to a decrease in the CDS spreads of the banking sector at the cost of the increase in the price of sovereign CDSs. Furthermore, the bailout schemes made sovereign CDSs even more sensitive to any future shocks.

Gross and Kok (2013) illustrate, using a mixed-cross-section Global Vector Autoregressive (MCS-GVAR) model, that: i) Spillover potential in the CDS market was particularly pronounced in 2008 and more recently in 2011-12; ii) In 2008 contagion primarily went from banks to sovereigns but the direction reversed in 2011-12 in the course of the sovereign debt crisis; and iii) The system of banks and sovereigns became more densely connected over time. Dieckmann and Plank (2011) also find evidence for a private-to-public risk transfer in the countries with government interventions. Moreover, the authors argue that the magnitude of this impact depends on the importance of a country's financial system in the pre-crisis and this transfer is larger for the EMU countries than non-EMU states.

3. Assessing banking and sovereign risk

3.1. Bank risk indicator

To assess the banking sector risk in each EMU country, we use a standard forward looking market based measure. Based on contingent claim literature pioneered by Black and Scholes (1973) and Merton (1974), we use 'distance-to-default (DtD)' as the bank risk indicator. Its foundation lies in the isomorphic relationship between equity and call option. Since equity is a junior claim to debt, it can be modeled as an European call option on the firms' assets (A) with exercise price equal to the face value of debt (D).

Calculation methodology: Consider a bank having simple capital structure with N shares of common stock (market capital E) and all debt denominated as zero coupon bonds (market value F, maturity T). Using value conservation equation:

$$A = E + F \tag{1}$$

Assuming that the assets returns follow the Generalized Brownian Motion, the Black-Scholes option pricing formula yields:

$$E = AN(d_1) - e^{-rT}DN(d_2) \tag{2}$$

where,

- $N(*)$ is the cumulative normal distribution;
- r is the risk-free rate under risk-neutrality;
- $d_1 = \frac{ln(\frac{A}{D})+(r+0.5\sigma_A^2)T}{\sigma_A\sqrt{T}}$; and $d_2 = d_1 - \sigma_A\sqrt{T}$.

Applying Ito's Lemma, the asset volatility (σ_A) can be linked with equity volatility (σ_E) as:

$$\sigma_E = N(d_1)\frac{A}{E}\sigma_A \tag{3}$$

Inverting Eqs. 2 and 3 and numerically solving for A and σ_A, yields the T periods ahead DtD as:

$$DtD = \frac{A - D}{\sigma_A A} \tag{4}$$

Once individual banks' DtD are calculated, following Harada et al. (2010), we consider the banking sector risk as the simple average of individual DtD (aDtD) of all banks headquartered in a particular country. For detailed calculation methodology, see Singh et al. (2015). DtD can be interpreted as how many standard deviations the asset value of the bank is away from the debt threshold. The closer it is to zero, the closer the firm is to distress.

Why DtD over CDS spreads? First, they offer a longer history compared to CDS spreads (Figure 1). Indeed most of the banking CDS started trading in the latter half of 2005 and quality data was not available until late 2007 (in most of the cases the data is available starting December 2007). Also very few of them have remained liquid since the onset of US financial crisis. Thus, this choice of risk indicator will allow us to examine the interconnection between the risk in the sovereign and the banking sectors starting 2005 (more than three years before the onset of the global financial crisis).

Second, it includes more banks in each country (see Table 2) than those for which CDS data are available (better representativeness) and seem to perform better in crisis monitoring (see Singh et al. (2015)). To see whether this indicator represents a similar movement as CDS, we plot aDtD and average CDS[6] for each country in our analysis separately (Figure 1). As can be seen, the aDtD at country level mirrors the average CDS movement in all cases (deterioration in aDtD corresponds to increase in average CDS, and vice versa).

Third, the CDS spreads capture only the credit risk with no established record of correct pricing. As DtD uses equity price and volatility data (having well established long history) together with consolidated option pricing methodology, it provides more authenticity. Also this is relatively free from political interference and allows us to include countries (e.g., Finland) for which bank CDS data is not available. Note that CDS spreads are market based real-time pricing while DtD is calculated on a quarterly basis.[7]

[Figure 1 about here.]

[6] We have collected 5-year senior bond CDS spread series for all EMU banks over the period 2005-2014 which are available in Datastream. To save space, the list of banks for which CDS spreads data is available is not tabulated here but is available from authors upon request. Note that the bank sample for countries changes over time due to bankruptcy, nationalization, de-/listing or other corporate actions.

[7] This loss of frequency restricts the dynamic analysis.

3.2. Sovereign risk indicator

Ten-year sovereign bond yield spreads with respect to the German bund will be the proxy used in this paper to measure sovereign risk, whilst the 10-year benchmark sovereign yield will be used in the case of Germany.[8] Our sample contains eleven EMU countries, six central (Austria, Belgium, Finland, France, Germany and the Netherlands) and five peripheral (Greece, Ireland, Italy, Portugal and Spain).

Why sovereign yield spreads over CDS spreads? Firstly, the CDS spreads capture only the credit risk while yield spreads include inflation expectations, re-denomination risk, demand/supply for lending conditions as well as default risk. Indeed, Krishnamurthy et al. (2014) decompose euro-denominated government bond yields into two components that are common across all countries using the euro (an expectations hypothesis component and a euro-rate term premium) and three components that are country-specific (default risk, redenomination risk and market segmentation). While the solvency risk component of bond yields is captured by default risk, if bond holders worry that rather than (or in addition to) default on obligations, the government will choose to exit the euro and redenominate its debt into a local currency at a depreciated exchange rate, then they will require a redenomination premium. The last component of the bond yield arises from segmentation and illiquidity frictions.

Secondly, they better represent the size and liquidity concerns in the government debt market. CDS contracts that reference sovereign credits are only a small part of the sovereign debt market ($3 trillion notional sovereign CDS outstanding in end-June 2012, compared with $50 trillion of government debt outstanding at end-2011: International Monetary Fund (2013)); and lastly, sovereign bonds are less prone to political interference. During the crisis, European authorities banned naked/uncovered purchases of sovereign CDS based on EMU countries (International Monetary Fund (2013)). Thus CDS spreads no longer show us what investors think about the credit risk. They reflect a mix of default risk expectations and forecasts of rescue measures. This is yet another instance of Goodhart's Law - '*a variable that becomes a policy target soon loses its reliability as an objective indicator*' (Goodhart (1975a), Goodhart (1975b)).

4. Data

4.1. Banking risk measure

The sample selection methodology is as follows: First, an exhaustive list of all listed and delisted monetary financial institutions is selected from Bankscope[9] database (as on

[8] We decided to use the 10-year bund yields as a proxy for the risk-free benchmark; they are considered as such in many academic studies because German sovereign debt has enjoyed a high credit rating for some time now and its returns can be seen as a good proxy for risk-free asset returns. For the sake of simplicity, this convention is maintained in the paper. However, since this decision would mean the omission of Germany from the analysis, we use the 10-year yield as a proxy of the sovereign risk in the case of Germany. We think that it is relevant to include Germany in the analysis taking into account that since 2008 this country had a deteriorated banking system and government measures to support the banking system accounted for 25% of its GDP at the end of 2008 (see Table 6).

[9] It provides a comprehensive balance sheet data for financial companies.

10^{th} February 2014). We obtain a total of 199 banks in western Europe. Secondly, only banks whose shares were publicly listed and traded between the last quarter of 2004 till the second quarter of 2013 and are headquartered in EMU countries are selected. Finally, credit institutions which are pure-play insurance, pension or mortgage banks are removed. To formalize this decision, we use Datastream as an additional source of information. The major reason for this exclusion is the difference in liability structure and business model compared to banks. However it doesn't mean that they are less risky to the financial system.

This choice also ensures that the selected banks share the same accounting currency. However, it does not mean that they have a similar exchange rate risk profile, since the level of foreign currency exposure will depend on their respective asset profiles. The market-based data include daily observations of risk-free interest rates, daily stock price and total outstanding share in public. The list of variables and data sources are summarized in Table 1 while Table 2 lists the name of banks considered in the analysis.

[Table 1 about here.]

[Table 2 about here.]

Computation of individual DtD: DtD is not measured directly; it is recovered implicitly from the balance sheet and market price of firm's liabilities. For our analysis we compute DtD at quarterly frequency. In practical terms, this means that the balance sheet information has to be modified from its original quarterly, half-yearly, or in few cases, yearly frequencies using cubic spline interpolation. Also the real debt contracts are not all written with a single terminal date. To overcome this problem, a common procedure used by Moody's KMV (Vasicek (1984)) and also employed here, is to adopt a one year horizon ($T = 1$), but to weight longer term debt (maturity > 1 year) at only 50% of face value. The debt barrier (D) will then be equal to the face value of short-term liabilities plus half of the long-term liabilities. Equity value of the firm (E) is computed as the quarterly average of daily market capitalization (number of common shares x share prices) while quarterly historical volatility based on daily log-returns is taken as equity volatility (σ_E). The individual DtD is then calibrated using the procedure outlined in Section 3.

4.2. Sovereign risk measure

Ten-year bond yield spreads with respect to the German bund (10-year yields in the case of Germany), which have been calculated from data drawn from Datastream, will be the proxy used in this paper to measure sovereign risk for all countries in the sample except for Germany. The 10-year yield is used in the case of Germany in order to be able to include this country in our analysis. We use quarterly data from 2004-Q4 to 2013-Q2 (i.e., T=35 observations).

4.3. Data anlaysis

Graphs in Figure 2 display the evolution of both sovereign and banking risk in the eleven countries in our sample during the crisis period: from 2004-Q4 to 2013-Q2. The right axis corresponds to the banking risk indicator (aDtD) and the left axis to the sovereign risk indicator (the 10-year sovereign yields spread or the 10-year yield).

[Figure 2 about here.]

5. Econometric methodology

The term 'contagion', generally used in contrast to 'interdependence', conveys the idea that after a shock there may be breaks or anomalies in the international transmission mechanism which arguably reflect switches across multiple equilibria, market panics unrelated to fundamentals, investors' herding, and the like. Contagion has been defined in many different ways in the literature,[10] including the transfer of any shock across countries (Edwards (2000)). Eichengreen and Rose (1999) and Kaminsky and Reinhart (1999) define it as the situation in which knowledge of crisis in one country increases the risk of crisis in another one.

Much of the empirical work on measuring the existence of contagion is based on comparing correlation coefficients during a relatively stable period with a crisis or a period of turbulence (see, e.g., Forbes and Rigobon (2002) and Corsetti et al. (2005)). In fact, Forbes and Rigobon (2002) argue that 'contagion is a significant increase in cross-market co-movements after a shock.' These authors stress that this notion of contagion excludes a constant high degree of co-movement that exists in all states of the world since; in that case, markets would be just interdependent. This definition is sometimes referred to as 'shift-contagion' and this very sensible term clarifies that contagion arises from a shift in cross-market linkages, and also avoids taking a stance on how this shift occurs.[11]

However, given the lack of consensus on contagion, in this study we adopt an eclectic approximation and directly investigate changes in the existence and the intensity of causality between banking and sovereign risk among a sample of eleven euro area countries. To that end, we follow a dynamic approach in order to assess the evolving nature of the Granger causal linkages and to detect episodes of significant and transitory increases in the pair-wise Granger causal relationships. The intuition is that if the causal linkage intensifies during a period of turmoil relative to a period of tranquility, this intensification could identify episodes of significant propagation of shocks from one side to the other.

5.1. Testing procedure

The concept of Granger-causality was introduced by Granger (1969) and Sims (1972) and is widely used to ascertain the importance of the interaction between two series. As is well known, Granger causality is not a relationship between 'causes' and 'effects.' Rather, it is defined in terms of incremental predictive ability (Hoover (2001)): a variable Y is said to Granger-cause another variable X if past values of Y help to predict the current level of X better than past values of X alone, indicating that past values of Y have some informational content that is not present in past values of X. Therefore, knowledge of the evolution of the

[10] Gómez-Puig and Sosvilla-Rivero (2015) present a detailed literature review of the different definitions of financial contagion and the most important strategies used in its empirical analysis.

[11] See Forbes and Rigobon (2001).

variable Y reduces the forecast errors of the variable X, suggesting that X does not evolve independently of Y. This concept is suitable for identifying and monitoring contagion.

Tests of Granger causality typically use the same lags for all variables. This poses a potential problem, since Granger-causality tests are sensitive to lag length.[12] In this paper we use Hsiao (1981) sequential method to test for causality to determine the optimal lag structure for each variable, combining Akaike's final predictive error (FPE, from now on) and the definition of Granger-causality.[13] Essentially, the FPE criterion trades off the bias that arises from under-parameterization of a model against a loss in efficiency resulting from its over-parameterization, removing the ambiguities of the conventional procedure.

Consider the following models,

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \epsilon_t \tag{5}$$

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \sum_{j=1}^{n} \gamma_j Y_{t-j} + \epsilon_t \tag{6}$$

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

1. Treat X_t as a one-dimensional autoregressive process (5), and compute its FPE with the order of lags m varying from 1 to m. Choose the order which yields the smallest FPE, say m,[14] and denote the corresponding FPE as FPE_X(m, 0).
2. Treat X_t as a controlled variable with m number of lags, and treat Y_t as a manipulated variable as in (6). Compute again the FPE of (6) by varying the order of lags of Y_t from 1 to n, and determine the order which gives the smallest FPE, say n, and denote the corresponding FPE as FPE_X(m,n).[15]
3. Compare FPE_X(m, 0) with FPE_X(m,n) (i.e., compare the smallest FPE in step 1 with the smallest FPE in step 2). If $\text{FPE}_X(\text{m},0) > \text{FPE}_X(\text{m,n})$, then Y_t is said to cause X_t. If $\text{FPE}_X(\text{m},0) < \text{FPE}_X(\text{m,n})$, then X_t is an independent process.
4. Repeat steps 1 to 2 for the Y_t variable, treating X_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 existence of Granger-causal relationships from ΔX_t to ΔY_t and from ΔY_t to ΔX_t, using the following error correction models:

[12] The general principle is that smaller lag lengths have smaller variance but run a risk of bias, while larger lags reduce the bias problem but may lead to inefficiency.

[13] Thornton and Batten (1985) show that Akaike's FPE criterion performs well relative to other statistical techniques.

[14] $FPE_X(m,0)$ is computed using the formula: $FPE_X(m,0) = \frac{(T+m+1)SSR}{(T-m-1)T}$ where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (5).

[15] $FPE_X(m,n)$ is computed using the formula: $FPE_X(m,n) = \frac{(T+m+n+1)SSR}{(T-m-n-1)T}$ where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (6).

$$\Delta X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \epsilon_t \tag{7}$$

$$\Delta X_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta Y_{t-j} + \epsilon_t \tag{8}$$

where Z_t is the OLS residual of the cointegrating regression ($X_t = \mu + \lambda Y_t$), known as the error-correction term. Note that, if X_t and Y_t are I(1) variables, but they are not cointegrated, then β in (8) 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 are not cointegrated), we can use Hsiao's sequential procedure substituting X_t with ΔX_t and Y_t with ΔY_t in steps 1 to 4), as well as substituting expressions (5) and (6) with equations (7) and (8). Proceeding in this way, we ensure efficiency since the system is congruent and encompassing (Hendry and Mizon (1999)).

As explained above, since the presence and intensity of Granger-causality may vary over time, we adopt a dynamic analysis to detect episodes of a significant, short-run abrupt increase in the causal linkages. To assess the dynamic Granger-causality between sovereign and banking risk, we carry out rolling regressions using a window of four quarterly observations.[16] In each estimation, we apply the Hsiao (1981)'s sequential procedure outlined above to determine the optimum FPE (m, 0) and FPE (m, n) statistics in each case.

5.2. Application

As a first step, we tested the order of integration of the aDtDs, and the sovereign risk indicator by means of Augmented Dickey-Fuller (ADF) tests. Then, following Cheung and Chinn (1997)'s suggestion, we confirmed the results using the Kwiatkowski et al. (1992) (KPSS) tests, where the null is a stationary process against the alternative of a unit root. The results, not shown here to save space but available from the authors upon request, decisively reject the null hypothesis of non-stationarity in the first regressions. They do not reject the null hypothesis of stationarity in the first differences, but strongly reject it in levels, in the second differences. So, they suggest that both variables can be treated as first-difference stationary. As a second step, we tested for cointegration between each of the 20 pair relationships using Johansen (1991, 1995)'s approach. The results suggest[17] the absence of long-run cointegration between the aDtD and the sovereign risk indicator. Therefore, we tested for Granger-causality in first differences of the variables, with no error-correction term added (i. e., equations (7) and (8) with $\beta = 0$).

To summarize, in Figures 3-4 we plot the evolution over time of the difference between FPE (m, 0) and FPE (m, n) statistics in each case. Therefore, these graphs provide us with a view of the dynamic bidirectional influence that exists between sovereign and banking risks

[16]We also used values of six and eight observations. The results are broadly in line with those obtained for the 4-quarterly windows and are therefore not presented in the interests of space; they are available from the authors upon request.

[17]Again, the results are not presented for reasons of space, but are available from the authors upon request.

for each EMU country and constitute our indicator of causality intensification based on time-varying Granger-causality analysis since it illustrates the changes in the directions and magnitudes over time. In Figure 3 we present the graphs corresponding to the five peripheral EMU countries included in the sample (Greece, Ireland, Italy, Portugal and Spain), whilst Figure 4 displays the graphs corresponding to the six central EMU countries in our sample (Austria, Belgium, Finland, France, Germany and the Netherlands).

Note that if the difference is positive and statistically significant at the 1% level in the case of, say, the banking to sovereign risk relationship, this indicates the existence of a significant, transitory increase in the Granger-causality relationship running from country banking risk towards sovereign risk.

[Figure 3 about here.]

[Figure 4 about here.]

6. Results

In order to examine the time-varying behavior of causality between the two risks, we follow the Bank for International Settlements (2009) and divide the entire time span (2005:Q1 to 2013:Q2[18]) into eight stages (stages 2 to 7 correspond to BIS[19] stages 1 to 6). The first three stages before the Lehman collapse are considered as pre-crisis periods while the rest are classified as crisis periods. Table 3 tabulates the episodes of causality intensification (that are significant at the 1% confidence level during each of the above mentioned stages), directionality and the involved countries.

[Table 3 about here.]

We also document the episodes of causality intensification between banks and sovereigns when the analysis is done using the important domestic banks in each individual country (Table 5). For this purpose, we classified all banks into systemically important bank (SIB) and other national bank based on the list of global or domestic SIBs prepared by European Central Bank, BIS and Federal Reserve. Countries for which no SIB exist, we took the biggest bank in terms of total asset. Table 4 list the banks considered for this analysis. For the ease of understanding directionality with major market events, Figure 5 and 6 documents the major crisis events for different EMU countries together with major policy actions coordinated at EU level.

[Table 4 about here.]

[Table 5 about here.]

[Figure 5 about here.]

[Figure 6 about here.]

[18]Note that our most parsimonious model is specified as an autoregressive model of order one [AR(1)] in differences and therefore we lose two observations at the beginning of the sample.

[19]Bank for International Settlements.

6.1. Pre-crisis stages

The first stage, which ran from 2005:Q1 to 2007:Q2, was the period of relative stability before the beginning of the global financial crisis. Starting from June 2007, losses from subprime mortgages began to expose large-scale vulnerabilities in US financial system. The second stage began in 2007:Q3 and ends in 2008:Q1. This was the first period of the crisis, characterized by concerns over losses on US subprime mortgage loans which escalated into widespread financial stress (on 9 August 2007, the turmoil spread to the interbank markets). The sharp rise in the defaults rates revealed the excessive exuberance in the housing market. The securitization market froze while the confidence in funding markets was eroded. The crisis spread rapidly through the worldwide financial market and severe stress were observed around the globe. In brief, what initially appeared to be a problem affecting only a small part of the US financial system quickly spread more widely, including European Banks.

The third stage ran from 2008:Q2 to 2008:Q3. During this period, after a short respite following the takeover of Bear Stearns on 16 March 2008, financial asset prices came under renewed pressure. The liquidity crisis started turning into a solvency crisis and governments started to take explicit rescue measures directed towards financial institutions. In September, Lehman Brothers collapsed which sent a shockwave to the entire financial system, leading to an acute shortage in the funding market, sharp rise in risk aversion and complete mistrust among financial players. A distinctive feature of the period up to mid-September was an increased investor focus on signs that the US recession had spilled over to other major economies, triggering a synchronized economic downturn (indeed, the euro area officially entered recession in the last quarter of 2008 when its GDP fell 2.1%).

Some important observations can be drawn from Figures 3-4 and Tables 3 and 5. Table 3 shows that during the first stage, before the financial crisis, causality intensification mainly took place from sovereigns to banks. We find evidence of at least one episode of causality intensification in this direction in nine out of the eleven cases studied, the exceptions being Greece and Italy. It is noticeable that these episodes are mainly concentrated in the second semester of 2005 and in the first semester of 2007, coinciding with a period of economic stagnation in EMU countries in the first case and with the beginning of a downturn in GDP growth from 2007 in the euro area, which after peaking in the last quarter of 2006 (3.7%) began to decrease until it reached negative values at the end of 2008.

In stage 2 not a single contagion episode is detected while in stage 3, only two episodes of causality intensification, from banks to sovereigns though, are detected in Germany, confirming that the deterioration of Germany's banking system after the US subprime crisis resulted in a sovereign risk increase. These results are corroborated when analyzing causality intensification between SIBs and sovereigns risk before Lehman Collapse (see Table 5). We do find episodes of contagion running from sovereigns to systematically important banks in two peripheral countries (Ireland and Spain) and two central (Germany and France).

6.2. Crisis stages

Stage 4: The collapse of Lehman Brothers in mid-September 2008 defined the beginning of the fourth stage, which ended in 2009:Q1. This stage of the crisis was marked by concerns about a deepening of the global recession and the repercussions of the Lehman Brothers bankruptcy, since the balance sheets of banks all around the globe indicated exposure to their assets. Therefore, policy action was implemented on an international scale as governments sought to support market functioning and to cushion the blow of rapid economic contraction. In the European context, the ECB announced liquidity to support European Banks (in September 2008 the Irish government already guaranteed all the deposits/debts of the country's banks), while the European Commission adopted the European Recovery Plan and allowed governments to implement measures to bailout banks.

Following the collapse of Lehman Brothers, fears of losses in the European banks which were more exposed to US assets triggered episodes of causality intensification from banks to sovereigns, mostly in central EMU countries. Indeed, we detect episodes of causality intensification in this direction in Austria, Finland, Germany and the Netherlands (see Table 3) and as it is shown in Table 5 in the case of Austria and Finland the causality intensification episodes might be triggered by their SIBs. These results might indicate that central EMU markets were hit more by the international financial crisis than peripheral markets. This finding is in accordance with the results presented in Table 6 indicating governments' commitments to supporting the banking system during the period October 2008-May 2010 and showing that in mid-2010 they were clearly higher in central than in peripheral countries (with the exception of Ireland). In particular, the government commitment to bail out banks in the three countries above mentioned was between 20% and 75% of their GDP.

[Table 6 about here.]

Stage 5: It started in 2009:Q2, when the first signs of recovery appeared and global uncertainty receded (announcements by central banks concerning balance sheet expansions, and the range and the amount of assets to be purchased, led to significant relief in the financial markets) and ends in 2009:Q3 just before the newly elected Greek government announced that the country's budget deficit was much larger than previously reported, marking the beginning of the sovereign debt crisis in Europe. Signs of recovery were noted as well as an atmosphere of some relief in the financial markets.

The group of countries which intervened at the earliest stages of the crisis by taking bulk of the losses associated with bailout (i.e. Austria, Germany and Ireland) or choose to nationalize banks (e.g., Belgium) saw a sharp reduction in the direction of risk transfer from banks to sovereign. However, Spain whose economy observed a serious slump (Spanish GDP fell 4.0% and 2.6%, in 2009:Q3 and 2009:Q4 respectively), saw a sudden rise in risk transfers from sovereign towards banks. There may also have been some pressure from governments on banks within their jurisdiction to buy their domestic debt. Indeed, at the end of 2011, the home share of all Spanish banks' sovereign exposure was 81% (the highest in the euro area) and they held the equivalent of 44% of Spanish GDP in the form of domestic bonds. This may have broadened concerns about their exposure to bad assets and may have fed speculation about their solvency. As a further step, it might be interesting to fully analyze the econometric link between the timing and level of government guarantees and the occurrences of events impacting the financial needs of the economy. Besides, episodes of causality intensification from banks to sovereigns in this stage were detected in only three central countries. France and the Netherlands if we use the average banking risk indicator for the whole country (Table 3) and Finland when using the risk indicator corresponding to its SIBs (Table 5).

Stage 6: The sixth stage began in 2009:Q4 and ended in 2011:Q3. This period was marked by concerns about European sovereign debt market's stability due to fears that Greece's debt crisis would spread to EMU peripheral countries. Indeed, during this period rescue packages were put in place in Greece (May 2010), Ireland (November 2010) and Portugal (April 2011). The sharp increase in sovereign spreads of euro-area countries with respect to Germany after the explosion of the Greek crisis was due to a combination of deteriorating macroeconomic and fiscal fundamentals and to some form of financial contagion. Indeed, a crisis in one country can lead to reassessment of objectively unchanged fundamentals in other countries. This is what some authors (Goldstein (1998)) call 'wake-up call' contagion since it leads market participants aware of existing problems or risks they failed to see before.

It is noticeable that during this period, in which concerns about European sovereign debt crisis transmission were at their peak and rescue packages were put in place, Table 3 shows that episodes of causality intensification from sovereigns to banks started rising gradually in all peripheral and central countries. Episodes of causality intensification from banks to sovereigns were identified in all peripheral and central countries (except for Belgium). These findings suggest the following ideas: (1) In Portugal and Italy, causality intensification from the sovereign to the banking sector can be easily understood, since the main source of vulnerability in those countries was concentrated in the public sector itself. Moreover, Portuguese and Italian banks held the equivalent of 23% and 21% of their countries' GDP in the form of domestic bonds which, as we stated above, might have fed speculation regarding their solvency; (2) The sudden drop in investor confidence induced fears of contagion in all euro area countries and led to 'flight-to-safety' investments, which increased the demand for the German bund and also caused a sharp rise in yield spreads of EMU central countries. This increase in risk in the sovereign sector may have been transmitted to their banking sectors[20]; (3) Not only in Ireland (where banks' debt-to-GDP was close to 450% at the end of 2012), but also in Portugal, Spain, Italy and Greece the high leverage registered in the banking sector (194%, 150%, 110% and 100% of their GDP respectively, at the end of 2012) may have increased tensions in their already vulnerable and distressed public sector. Moreover, when looking at Table 5, we detect two episodes of risk transfer from SIBs to sovereigns in Greece and Austria, jointly with one episode in France. It must be noticed that the episodes detected in 2011:Q3 in Greece and France are also detected when analyzing causality running from the average bank risk indicator for the whole country.

Stage 7: The seventh stage of the crisis, which began in 2011:Q4 when Mario Dragi

[20]The role of investors' risk aversion is revealed by the reaction of yields on highly rated sovereign securities. In fact, yields of bonds issued by countries with solid fiscal fundamentals, such as Austria, Finland and the Netherlands, also rose vis-a-vis the German bund. These countries maintained their triple-A ratings and therefore the surge in their yields cannot be explained by increased credit risk. Since the intensification of the financial crisis in September 2008, flight-to-safety tendencies have increased demand for the bund, affecting all euro area countries' sovereign spreads, including those for Austria, Finland and the Netherlands (see European Central Bank, 2014).

replaced Jean-Claude Trichet as President of the European Central Bank and ended in 2012:Q2, was still a period of high turmoil in European markets. 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 European Central Bank 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). 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 recapitalizes its banking sector.

During the seventh stage, coinciding with the nonstandard monetary policies implemented by the ECB (two LTRO) to support the banking system, episodes of causality intensification from banks to sovereigns (see Table 3) were found mainly in peripheral countries (Greece, Ireland, Italy and Portugal). Recall that in spring 2011, the three program countries (Greece, Ireland and Portugal) made up more than 50% of total liquidity provided through both the main refinancing operations (MRO) and the LTRO windows - although some episodes were also detected in this direction in Austria, France, Germany and the Netherlands. These results are reinforced in the analysis presented in Table 5.

However, it is also noticeable that in Spain, a country that requested financial assistance to recapitalizes its banking sector in June 2012, one episode of causality intensification from the sovereign to the banking sector was identified just after the rescue (2012:Q3). This result suggests that in the Spanish case, even though the country only requested assistance for its financial sector, the sovereign risk was clearly transferred to the banking sector.

Stage 8: Finally, the last stage of the crisis began in 2012:Q3 after Mario Draghi's statement on July 26 that '*within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough*,' which had a healing effect on markets, and finished at the end of the sample period in 2013:Q2. It is important to remark that after July's statement, on September 6 the ECB introduced the Outright Monetary Transactions (OMT) program. The program had two key elements. First, under the OMT, the ECB could purchase government bonds of a given country, focusing on maturities between 1 and 3 years, and with no ex-ante quantitative limits. Second, a country had to apply for the OMT in which case it would also have to undertake a set of fiscal adjustments. That is, the program involved conditionality. The ECB action implied an important reduction of redenomination risk. Therefore, as some authors have pointed out (see Angelini et al. (2014)), commitments by the ECB or the government to never redenominate, such as the OMT, have proved to be effective. Indeed, Angelini et al. (2014) present empirical evidence that suggest that OMT announcements decreased bond yields in peripheral countries. In this context, despite the healing effects of Mario Draghi's words and OMT announcements on financial markets, some episodes of causality intensification were still found from sovereigns to banks in Italy and Finland (in the latter country, their SIBs were the main recipients of the risk, see Table 5) and from banks to sovereigns (Portugal, Spain, France and the Netherlands). We should keep in mind that, although turbulence in financial markets fell sharply, the economic recession entered its second dip during this period. Thus, as Shambaugh (2012) mentioned, not only did the problems of weak banks and high sovereign debt reinforce each other, but were both exacerbated by weak economic growth.

6.3. Pre-crisis vs crisis period: In comparison

From early 2005 till the collapse of Lehman Brothers, 77% of the total episodes of causality intensification detected were from sovereigns to banks, whereas after the last quarter of 2008, coinciding with the beginning of the financial crisis and the implementation of government measures to support financial institutions, the direction of causality intensification underwent a change. In this second sub-period the majority of the episodes of causality intensification (around 63% of the total) ran from banks to sovereigns: specifically, in the cases of France, Greece, and Ireland (where episodes of causality intensification were detected only in this direction), and Portugal and the Netherlands (where they accounted for more than 70% of the total episodes). Conversely, in Belgium and Finland causality intensification was mainly identified from sovereigns to banks, whilst in Spain, Italy and Austria there were similar numbers of episodes of causality intensification in both directions.

Germany represents an exception since we find two episodes of contagion from bank to sovereigns in the first sub-period, at the end of stage 3 (2008:Q2 and 2008:Q3), while not a single contagion episode is detected in any other stage or direction. In our opinion, the immunity of German bunds to the weakness of German banking sector might be explained by the specific form of its government interventions to bailout financial institutions or the stability of German government revenues (see Eschenbach and Schuknecht (2002)). In addition, it is important to keep in mind that the sudden drop in investor confidence that followed the crisis led to 'flight-to-safety' investments, increasing the demand for the German Bund in times of distress. These results are corroborated when analyzing causality intensification between SIBs and sovereign risk in each of the eleven countries in the sample. In the pre-crisis period (stages 1 to 3) all the detected episodes run from sovereigns to SIBs; whilst in the crisis period (stages 4 to 8) 82% of the total detected episodes of causality intensification run from SIBs to sovereigns.

7. Concluding remarks

Based on our selection of bank and sovereign risk indicators at country level in eleven of the countries that have belonged to the EMU since its inception (only Luxembourg is excluded from the analysis), we applied a dynamic approach to testing for sudden and transitory increases in Granger-causality linkages to investigate the possible existence of causality intensification. Our direct analysis of the data allowed us to detect, trace and quantify the directional linkages. To contextualize the empirical results, we followed the Bank for International Settlements (2009) and divide the entire time span (2005:Q1 to 2013:Q2) into eight stages.

In the first three stages, from early 2005 till the collapse of Lehman Brothers, more than 77% of the total episodes of causality intensification detected were from sovereigns to banks, corresponding with a period of economic stagnation in EMU countries or with the beginning of a downturn in GDP growth in the euro area. After the last quarter of 2008, coinciding with the beginning of the financial crisis and the implementation of government measures to support financial institutions, the direction of the causality intensification underwent a change. In this second sub-period (stages four to eight) the majority of the episodes (around 63% of the total) ran from banks to sovereigns, notable cases being France, Greece, Ireland (only episodes of causality intensification in this direction were detected), Portugal and the Netherlands (where they account for more than 70% of the episodes). These results reinforces the idea that banks were the source of market turbulence, possibly reflecting the substantial government measures adopted at that time to support the domestic banking sectors that in turn adversely affected the fiscal position of sovereigns. Conversely, in Belgium and Finland causality intensification was mainly from sovereigns to banks, indicating that banks suffered from the deteriorating values of their sovereign bond holdings as well as higher funding costs. Finally, for Spain, Italy and Austria, we detected similar numbers of episodes of causality intensification in both directions, pointing to an adverse feedback loop between sovereigns and banks with shocks propagating from one to each other. These results are validated when analyzing causality intensification between SIBs and sovereign risk in each of the eleven countries in the sample, although only 18% of the detected episodes of contagion between banking and sovereign risk corresponds to SIBs. These findings might suggest that most of the risk transfer episodes are not related with SIBs and the strong emphasis placed on SIBs for detecting and monitoring systemic risk and financial system stability should be carefully reassessed.

We do find empirical evidence supporting the direct two-way negative feedback between the banking and sovereign CDS market of the Eurozone countries for the period of 2009-2011 in line with Acharya et al. (2014) and Alter and Beyer (2014). However our results differ from those of Alter and Schüler (2012) who using CDS spreads find that before the government rescue interventions contagion spills over from the banking sector to the sovereign market, whereas after the interventions sovereign CDS spreads largely determine the price of banks' CDS series. In line with the results obtained by Dieckmann and Plank (2011), we also find evidence for a private-to-public risk transfer in countries with government interventions. Using different risk indicators and empirical methodology, we still find evidence supporting: (i) Spillovers heightening during 2008 and more recently in 2011-12; and (ii) From 2008 contagion primarily went from banks to sovereigns but the direction reversed in 2011-12 in the course of the sovereign debt crisis, as obtained in Gross and Kok (2013).

In view of the encouraging results of the present study, we are planning to extend the research to explore the determinants of causality intensification based on the country specific bailout strategies employed to address the stress in individual EMU countries (see Stolz and Wedow (2010)). As the country specific fiscal support and banking regulation creates market distortions, we can also explore the role of banking union in disentangling the risk of EMU banks and their governments in influencing the risk patterns (Belke (2013), Belke and Gros (2015) and Breuss et al. (2015)).

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Table 1: Description of variables

Balance sheet variables		Source
Total assets	As reported in annual/interim reports	Bankscope (Code 2025)
Short-term liabilities	Deposits and short term funding	Bankscope (Code 2030)
Total equity	As reported in annual/interim reports	Bankscope (Code 2055)
Daily market based variables		
Risk-free interest rate	Benchmark 10Y bond yield of country where the bank headquarter is based	Thomson Datastream
Market capitalization	Daily closing share price multiplied by total outstanding share in public	Thomson Datastream

Table 2: List of banks (by country)

AT - UniCredit Bank Austria AG (AT0000995006)*
AT - Erste Group Bank AG (AT0000652011)
AT - Raiffeisen Bank International AG (AT0000606306)
BE - Dexia (BE0003796134)
BE - KBC Groep NV (BE0003565737)
DE - Landesbank Berlin Holding AG (DE0008023227)*
DE - Hypothekenbank Frankfurt AG (DE0008076001)*
DE - UniCredit Bank AG (DE0008022005)*
DE - Oldenburgische Landesbank (DE0008086000)
DE - Deutsche Postbank AG (DE0008001009)
DE - UmweltBank AG (DE0005570808)
DE - Hypo Real Estate Holding AG (DE0008027707)*
DE - HSBC Trinkaus & Burkhardt AG (DE0008115106)
DE - Deutsche Bank AG (DE0005140008)
DE - Commerzbank AG (DE000CBK1001)
DE - Wüstenrot & Württembergische (DE0008051004)
DE - Comdirect Bank AG (DE0005428007)
DE - Net-M Privatbank 1891 AG (DE0008013400)*
DE - Merkur-Bank KGaA (DE0008148206)
DE - Quirin Bank AG (DE0005202303)
ES - Banco Santander SA (ES0113900J37)
ES - Banco Bilbao Vizcaya Argentaria SA (ES0113211835)
ES - Caixabank, S.A. (ES0140609019)
ES - Bankia, SA (ES0113307021)
ES - Banco de Sabadell SA (ES0113860A34)
ES - Banco Popular Espanol SA (ES0113790226)
ES - Caja de Ahorros del Mediterraneo (ES0114400007)
ES - Bankinter SA (ES0113679I37)
ES - Renta 4 Banco, S.A. (ES0173358039)
FI - Pohjola Bank Plc (FI0009003222)
FI - Aktia Bank Plc (FI4000058870)
FI - Alandsbanken Abp-Bank of Aland Plc (FI0009001127)
FR - Crédit Agricole Sud Rhône Alpes (FR0000045346)
FR - Paris Orléans SA (FR0000031684)
FR - Crédit Agricole de la Touraine et du Poitou (FR0000045304)
FR - Credit Agricole Alpes Provence (FR0000044323)
FR - Crédit Agricole Nord de France (FR0000185514)
FR - Crédit Agricole d'Ile-de-France (FR0000045528)
FR - Crédit Agricole Loire Haute-Loire (FR0000045239)
FR - Crédit Industriel et Commercial (FR0005025004)
FR - Banque Tarneaud (FR0000065526)*
FR - Caisse régionale de Crédit Agricole Mutuel de Normandie-Seine (FR0000044364)
FR - Caisse Régionale de Crédit Agricole Mutuel du Languedoc (FR0010461053)
FR - Natixis (FR0000120685)
FR - Crédit Agricole de l'Ille-et-Vilaine (FR0000045213)
FR - Crédit Agricole d'Aquitaine (FR0000044547)*
FR - Société Générale (FR0000130809)
FR - Crédit Agricole S.A. (FR0000045072)
FR - BNP Paribas (FR0000131104)
FR - Boursorama (FR0000075228)
FR - Crédit Agricole du Morbihan (FR0000045551)
FR - Crédit Agricole Brie Picardie (FR0010483768)
FR - Société Alsacienne de Développement et d'Expansion (FR0000124315)*
GR - National Bank of Greece SA (GRS003003019)
GR - Piraeus Bank SA (GRS014003008)
GR - Eurobank Ergasias SA (GRS323003004)
GR - Alpha Bank AE (GRS015013006)
GR - Marfin Investment Group (GRS314003005)
GR - Attica Bank SA-Bank of Attica SA (GRS001003003)
GR - General Bank of Greece SA (GRS002003010)
IE - Depfa Bank Plc (IE0072559994)*
IE - Irish Bank Resolution Corp. Ltd. (IE00B06H8J93)*
IE - Permanent TSB Plc (IE0004678656)*
IE - Bank of Ireland (IE0030606259)
IE - Allied Irish Banks plc (IE0000197834)
IT - UniCredit SpA (IT0004781412)
IT - Intesa Sanpaolo (IT0000072618)
IT - Banca Monte dei Paschi di Siena SpA (IT0001334587)
IT - Unione di Banche Italiane Scpa (IT0003487029)
IT - Banco Popolare Società Cooperativa (IT0004231566)
IT - Mediobanca SpA (IT0000062957)
IT - Banca popolare dell'Emilia Romagna (IT0000066123)
IT - Banca Popolare di Milano SCaRL (IT0000064482)
IT - Banca Carige SpA (IT0003211601)
IT - Banca Popolare di Sondrio Societa Cooperativa per Azioni (IT0000784196)
IT - Credito Emiliano SpA-CREDEM (IT0003121677)
IT - Credito Valtellinese Soc Coop (IT0000064516)
IT - Banca popolare dell'Etruria e del Lazio Soc. coop. (IT0004919327)
IT - Credito Bergamasco (IT0000064359)
IT - Banco di Sardegna SpA (IT0001005070)
IT - Banco di Desio e della Brianza SpA (IT0001041000)
IT - Banca Ifis SpA (IT0003188064)
IT - Banca Generali SpA (IT0001031084)
IT - Banca Intermobiliare di Investimenti e Gestioni (IT0000074077)
IT - Banca Popolare di Spoleto SpA (IT0001007209)
IT - Banca Profilo SpA (IT0001073045)
IT - Banca Finnat Euramerica SpA (IT0000088853)
NL - SNS Reaal NV (NL0000390706)*
NL - RBS Holdings NV (NL0000301109)*
NL - ING Groep NV (NL0000303600)
NL - Delta Lloyd NV-Delta Lloyd Group (NL0009294552)
NL - Van Lanschot NV (NL0000302636)
NL - BinckBank NV (NL0000335578)
PT - Montepio Holding SGPS SA (PTFNB0AM0005)*
PT - Banco Comercial Português, SA (PTBCP0AM0007)
PT - Banco Espirito Santo SA (PTBES0AM0007)
PT - Banco BPI SA (PTBPI0AM0004)
PT - BANIF, SA (PTBAF0AM0002)

Parenthesis contains the ISIN (International Securities Identification Number), an asterisk (*) mark represents companies which got delisted during the study period. SIBs are indicated in italics (based on Bank of International Settlements Global-SIBs as of November 2014). AT: Austria, BE: Belgium, DE: Germany, ES: Spain, FI: Finland, FR: France, GR: Greece, IE: Ireland, IT: Italy, NL: The Netherlands, PT: Portugal.

Table 3: Evolution of episodes of causality intensification

Stage	Contagion	Direction	Peripheral	Central
First stage (2005:Q1-2007:Q2)	Yes	Sovereign to banks	Ireland (2007:Q1)	
	No	Banks to sovereign		
Second stage (2007:Q3-2008:Q1)	No	Sovereign to banks		
	Yes	Banks to sovereign		Germany (2007:Q4) Germany (2008:Q1)
Third stage (2008:Q2-2008:Q3)	No	Sovereign to banks		
	Yes	Banks to sovereign		Germany (2008:Q2) Finland (2008:Q3)
Fourth stage (2008:Q4 - 2009:Q1)	No	Sovereign to banks		
	Yes	Banks to sovereigns		Austria (2008:Q4) Finland (2008:Q4) Netherlands (2008:Q4)
Fifth stage (2009:Q2 - 2009:Q3)	Yes	Sovereign to banks	Italy (2009:Q3)	
	No	Banks to sovereigns		
Sixth stage (2009:Q4 - 2011:Q3)	Yes	Sovereign to banks	Italy (2010:Q3)	Austria (2010:Q4) Austria (2011:Q1)
	Yes	Banks to sovereigns	**Greece (2011:Q2)** Italy (2011:Q2) Italy (2011:Q3)	
Seventh stage (2011:Q4 - 2012:Q2)	Yes	Sovereign to banks	Spain (2012:Q2)	
	Yes	Banks to sovereigns	**Greece (2011:Q4)** Italy (2011:Q4) Portugal (2012:Q1)	
Eighth stage (2012:Q3 - 2013:Q2)	No	Sovereign to banks		
	Yes	Banks to sovereigns		France (2012:Q3)

Note: Only two of the detected episodes (the ones in bold face letters) correspond to SIBs.

Table 4: List of SIBs in individual countries

Country	Name
Austria	Erste Group Bank AG
Belgium	Dexia
Germany	Deutsche Bank AG
Germany	Commerzbank AG
Spain	Banco Bilbao Vizcaya Argentaria SA
Spain	Banco Santander SA
Finland	Pohjola Bank plc - Pohjola Pankki Oyj
France	Crdit Agricole S.A.
France	Société Générale
France	BNP Paribas
Greece	National Bank of Greece SA
Ireland	Allied Irish Banks plc
Italy	UniCredit SpA
The Netherlands	ING Groep NV
Portugal	Banco Comercial Português

Table 5: Evolution of episodes of causality intensification between SIBs and sovereign risk.

Stage	Contagion	Direction	Peripheral	Central
First stage (2005:Q1-2007:Q2)	Yes	Sovereign to systemic bank	Ireland (2007:Q2)	Germany (2007:Q1)
	No	Systemic bank to sovereign	-	-
Second stage (2007:Q3-2008:Q1)	No	Sovereign to systemic bank	Spain (2008:Q1)	France (2007:Q3)
	No	Systemic bank to sovereign	-	-
Third stage (2008:Q2-2008:Q3)	No	Sovereign to systemic bank	-	-
	No	Systemic bank to sovereign	-	-
Fourth stage (2008:Q4 - 2009:Q1)	No	Sovereign to systemic bank	-	-
	No	Systemic bank to sovereign	-	Austria (2009:Q1) Finland (2009:Q1)
Fifth stage (2009:Q2 - 2009:Q3)	Yes	Sovereign to systemic bank		-
	No	Systemic bank to sovereign	-	Finland (2009:Q2)
Sixth stage (2009:Q4 - 2011:Q3)	Yes	Sovereign to systemic bank		
	No	Systemic bank to sovereign	**Greece (2011:Q2)** Greece (2011:Q3)	Austria (2009:Q4) Austria (2010:Q1) France (2011:Q3)
Seven stage (2011:Q4 - 2012:Q2)	Yes	Sovereign to systemic bank		
	No	Systemic bank to sovereign	**Greece (2011:Q4)** Greece (2012:Q1) Greece (2012:Q2) Italy (2012:Q1)	France (2011:Q4) France (2012:Q1)
Eight stage (2012:Q3 - 2013:Q2)	Yes	Sovereign to systemic bank		Finland (2012:Q3) Finland (2012:Q4) Finland (2013:Q1)
	No	Systemic bank to sovereign	-	-

Table 6: Government support measures for financial institutions (October 2008-May 2010)

Country	Capital injection		Liability guarantees		Asset support		Total commitment as % of 2008 GDP	Deposit insurance in Euros
	Within schemes	Outside schemes	Guaranteed issuance of bonds	Other guarantees, loans	Within schemes	Outside schemes		
Austria	5.8 (15)	0.6	21.8 (75)	0	- (-)	-	32	Unlimited
Belgium	- (-)	19.9	34 (-)	90.8	-(-)	16.9	47	100000
Finland	-4	-	-50	0	-(-)	-	29	50000
France	8.3 (21)	3	134.2(320)	0	-(-)	-	18	70000
Greece	3.2 (5)	-	14.4 (30)	0	4.4 (8)	-	18	100000
Germany	29.4 (40)	24.8	110.8 (400)	75	17 (40)	39.3	25	Unlimited
Ireland	12.3 (10)	7	72.5 (485)	0	8(90)	-	319	Unlimited
Italy	41.1 (12)	-	-(-)	0	-50	-	4	103291
Netherlands	10.2 (20)	16.8	54.2(200)	50	-(-)	21.4	52	100000
Portugal	-4	-	5.4 (16)	0	-(-)	-	12	100000
Spain	11 (99)	1.3	56.4 (100)	9	19.3 (50)	2.5	24	Unlimited

Notes: All amounts are in billions of EUR, except for the last two columns. Figures in brackets denote total committed funds and figures outside brackets are the amounts utilized up to May 2010. 'Within schemes' refers to a collective bailout program that can be accessed by any bank that fulfills the requirements for that particular aid scheme. 'Outside schemes' are individually tailored aid measures (ad hoc schemes). Source: Stolz and Wedow (2010).

Figure 1: Country-wise banking sector aDtD and average CDS spreads

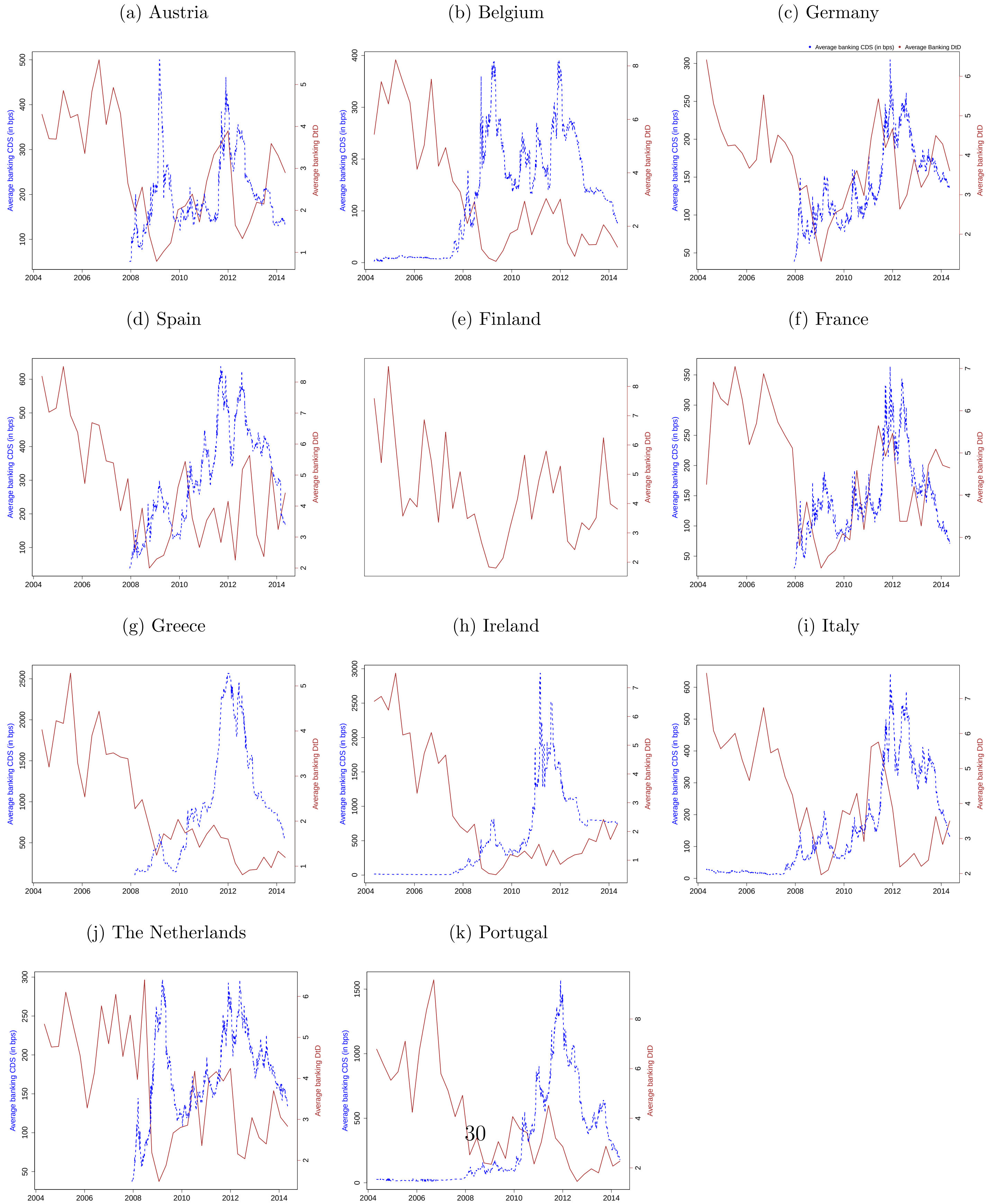
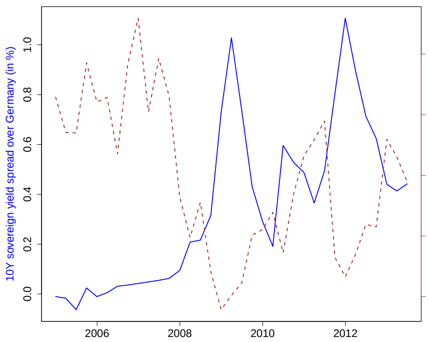
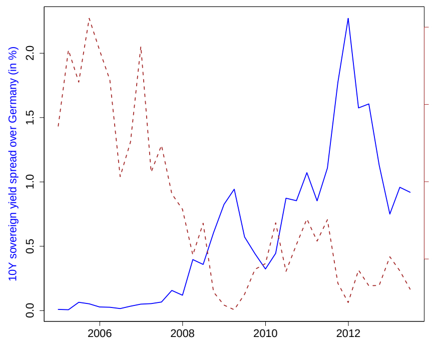


Figure 2: Country-wise banking sector aDtD and 10Y sovereign spreads over Germany

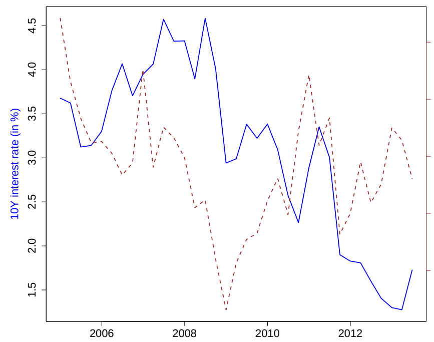
(a) Austria



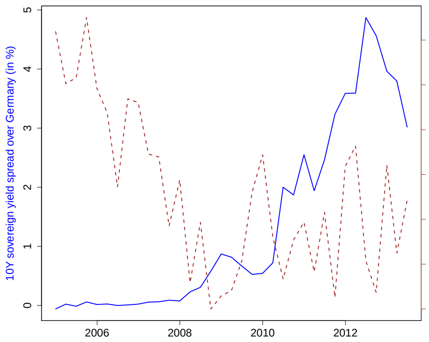
(b) Belgium



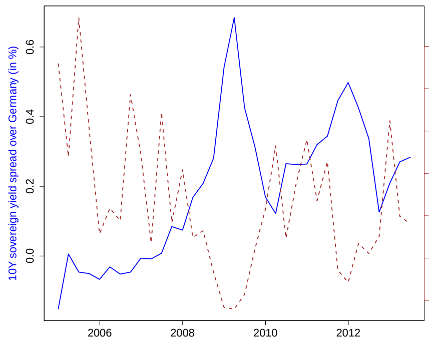
(c) Germany



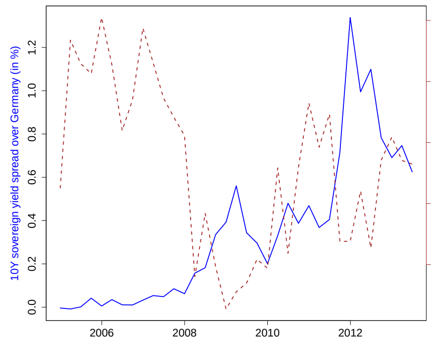
(d) Spain



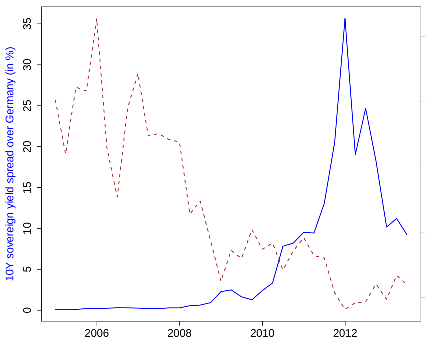
(e) Finland



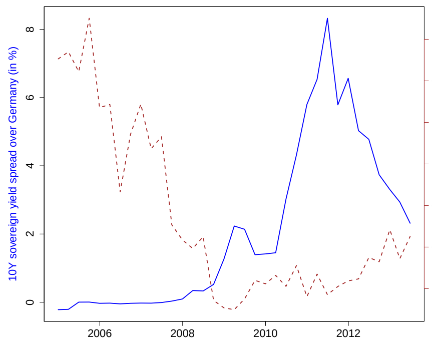
(f) France



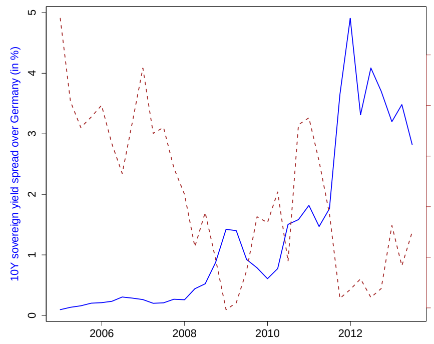
(g) Greece



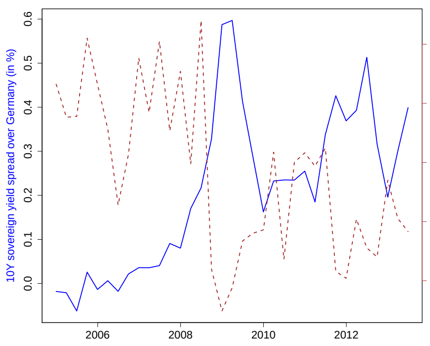
(h) Ireland



(i) Italy



(j) The Netherlands



(k) Portugal

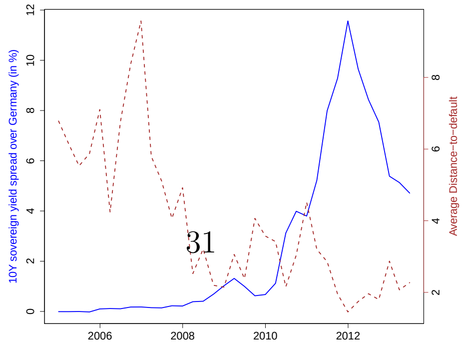
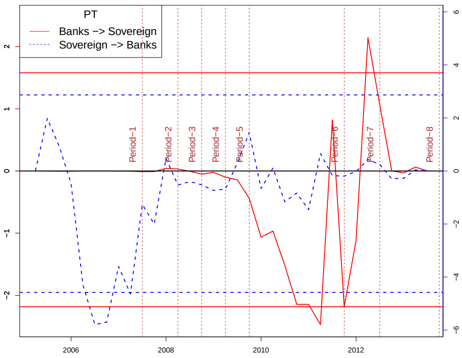
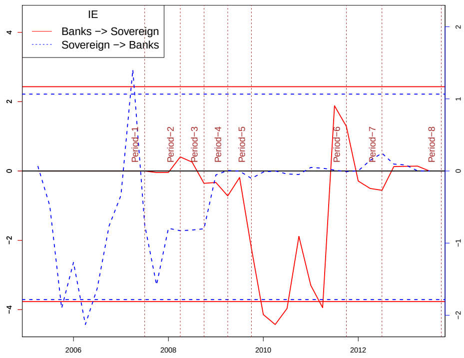


Figure 3: Time-varying causality between sovereign and banking risk in EMU peripheral countries, 2005:Q1-2013:Q2

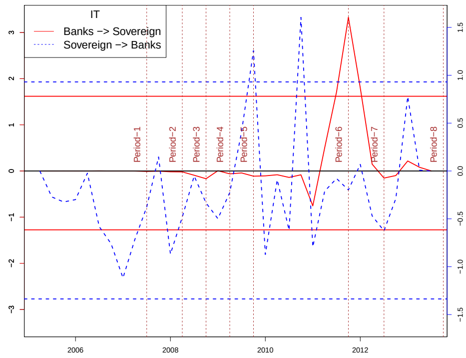
(a) Portugal



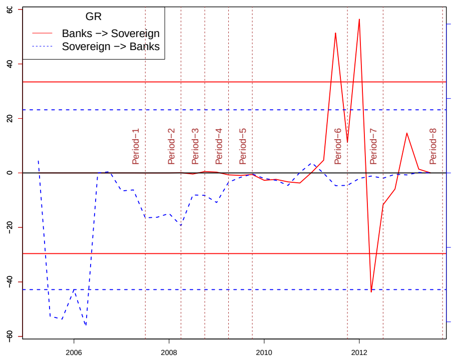
(b) Ireland



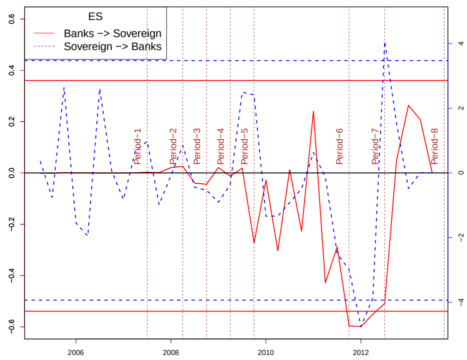
(c) Italy



(d) Greece

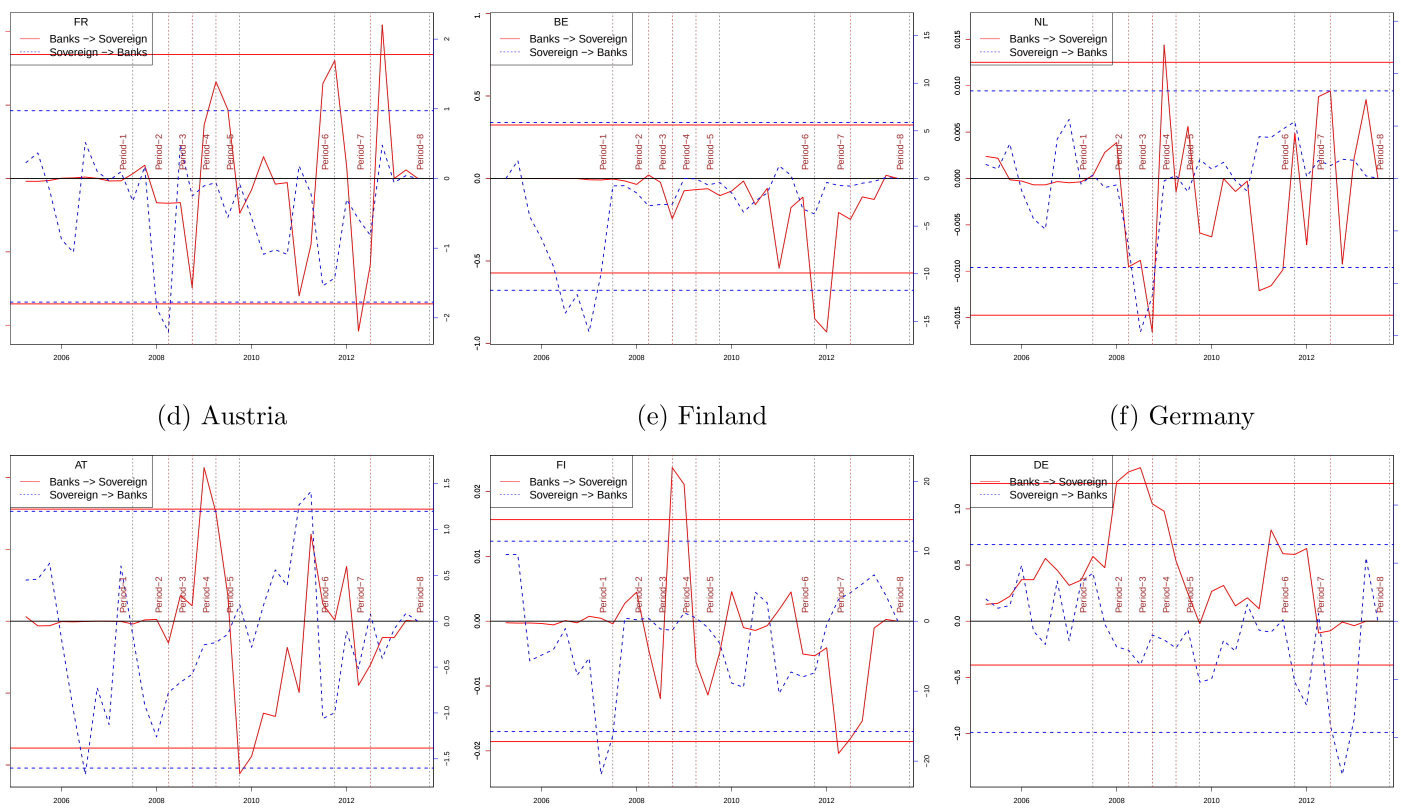


(e) Spain



Note: We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past aDtD series (aDtD → Spreads) and the differences between FPE obtained when estimating the aDtD series using only the information contain in past aDtD series and the FPE obtained using also the information contained in past sovereign spread series (Spreads → aDtD). We associate causality intensification from country banking risk towards sovereign risk with those episodes where the difference aDtD → Spreads (left axis) is positive and statistically significant at the 1% level, and causality intensification from sovereign risk towards country banking risk with those episodes where the difference Spreads → aDtD (right axis) is positive and statistically significant at the 1% level (see Table 3). The horizontal lines represents 95% confidence band around the median FPE differences.

Figure 4: Time-varying causality between sovereign and banking risk in EMU core countries, 2005:Q1-2013:Q2

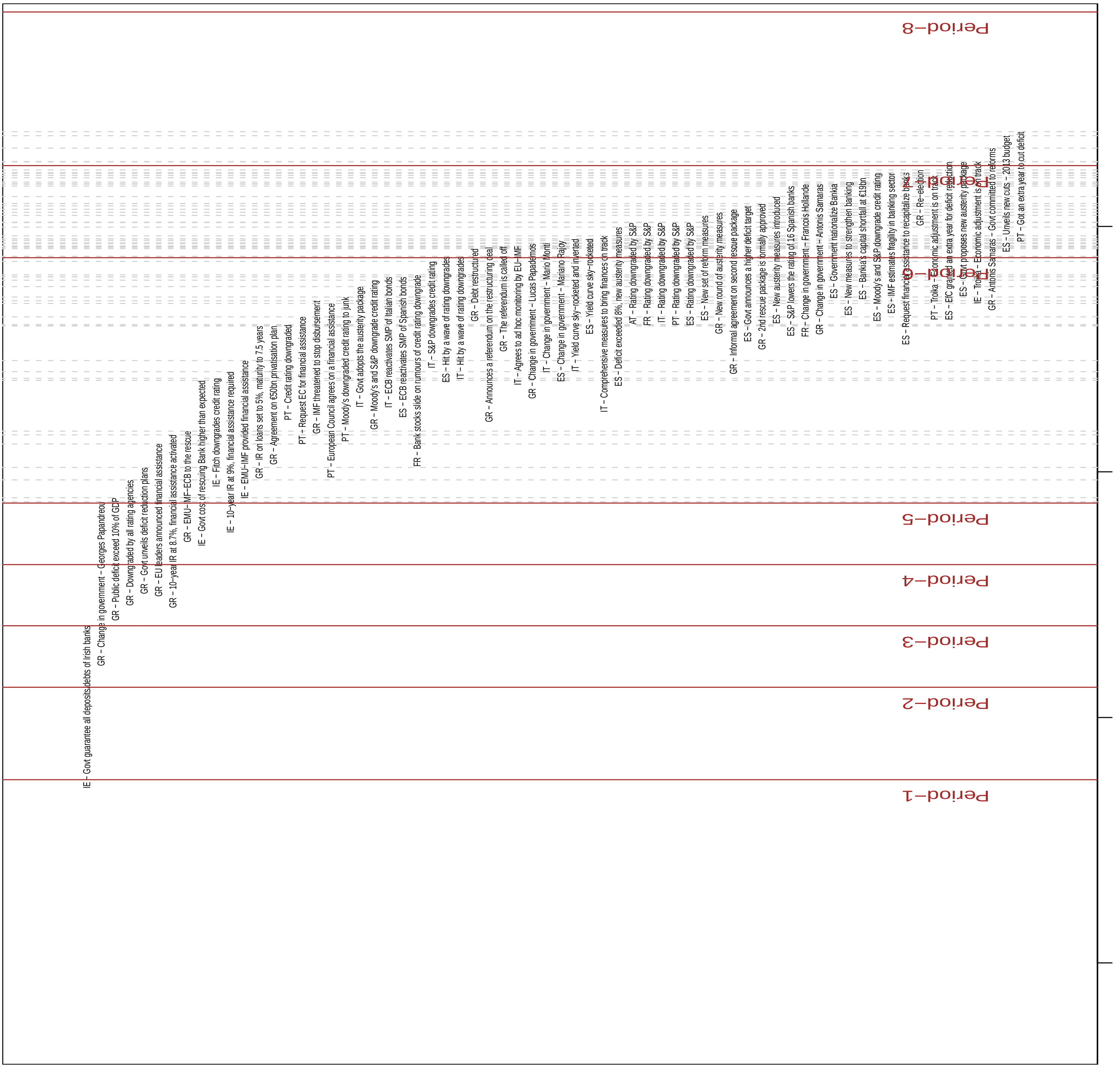


(a) France (b) Belgium (c) The Netherlands

(d) Austria (e) Finland (f) Germany

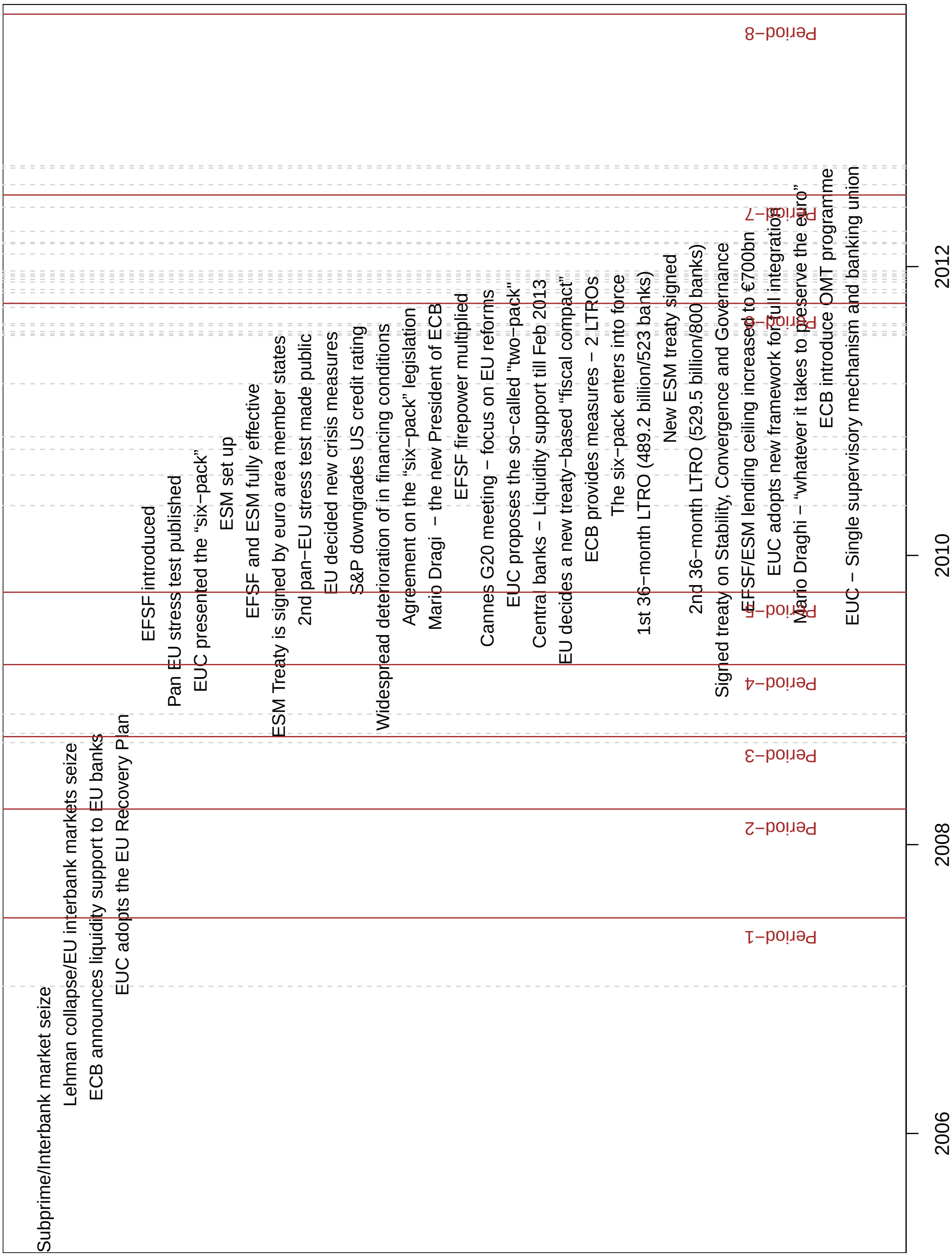
Note: We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past aDtD series (aDtD → Spreads) and the differences between FPE obtained when estimating the aDtD series using only the information contain in past aDtD series and the FPE obtained using also the information contained in past sovereign spread series (Spreads → aDtD). We associate causality intensification from country banking risk towards sovereign risk with those episodes where the difference aDtD → Spreads (left axis) is positive and statistically significant at the 1% level, and causality intensification from sovereign risk towards country banking risk with those episodes where the difference Spreads → aDtD (right axis) is positive and statistically significant at the 1% level (see Table 3). The horizontal lines represents 95% confidence band around the median FPE differences.

Figure 5: Country wise major crisis events



Source: ECB, Brugels and authors' calculation. EC: European Council; SGP: Stability and Growth Pact; EfC: Ecofin council; IMF: international Monetary Fund; EU: European Union; Govt: Government; EUC: European Commission; IR: Interest Rate; EFSF: European Financial Stability Facility; ESM: European Stability Mechanism; SMP: Secondary Market Purchase; LTRO: Longer-term refinancing operations.

Figure 6: Major policy actions at EU level



Source: ECB, Brugels and authors' calculation. EC: European Council; SGP: Stability and Growth Pact; EfC: Ecofin council; IMF: international Monetary Fund; EU: European Union; Govt: Government; EUC: European Commission; IR: Interest Rate; EFSF: European Financial Stability Facility; ESM: European Stability Mechanism; SMP: Secondary Market Purchase; LTRO: Longer-term refinancing operations.