The sovereign-bank nexus in peripheral euro area: Further evidence from contingent claims analysis

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Abstract

New evidence is presented on the nexus between the sovereign and banking sector risk. Applying the contingent claims methodology to the peripheral euro area countries over the 2004Q4-2013Q2 period, we build indicators of sovereign and bank risk and assess their interconnection in comparison with existing market-based indicators of bank and sovereign distress. We use three different statistical measures of interdependence based on principal components analysis, Granger causality framework and Diebold-Yilmaz's connectedness index. The empirical results show strong interconnection and co-movement between country-level banking and sovereign risk indicators. We also find evidence of bi-directional bank-sovereign causal linkages only for Spain during the European sovereign debt crisis period. For the late crisis period, we detect weak interrelationship and more divergence across the various risk indicators. Our findings indicate that secondary and derivatives market indices are more driven by common underlying factors than are contingent claim based risk measures. Finally, our results also suggest that market participants risk appetite was the main channel of risk transmission between sovereigns and banks for the countries under study during the sample period.

Keywords: sovereign risk, bank risk, sovereign-bank nexus, contingent claims
JEL: G13, G21, G33, H63

"At the present stage of development in Economics it is probably an advantage to have different groups looking at the same problem from different viewpoints, so that their conclusions can be compared and possibly then form the basis for a new compressive model"
- Granger (1990)

1. Introduction

The European sovereign debt crisis, which started in late 2009, raised serious concerns about the negative feedback loop between sovereign and bank risk. The risk was especially pronounced in peripheral euro area countries, where banks and sovereign CDS spreads started to follow each other very closely. One reason for this increased interconnection was the fear of the development of a vicious circle in which sovereign fragility would jeopardize the asset side of the banks' balance sheet. In turn, bank distress would increase the explicit and implicit bail-out costs for sovereigns, which would endanger public finances and raise questions about their debt sustainability (see Farhi and Tirole (2017), Acharya et al. (2014), Alter and Schüler (2012) among others).

Another plausible reason is the 'wake-up call' hypothesis (Goldstein (1998)), according to which a crisis alerts international investors to the need to reassess the creditworthiness of all borrowers. This makes market participants price the same fundamentals differently over time. Comparing the drivers of sovereign risk for 31 advanced and emerging countries, Beirne and Fratzscher (2013) show sharp rises in the sensitivity of financial markets to fundamentals as the main explanation for the rise in sovereign risk between 2008 and 2011, not only for euro area countries but globally. They also note the substantial and sustained differences in the pricing of fundamentals for sovereign risk among euro area peripheral countries before and during the crisis (see also Gómez-Puig et al. (2014)), suggesting the presence of multiple equilibria in this relationship.

The sovereign-bank nexus is of particular concern in monetary unions (De Grauwe (2012)), given that their member countries issue debt in a currency over which they do not have direct control and, therefore, they cannot guarantee bondholders nominal repayment. This could lead to a self-fulfilling debt crisis (Obstfeld (2012)).

While acknowledging the achievements of various studies that analyse systemic risk in the sovereign and banking sector [Acharya et al. (2014), Kallestrup et al. (2016), Beltratti and Stulz (2015), Yu (2017), Banerjee et al. (2016) and Klinger and Teplý (2016), just to name a few],[1] to our knowledge, this is the first paper that examines the sovereign-bank risk interconnection using in both cases an indicator based on the contingent claims analysis (CCA) methodology - which includes both accounting metrics and market-based measures. Then, our results will be compared with those obtained using the existing market-based indicators of bank and sovereign distress.

The main objective of this paper is to offer further empirical evidence and explanations on the nexus between the sovereign and banking sector risk. Our work contributes to

[1] Other authors have examined the transmission of sovereign to corporate risk. See, e.g., Augustin et al. (2018) who find that a 10% increase in sovereign credit risk raises corporate credit risk on average by 1.1% after the Greek bailout.

the literature in several ways. First, we quantify the interconnection between banking and sovereign risk in five, heavily exposed peripheral euro area countries, and document the time-varying nature of those linkages. To that end, in addition to the traditional banking and sovereign risk indicators based on the secondary market (sovereign yield spreads and banking sector equity return) and the derivatives market (banking sector average CDS spreads and sovereign CDS spreads), we compute a contingent claim model-based distance-to-default (DtD) measure for banks and sovereigns. As far as we know, this is the first paper that uses DtD risk indicators (both in the banking and in the sovereign sector) to examine and quantify risk transfer between banks and sovereigns in euro area peripheral economies.

The second contribution is the comprehensive analysis of the underlying interconnection between bank and sovereign risk by means of three different econometric techniques in order to gain further insights of the nature of these linkages: Principal component analysis, pairwise Granger causality, and Diebold and Yilmaz's connectedness index,[2] since each econometric technique allows to examine a different perspective of the risk transfer. Principal component analysis is used to analyse the interrelationships between the sovereign and the banking sector and to explain these indicators in terms of a smaller number of variables with a minimum loss of information. Pairwise Granger causality is applied to identify and quantify the bidirectional bank-sovereign network linkages. Finally, the framework proposed by Diebold and Yilmaz (2009, 2012, 2014) is used to examine the directional spillovers emanating from each market. Due to data restrictions, our sample spans the period from 2004Q4 to 2013Q2 (i.e., 35 observations) - including four years of the pre-crisis period as well as the peak of the European sovereign debt crisis episode.[3] The third contribution is, using the DtD indicators, to explore the channel (market participants risk appetite or balance sheet connection) through which the banking sector risk is linked to the sovereign one.

All in all, our results suggest that the banking and sovereign risk are highly interconnected during the time period we study. Also, there is clear evidence of an increasing role of idiosyncratic risk factors driving the evolution of all the risk indices in the post-crisis period, thus supporting the claims by Beirne and Fratzscher (2013). Country-wise analysis of time-varying bi-directional Granger causal linkages suggest the development of bank-sovereign doom loop only in Spain during the European sovereign debt crisis period. This result is in line with the findings of Singh et al. (2016) where a two-way negative feedback between banks and sovereign risk was also detected using sovereign yield spreads and banking sector average DtD data (see also Acharya et al. (2014) and Fratzscher and Rieth (2018)). The analyses based on Diebold-Yilmaz's connectedness index suggest that increased risk is being driven away from market-based indices to DtD indicators, suggesting that contingent claim based DtD indices capture the balance-sheet based uncertainty and vulnerabilities more precisely. Finally, our results also suggest that market participants risk appetite was the

[2] Singh et al. (2016) analysed sovereigns-banks linkages using the DtD indicator as a measure of the banking sector credit risk, but yield spreads in the case of sovereigns. Besides, their econometric methodology only relied on a dynamic Granger causality approach.

[3] Since our sample ends in 2013Q2, we will not be able to disentangle the effect of the European Central Bank's (ECB's) actions on the sovereign-bank interconnection.

main the channel of risk transmission between sovereigns and banks for the countries under study during the sample period.

The rest of the paper is organized as follows. Section 2 explains the channels via which interconnection arise between sovereign and bank risk and presents a brief review of the related empirical literature. Section 3 describes the risk indicators used in our empirical analysis. Section 4 briefly presents the econometric methodology used to assess the interconnections between the bank and sovereign risk indicators and reports the empirical findings. Finally, Section 5 offers some concluding remarks.

2. Interconnection between sovereign and banking institutions: A simple conceptual framework

Let us start with a simple conceptual framework to understand the idea of interconnection. Figure 1 shows the stylized balance sheet of a financial institution and its direct inter-linkages with the sovereign balance sheet and another financial institution. The figure is purely schematic and is not intended to indicate the relative magnitudes of the various parts of the balance sheet. Bank A (based in country A) has three categories of assets - (1) Treasury securities: the banks' total exposure to all treasury securities issued by various sovereigns. Generally, a large part of treasury securities consists of the securities issued by the domestic sovereign (here sovereign A), where the bank is based (home bias); (2) Loans to the real economy: exposures outside the financial network, consisting of claims on non-financial entities, such as mortgages and commercial loans; and (3) Claims on other banks: in-network assets claim on other banks, including the interbank loans and exposures through derivatives.

[Figure 1 about here.]

The bank's liabilities include obligations to depositors, other financial entities and bank's equity holders. Bank deposits are money placed by depositors into banks for safekeeping. In most countries, these are guaranteed by deposit insurance corporations (either public or private). The interbank obligations arise as a mechanism for banks to manage their liquidity risk and perform maturity transformation.[4] Bank equity is the owner's capital. It is kind of skin-in-the-game of promoters and shareholders of the bank and is of great interest to regulators. The sovereign liabilities consist of - Treasury securities issued by the sovereign and explicit/implicit guarantees provided by the government on domestic banks' liabilities.

2.1. Why does financial interconnection arise? Channels of interconnection

Consider N financial institutions indexed by i which are distributed across M countries indexed by j. Consider a financial institution i, having a risk exposure x_i, based in country j. Assume that fractions α_{ik} $(k \in 1, 2, .., M)$ of this exposure are directly concerned with

[4] This network serves as a risk-sharing mechanism for banks. However, some of these links become vulnerable in times of crisis and work as channels via which problems are amplified within the network.

the credit worthiness of various countries. Then the home sovereign exposure (home bias) in i's portfolio will be given by $\alpha_{ij}x_i$, while the total sovereign exposure will be $(\sum_{k=1}^{M}\alpha_{ik})x_i$.[5] Home exposure is extremely important in assessing the health of the banks' assets. Higher home bias will make banking sector assets extremely sensitive to government health. On the other hand, the high foreign sovereign exposure will diversify the sovereign risk exposure for banks but will provide the incentive for governments to collude if there is a looming threat of bank failure. If the fate of a country's banks is strongly intertwined with the health of a neighbouring country, this country will be more supportive of any external interventions to support its neighbour. This may have been the case in the Greek bailout, since there was some exposure to Greece, especially within the German and French banking sectors (Ardagna and Caselli (2014)).

Another factor in the banks' exposure concerns the risk factors idiosyncratic to i, i.e., the risk that stems from the direct exposure of banks to their home country's real sector. Let's denote by β_i the fraction of total bank exposure idiosyncratic to i. The idiosyncratic exposure of institution i will then be given by $\beta_i x_i$. The sum of idiosyncratic exposure of all banks based in country j, $\sum_{i\in j}\beta_i x_i$ will be the amount of credit available in country j. If the amount of available credit contracts, the government might have to step in (we might observe higher unemployment) thus placing a strain on government finances. The government has a choice to bail out either the banks or the real sector directly.

The last factor in the bank exposure is the in-network assets. These are direct 'links' among financial institutions, for instance, interbank loans or derivatives, given by the $N\times N$ matrix B, whose elements b_{ik} denote how much bank i is exposed to bank k.

Note that, the sum of the individual component of bank i's exposure will equal to 1. Mathematically,

$$\sum_{j=1}^{M}\alpha_{ij}+\beta_i+\sum_{k=1,k\neq i}^{N}b_{ik}=1$$

Similarly, the total exposure of banks to sovereign j (E_j) will be given by

$$E_j=\sum_{i=1}^{N}\alpha_{ij}x_i$$

Assuming that the returns on the sovereign exposure, idiosyncratic factor and in-network assets for bank i are $\rho_s+\epsilon_s$, $\rho_i+\epsilon_i$ and $\rho_n+\epsilon_n$ respectively, where ρ_s, ρ_i and ρ_n are constants, while ϵ_s, ϵ_i and ϵ_n are independently distributed random variables with zero mean. We can define the benchmark payoff $\hat{\pi}_i$ as what i would receive and we can write it in general as $\hat{\pi}_i(\rho_s,\rho_i,\rho_n,\epsilon_s,\epsilon_i,\epsilon_n)$. For illustration, a simple specification could be:

$$\hat{\pi}_i=(\rho_s+\epsilon_s)\sum_{j=1}^{M}\alpha_{ij}x_i+(\rho_i+\epsilon_i)\beta_i x_i+(\rho_n+\epsilon_n)\sum_{k=1,k\neq i}^{N}b_{ik}x_i$$

[5]The total foreign sovereign exposure will be given by $(\sum_{n\in M,n\neq j}\alpha_{in})x_i$.

However, since the fate of countries j and bank i are intertwined and i also depends on a system of financial institutions via interlinked claims, its actual pay-off differs from $\hat{\pi}_i$ substantially in case of crisis, when banks and sovereign default risk start moving in locksteps (see Figure 2).

[Figure 2 about here.]

2.2. Literature: Direct and indirect linkages between sovereigns and banks

As explained above, sovereign and banks have direct linkages via the bank's asset holding channel. Banks hold sovereign debt which makes them vulnerable to the sovereign's deteriorating fundamentals. Indirectly, sovereign debt rating provides a credit ceiling for domestic banks. Also, the worsening creditworthiness of the sovereign squeezes the fiscal space, leading to deteriorating economic activity that indirectly impacts banks' lending. On the reverse, bank distress leading to explicit or implicit government support jeopardizes government finances and its debt sustainability conditions.

Those linkages have been examined by a wide literature both from a theoretical and from an empirical perspective. Here, we briefly review the main contributions by focusing on a non-exhaustive list of works. The papers that examine the drivers or channels through which risk transmission takes place include De Marco and Macchiavelli (2016), Horváth et al. (2015), Ongena et al. (2016), Altavilla et al. (2017), Gennaioli et al. (2014) and Farhi and Tirole (2017). De Marco and Macchiavelli (2016) and Horváth et al. (2015) show that the bank-sovereign nexus was strongly driven by the moral suasion according to which government-owned banks or banks with politicians on their boards of directors displayed higher home bias and purchased more domestic sovereign debt than did privately-owned banks throughout the 2010-2013 period. They also find the moral suasion to be stronger in countries under stress and where sovereign debt is risky. Using propriety data on banks' monthly securities holdings, Ongena et al. (2016) also show that in times of crisis, European banks in peripheral stressed countries increase their holdings of domestic sovereign bonds in months with relatively high domestic sovereign bond issuance. The effect was also stronger for state-owned banks. Investigating monthly data for 226 European banks from 2007 to 2015, Altavilla et al. (2017) show that the publicly owned, recently bailed out and less strongly capitalized banks reacted to sovereign stress by increasing their domestic sovereign holdings more than other banks, suggesting that their choices were affected both by moral suasion and by yield-seeking. Their exposures significantly amplified the transmission of risk from the sovereign and its impact on lending. According to Gennaioli et al. (2014), who develop a theoretical model that characterizes the connection between public defaults and private financial markets, the willingness of a government to repay its debt, and thus its ability to borrow in the first place, depends on the development of private financial markets. More developed financial markets translate into more severe consequences of public defaults, thereby providing governments with stronger incentives to repay. Finally, Farhi and Tirole (2017) relate these developments to domestic bailouts of the banking system by the sovereign on the one hand, and sovereign debt forgiveness by international creditors or country bailouts by other countries on the other hand. These authors contend that an important feature of this "double-decker bailout" theory is that the fates of sovereigns and their banks are deeply intertwined, and yet consolidating their balance sheet would be misleading.

From an empirical perspective, a large literature has also focused its analysis on the sovereign-bank nexus [Acharya et al. (2014), Kallestrup et al. (2016), Beltratti and Stulz (2015), Yu (2017), Banerjee et al. (2016), Fratzscher and Rieth (2018) and Klinger and Teplý (2016), among them]. In particular, using CDS spreads on European sovereigns and banks for the period 2007-11, Acharya et al. (2014) find empirical evidence to support the bi-directional negative feedback loop between banking and sovereign risk during the recent crisis. They also show that bailouts triggered the rise of sovereign risk and find evidence for the widening of sovereign spreads, and the narrowing of banking spreads, after a bailout.[6] Fratzscher and Rieth (2018), who use daily data for the period 2004-2013 and a system of simultaneous equations identified through heteroskedasticity to analyse the empirical relationship between bank and sovereign risk in the euro area, also use CDS spreads as a measure of risk. Their results confirm a two-way causality between both risks in some euro area countries - which amplifies initial credit risk shocks - and also document significant credit risk spillovers between sovereigns and banks in the periphery and the core countries. De Bruyckere et al. (2013) document significant empirical evidence of contagion (defined as excess correlation) between bank and sovereign credit risk during the European sovereign debt crisis, especially strong in 2009, when the sovereign debt crisis emerged. By constructing a simple risk-weighted measure of foreign exposures of banking systems in 17 countries, Kallestrup et al. (2016) show that the foreign asset holdings of the largest banks are an important determinant not only of their own CDS premiums but also of the CDS premium of the sovereign in which the banks reside. Thus, banks' foreign sovereign debt holdings not only impact the banks' own credit risk but also transfer the risk partially to their own sovereigns. The exact opposite is also observed. Studying the relation between bank stock returns from EU countries and the returns on sovereign CDS of peripheral countries for 2010 to 2012, Beltratti and Stulz (2015) found the relationship to be negative. Using days with tail sovereign CDS returns of peripheral countries to identify the effects of shocks to the cost of borrowing of these countries on EU banks from other countries, they found that the CDS tail return has a greater effect on banks with greater exposure to the country experiencing that return, but it also has an impact on banks that were not exposed. More pervasive shocks to peripheral countries have a stronger impact on the returns of banks from countries that experience no shock more than do shocks to small individual peripheral countries. In a related empirical work, Yu (2017) analysing the dynamic linkage between European sovereign and bank CDS spreads from 2006 to 2012, shows that risk initially transferred from banks to sovereigns soon led to a reverse spillover due to deteriorating fiscal conditions. Moreover, Banerjee et al. (2016) assess the effectiveness of large scale bailouts during the European sovereign debt crisis and show that before the first Greek bailout, the sovereign and financial sectors exhibit a two-way feedback effect, but the pattern disappears during all later bailouts. Finally, Klinger and Teplý (2016) examine the link between financial system

[6] See also Attinasi et al. (2011), Sgherri and Zoli (2011), Ejsing and Lemke (2011), and Alter and Schüler (2012), who provide similar descriptive evidence as Acharya et al. (2014).

and sovereign debt crises by examining sovereign support to banks and banks' resulting exposure to the bonds issued by weak sovereigns that is reflected in the higher CDS spreads of these sovereigns.

Therefore, though all these empirical papers use different methodologies to examine the sovereign-bank risk nexus, all of them use market-based measures of banking and sovereign risk, mainly credit default swap (CDS) spreads on 5-year senior debt contracts, since these are known to be the most actively traded and therefore the most liquid.

3. Bank and sovereign risk indicators: Data and preliminary analysis

Our paper represents an important step forward from the previous literature. First, to measure the vulnerability of banks and sovereigns, we use the contingent claims literature and derive a set of risk indicators. Then, to examine the reliability of our results, we compare them with other market-based indicators of bank and sovereign risks. Second, the analysis relies on three different econometric methodologies in order to provide further insights of the issue by means of examining it from different perspectives. The variables and data sources used in each risk indicator are summarized in Table 1.

[Table 1 about here.]

3.1. An overview of CCA

Consider a legal entity (firm, bank or sovereign) whose capital structure consists of only two types of liabilities (both due at time T), differing only in terms of their seniority.[7] For simplicity let's call them - senior and junior claims. Also, assume that the entity promises to pay a fixed amount S to the senior creditors, and the remainder to the junior creditors. Therefore at maturity T, if the total value of assets of the entity is A, then the pay-off for the senior claim holder 'P_S' will be, $P_S = min\{S, A\}$, while the pay-off for the junior claim holder 'P_J' will be $P_J = max\{A - S, 0\}$.

This pay-off for the junior creditors is analogically similar to the pay-off for the buyer of a typical call option. For a given strike price K, the pay-off for the buyer of the call option depends on the firm's equity price E, and is given by $P_C = max\{E - K, 0\}$, where E is the firm's equity value at the maturity of the option. CCA exploits this analogy and the fundamental relationships between the value of an entity's assets and the dependent contingent claim (the call option). The junior claims are modelled as an implicit call option on the value of the entity's assets while considering the senior claims as the strike price. So if the entity's future senior claims are known and its junior claims are tradable in the marketplace, then CCA uses this information to derive the value of the entity's asset (A) and asset volatility (σ_A). The methodology is well established in the literature (see Black and Scholes (1973), Merton (1974, 1977), Gray et al. (2007), European Central Bank (2012),

[7] By seniority, we mean that the senior creditors are the first to recover their money in case of insolvency while the junior creditor receives only what is left once the senior creditors have been paid.

Saldias (2013), Gray and Jobst (2010), Gray et al. (2010)). For a detailed presentation, please see Appendix A.

Distress occurs when the market value of an entity's assets declines relative to its contractual obligations (S in this case) or when asset volatility increases such that the value of assets becomes highly uncertain and the probability of the value falling below the contractual obligation increases. Default occurs when the value of an entity's assets falls below its contractual obligation known as the 'default point' in the literature.[8] One way to define this concept is through the calculation of "Distance-to-default (DtD)" which is defined as the number of standard deviation the entity's asset value is away from its contractual obligation.

$$Distance - to - default\ (DtD(t)) = \frac{A(t) - S}{A(t)\sigma_A(t)} \tag{1}$$

An alternate way is to define a risk-adjusted Distance-to-default (DtD^{RA}) as the distance between the expected future value of the entity's asset and the default point.

$$DtD^{RA}(t) = \frac{log(\frac{A(t)}{S}) + (r - 0.5\sigma_A^2)(T - t)}{\sigma_A\sqrt{T - t}} \tag{2}$$

Here r denotes the risk-free rate. If substituted in the normal cumulative density function, we can calculate the probability of default ($PD(t)$) as,

$$PD(t) = P[A(t) \leq D] = \Phi(-DtD^{RA}(t)) \tag{3}$$

Conceptually there is not much difference between these risk indicators. The level and variation vary numerically but the change always points in the same direction for the entity's health. Given this, from now on, we will document all our analysis based on the DtD calculated using equation 1.

3.2. Banking sector risk measures

To assess the banking sector risk in each individual country, we use three different bank risk measures. Our primary indicator of bank risk is the banking sector average DtD based

[8] DtD is a relative risk measure and lower value of DtD does not guarantee default. It only suggests the riskiness of an entity based on the current state of its finances. There can be multiple reasons for this: a) Term structure of debt: Since all debt contracts are not written with a single terminal date, the total debt used in the calculation might not be due within a year; b) Future prospects: Even if the current state of finances look bleak, the entity might show better prospects in the coming future. One can think of it like non-profit generating start-ups. In this case, even if the DtD comes negative, the entity will not default, as the debt holders will lose all value if they trigger bankruptcy against the firm; c) Rescue measures: In case of sovereign DtD, we can think of rescue packages provided by multilateral institutions, central banks or different financial stability facilities. We also observed domestic bank supporting sovereign debt level suggesting the role of 'moral suasion'. These rescue measures and bank support, converted many junior claims to senior claims in European sovereign debt crisis, that helped delay default. The sovereign DtD calculation methodology accounts for this by increase in senior claims (reducing the numerator).

on the CCA literature.[9] Two other standard market-based measures, average banking sector CDS spreads (based on derivatives market) and banking sector equity index (based on secondary market) are used for comparison. The rest of the subsection enumerates them in greater detail.

3.2.1. Banking sector average DtD (BankDtD)

Based on the contingent claim literature discussed in Section 3.1, we use average bank DtD based on all publicly listed banks head-quartered in each country as the bank risk indicator. Its foundation lies in the isomorphic relationship between equity and call options. Since equity is a junior claim to debt, it can be modelled as a European call option on the banks' assets (A) with an exercise price equal to the face value of debt (D).

Typically, a schematic view of the bank liability has two basic components: One is the debt contracts to borrow money for a fixed period of time in the form of loans and bonds, and their holders (creditors) have to be repaid irrespective of whether the bank is successful. The second is equity contracts to borrow money with no promise of repayment. Repayment is conditional on whether the firm succeeds. If it is successful, the equity holders (shareholders) receive a part of the profit. A formal insolvency regime for corporate debt restructuring sets out, in general terms, how these different types of claimants on a distressed bank will be treated in a restructuring process and establishes the order of payment in the event of outright liquidation. These rules tell a bank's creditors/shareholders where their claims stand in the pecking order. As the contracts suggest, the bankruptcy laws consider debt holders as senior claimants compared to shareholders. Debt gets paid first, and whatever remains is paid to the shareholders. As shareholder claims are junior compared to creditors, the value of the firm's equity can be modelled as a call option on its assets in which the outstanding debt is considered as the strike price.

However, in practice, the application of CCA for a bank DtD calculation is quite challenging. A bank's liability structure usually involves debt and equities of many different kinds with different priorities. Since all banks considered here are publicly traded, we use the market value of bank equity and equity volatility as proxy for the value of junior claims and its volatility. Since all debt contracts are not publicly traded, we use the notional value of all debt as proxy for the value of senior claims. In general, the levels and amounts of contractual liabilities due are relatively easy to determine from the balance sheet information but they are spread across time, based on the debt maturity profile. This makes defining the exact default point (the strike price in the case of a call option) extremely difficult. Based on the time horizon of interest, different distress barriers can be defined which can be combinations of the contractual obligations which are due in the coming years. An extensive survey of the literature suggests that for bank risk measurement, the default point is calculated as

[9] Singh et al. (2015) did a comparison of country level bank risk measure comparing indices build on simple average, total asset weighted average and market capital weighted average. Since banking assets in euro-area countries are very concentrated in the hands of top few banks and the CDS spreads are also available only for these limited set of banks, we found that simple average DtD or CDS capture the country level risk better with less fluctuations and exhibits better predictive ability than asset/market capital weighted indices.

the sum of short-term debt, interest payments due within a year, and 50% of the long-term debt (for detailed discussion and calculation methodology, refer to Singh et al. (2015)).[10]

Once individual banks' DtD are calculated, following Harada et al. (2010), we consider the banking sector risk as the simple average of individual DtD ($BankDtD$) of all banks headquartered in a particular country. For a detailed description of the calculation methodology, see Singh et al. (2015). DtD can be interpreted as the number of 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.

Data: The sample selection methodology is as follows. First, an exhaustive list of all listed and delisted monetary financial institutions is selected from the Bankscope[11] database. Only banks whose shares were publicly listed and traded between the last quarter of 2004 till the second quarter of 2013 and are head-quartered in peripheral euro area countries are selected.[12] 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 main reason for this exclusion is the difference in liability structure and business model compared to banks. However, this does not mean that they are less risky to the financial system. The market-based data include daily observations of risk-free interest rates, daily stock price and total outstanding share in public. For our analysis, we compute DtD at the quarterly frequency. The variables and data sources are summarized in Table 2, while Table 3 lists the name of banks considered in the analysis.

[Table 2 about here.]

[Table 3 about here.]

3.2.2. Banks average CDS spreads ($BankCDS$)

Based on the derivatives market, we use banks 5-year CDS daily mid-quotes from Datastream for all banks headquartered in the five peripheral euro area economies, namely Greece, Ireland, Italy, Portugal, and Spain, that were heavily affected by the sovereign debt crisis between 2010-2012.[13] Following previous studies, we focus on the 5-year maturity for senior unsecured debt, as these contracts are regarded as the most liquid in the market. The time series of bank CDS spreads for each country was created by averaging individual bank CDS

[10]Evidence from the universe of corporate defaults also indicates that the market value of a firm's assets can sometimes trade below its contractual liabilities for a significant period of time. This is most often the case when the majority of liabilities are long-term, allowing the firm to continue servicing debt payments while undertaking steps to improve its financial health. Another possible explanation can be investors' faith in the firm's long-term sustainability and recovery. Therefore, in estimating corporate default risk, the value of assets that triggers a distress is assumed to lie somewhere in between the book value of total liabilities and short-term liabilities.

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

[12]Data restrictions conditioned the time period, the frequency and the countries used in the empirical analysis.

[13]Acharya and Steffen (2015), Eser and Schwaab (2016) and Fratzscher and Rieth (2018), among others, also consider this group of stressed countries as special study cases.

spreads at the country level. We have an overall sample of 25 banks spread across the five countries for which CDS data were available in Datastream (see Table 4).

[Table 4 about here.]

3.2.3. Banks equity index based on average returns (BankEQU)

Based on the secondary market, we use the country-wise banking sector equity index. The index is based on average logarithmic returns of all publicly traded banking firms' headquartered in a particular country (for the list of banks, please refer to Table 3). The indices are normalized to 100 (at the beginning of the last quarter in 2004) for all countries.[14]

3.2.4. Commonality and differences among banking sector risk measures

Our sample contains Greek, Irish, Italian, Portuguese and Spanish banks. We use quarterly data from 2004-Q4 to 2013-Q2 (i.e., $T = 35$ observations).[15] Table 5 provides summary statistics of all banking sector risk measures. The mean $BankDtD$ ranges from 2.35 for Greece to 4.58 for Spain. The highest variation is observed for Portugal and Ireland, whereas Greece shows a consistently low level. The median values for Greece and Ireland are 1.87 and 1.75, reflecting the precarious banking conditions in these countries for our time period of study.

[Table 5 about here.]

The mean value of $BankCDS$ for individual countries are lowest in case of Italy (1.48%) and highest in case of Greece (9.64%). We also observe extremely high values for Greece (24%), Ireland (20%) and Portugal (13.65%). These peaks coincide the period when the banking crisis was at its highest point (as in the case of Ireland) or when the sovereign government in these countries lost market access for issuing new government bonds (as in Greece and Portugal). Also noteworthy is the fact that Irish banks' CDS spreads before the crisis were negligible and then shot up within a very short period of time during the crisis. If we compare this with the $BankEQU$, we find a similar trend for Ireland. The $BankEQU$ for Spain and Greece also shows huge gains before the crisis compared with Ireland, Italy, and Portugal. Post-crisis, however, the Irish and Greek banking sectors show continuous sign of stress with very low index values.

[14]Note that the methodology creates an upward bias in the returns indices due to bank failures, and must be interpreted carefully. All the result documented in this paper are based on this unbalanced panel. However, our results are robust to the balanced panel of banks where we only consider banks for which data is available for the entire period.

[15]To compute DtD, we use the stock prices together with the balance sheet data. The accounting data is available only at quarterly frequency. Some authors have used statistical techniques to convert quarterly data to daily data, but this might not be a reasonable interpolation in our opinion, since the interpolation uses forward looking information which was not available. Also low frequency data helps us keep the market noise low in our analysis. This is the cost we pay for incorporating balance-sheet based information in our risk measure.

To study the commonality in different banking sector risk indicators, we compute the cross-country correlations matrix for each alternative indicator. Since the time series of observations are not always of equal length, the correlation between each pair of banking sector risk indicators is based on the common sample. The correlations matrices are shown in Table 6. To evaluate these results, we use the adjective 'strong' for estimated values included in the interval (2c,1], the adjective 'weak' for estimated values included in the interval (c,2c], and when the estimated values are included in the interval (0,c], we say that the series is 'not correlated'. The cut-off point c is chosen because it roughly corresponds to the null hypothesis that the correlation coefficient is zero at 5% level of significance.[16]

[Table 6 about here.]

As can be seen, there is evidence of a strong positive correlation between the *BankDtD* indicators. Regarding the *BankCDS*, we also find a strong positive correlation, except for the case of Ireland with Greece. Finally, and in relation to the *BankEQU*, we observe a strong positive association between Greece and Italy, a weak positive correlation in Spain with Greece, Italy, and Portugal, in Portugal with Greece and Ireland, and between Portugal and Italy. There is no significant evidence of a correlation between Ireland and Greece, Spain or Italy. The highest pair-wise correlations are between *BankCDS* indices followed by *BankDtD* and *BankEQU*. The average pair-wise correlations are above 0.85 for *BankCDS* which comes down to 0.78 for *BankDtD*. However, the pair-wise correlation in case of *BankEQU* is extremely low. We even find a negative correlation between the Spanish and Irish *BankEQU*.

3.3. Sovereign risk measures

To assess the sovereign risk, we also use three different risk measures. Our primary measure of risk is the sovereign *DtD* indicator as suggested in Singh et al. (2018). Sovereign yield spreads (based on secondary capital market) and sovereign CDS spreads (from the derivative market) are used as secondary measures of risk. The rest of the section describes all sovereign risk measures in detail.

3.3.1. Sovereign distance-to-default (SovDtD)

We build a debt sustainability indicator for individual peripheral euro-area countries (for both non-/defaulted) based on CCA. Instead of calculating the net asset value of sovereign directly, we use the sovereign's liability side balance-sheet information and market's view to figure out the implied value and volatility of sovereign's assets.

Incorporating lessons from the sovereign debt crises in general and from the Greek debt restructuring in particular, we define the priority structure of sovereigns' creditors that is most relevant for peripheral euro-area countries in severe crisis episodes. The basic idea is that even though *de jure* there is no explicit seniority to a particular group of creditors,

[16] The standard error is approximately $T^{-1/2}$, T being the sample size. In our case, $T = 35$ for *BankDtD* and *BankEQU* and $T = 22$ for *BankCDS*. Thus the two standard errors would be 0.34 and 0.43 respectively.

almost all market participants expect multilateral creditors' holdings to be senior to private markets. Rating agencies' downgrade of euro area countries during the sovereign debt crisis were also explicitly motivated by seniority issues (see Steinkamp and Westermann (2014)). The Greek debt restructuring of 2012 also validated this differentiation where we observe asymmetrical losses across creditors and across debt instruments based on the seniority of creditors and maturity of different bonds (see, e.g., Zettelmeyer et al. (2013)). Thus, tranching of the sovereign default risk for creditors based on their seniority pushes the market-based measures of risk gradually towards the riskiness of junior claim holders.

We exploit this market development to define the priority structure of sovereign creditors based on their place of residence and institutional classification (see Figure 3). This classification is used to define two kinds of sovereign liabilities: senior and junior claims holders. Giving legitimacy to the current bankruptcy proceedings where the bankrupt entity formally surrenders its assets to its creditors and sale proceedings are divided among creditors based on the priority structure of liabilities, we price the junior claims as a call option on the sovereign's assets.

[Figure 3 about here.]

To this end, we use the market value of sovereign debt in the hands of junior creditors as the equity value. The value of junior claims is calculated by multiplying the market value of the sovereign's total debt with the fraction of the total debt in the hands of junior creditors. The volatility of the sovereign bond price as provided by the CNMV[17] is taken as the direct measure of the junior claims volatility. To calculate the default barrier (strike price in case of call option), we use the sum of the general government's short-term debt obligations (where the payment is due in one year or less in nominal terms) and half of the long-term debt.

An implied value of sovereign assets and its volatility are then estimated using the CCA methodology as discussed in Section 3.1. We define Distance-to-default as the number of standard deviation the sovereign's asset (V_A) is away from its default barrier (DB) and is calculated as:

$$DtD = \frac{V_A - DB}{V_A \sigma_A}$$

We calculate a quarterly time series of the $SovDtD$ for Greece, Ireland, Italy, Portugal and Spain. For a detailed description of the methodology, refer to Singh et al. (2018). $SovDtD$ can be interpreted as the number of standard deviation the sovereign's assets value are away from its debt obligations. Figure 4 shows the evolution of $SovDtD$ and $BankDtD$ for each country considered in our analysis.

[Figure 4 about here.]

[17] We use data from the National Securities Market Commission (Comisión Nacional del Mercado de Valores (CNMV)), the agency responsible for the financial regulation of the securities markets in Spain. These are daily data on bond market volatility which is calculated as the annualized standard deviation of daily changes in 40-day sovereign bond prices. The quarterly value is then computed as the average of the last three months daily volatility.

3.3.2. Sovereign CDS spreads (SovCDS)

We use five-year benchmark sovereign CDS daily mid-quotes from Datastream as the second measure of sovereign credit risk ($SovCDS$). These data are available starting at 2007Q4. Following previous studies we focus on the 5-year maturity, as these contracts are regarded as the most liquid in the market. Figure 2 shows the evolution of $SovCDS$ and $BankCDS$ for each country considered in our analysis.

3.3.3. Sovereign yield spreads (SovSPR)

To calculate yield spreads for individual countries ($SovSPR$), we use the Maastricht criterion bond yields (the long-term interest rates). These are the rates used as a convergence criterion for the European Economic and Monetary Union (EMU) countries, based on the Maastricht Treaty. The series relates to interest rates on long-term government bonds denominated in national currencies. The data are based on central government bond yields on the secondary market, gross of tax, with a residual maturity of around 10 years. Yield spreads are calculated as the difference between the ten-year benchmark sovereign bond yield of each individual country and that of Germany. Figure 5 shows the evolution of $SovSPR$ and $BankEQU$ for each country considered in our analysis.

[Figure 5 about here.]

3.3.4. Commonality and differences among sovereign risk measures

Our sample contains Greece, Ireland, Italy, Portugal and Spain and we use quarterly data from 2004-Q4 to 2013-Q2. Table 7 provides summary statistics of all sovereign risk measures. The mean $SovDtD$ ranges from 10.94 for Portugal to 18.88 for Italy. The highest variation is observed for Ireland and the lowest for Portugal. A closer look at the data shows consistently low values for Portugal, suggesting its vulnerability for our entire period of study. The minimum value is observed for Greece at 1.43.

[Table 7 about here.]

Comparing this with $SovCDS$, we find similar trends. If we look at the minimum values for Spain (0.19%), Greece (0.20%), Italy (0.20%) and Portugal (0.29%), it suggests that before the crisis financial markets priced the default risk of all peripheral sovereign on a par with other central European countries. However, with the advent of the sovereign debt crisis, Greece, Portugal, and Ireland show consistently high CDS spreads (7.94%, 2.86%, and 2.71% respectively) compared with Spain and Italy. For Greece, Ireland, and Portugal, we observe huge spikes in CDS spreads coinciding with there loss of market access. For Greece, since it formally restructured its sovereign debt in 2012, we find consistently high values. Looking at yield spreads, we find very low levels for countries before the crisis (Ireland has negative yield spreads for some periods). However, during the crisis, the levels shot up for Greece (26.51%) and Portugal (11.18%) creating a vicious loop in which high debt cost made the debt unsustainable, thus increasing the cost of debt further. We see a similar trend for Spain (5.29%) and Italy (4.88%), but with a less dramatic increase in yield spreads.

To study the commonality between the different sovereign risk measures under study, we compute the cross-country correlations matrix for each alternative indicator. Since the time series of the observations are not always of equal length, the correlation between each sovereign risk indicator is based on the common sample. The correlations matrices are shown in Table 8. As above, we use the adjective 'strong' for estimated values included in the interval (2c,1], the adjective 'weak' for estimated values included in the interval (c,2c] and, when the estimated values are included in the interval (0,c], we say that the series is 'not correlated'. The cut-off point c is chosen because it roughly corresponds to the null hypothesis that the correlation coefficient is zero at 5% level of significance.[18]As can be seen, we find evidence of a strong positive correlation between the $SovDtD$ indicators in all cases except Italy with Greece and Ireland and Portugal with Ireland and Italy, where we detect high but weak positive correlations. Turning to the $SovCDS$, we observe a strong and high positive correlation between Italy and Spain, but a weak positive correlation for all other cases except for the pair Greece and Ireland, where no significant correlation is found. Finally, and with respect to the $SovSPR$, we observe a strong positive association in all cases.

[Table 8 about here.]

3.4. Cross-correlations between sovereign and banking sector risk

To study the commonality between sovereign and banking sector risk indicators, we compute the cross-country correlations matrix for each peripheral euro area country under study. Since the time series of observations are not always of equal length, the correlation between each sovereign risk indicator is based on the common sample. The correlations matrices are shown in Table 9.[19] Focusing only on the association between the bank and sovereign indicators, we find evidence of a weak negative correlation between $BankDtD$ and $SovCDS$ and $SovSPR$ in all countries except Spain, where no significant correlation between them is found. There is also evidence of strong negative (Italy and Spain) or high but weak negative correlation (in the remaining countries) between $BankEQU$ and $SovCDS$.

[Table 9 about here.]

In the case of Greece, we also observe strong positive correlations between $BankCDS$ and $SovSPR$ and between $BankEQU$ and $SovDtD$, as well as a high but weak positive correlation between $BankCDS$ and $SovCDS$ and between $BankDtD$ and $SovDtD$ and a high but

[18]In our case, $T = 19$ for $SovCDS$, $T = 23$ for $SovDtD$ and $T = 35$ for $SovSPR$. Thus the two standard errors would be 0.46, 0.43 and 0.34 respectively.

[19]Once again, we use the adjective 'strong' for estimated values included in the interval (2c,1], the adjective 'weak' for estimated values included in the interval (c,2c] and, when the estimated values are included in the interval (0,c], we say that the series is 'not correlated'. The cut-off point c is chosen because it roughly corresponds to the null hypothesis that the correlation coefficient is zero at 5% level of significance. In our case, $T = 22$ for Greece, $T = 19$ for Ireland and $T = 23$ for Italy, Portugal, and Spain. Thus the two standard errors would be 0.43, 0.46 and 0.42, respectively.

weak negative correlation between $BankEQU$ and $SovSPR$. For Ireland, we also observe a strong positive correlation between $BankCDS$ and both $SovCDS$ and $SovSPR$, and a weak positive correlation between $BankDtD$ and $SovDtD$ and between $BankCDS$ and $SovSPR$, while no significant correlation is found between $BankEQU$ and either $SovDtD$ or $SovSPR$. In the case of Italy, we also detect strong positive correlations between $BankCDS$ and both $SovCDS$ and $SovSPR$, as well as a high but weak positive correlation between $BankDtD$ and $SovDtD$ and between $SovDtD$ and $SovSPR$, and a strong negative correlation between $BankEQU$ and $SovSPR$. Regarding Portugal, we find a strong positive correlation between $BankCDS$ and both $SovCDS$ and $SovSPR$ and between both $SovCDS$ and $SovSPR$. Finally, for Spain, we also observe a strong positive correlation between $BankCDS$ and both $SovCDS$ and $SovSPR$ and a strong negative correlation between $BankEQU$ and $SovSPR$, while no significant correlation is found between $BankDtD$ and either $SovCDS$ or $SovDtD$ or $SovSPR$.

4. Econometric methodology and empirical results

We use several econometric techniques to assess the interconnection between the banking sector and sovereign risk indicators without modelling the details of the entire network structure. We show that just by including the banks and sovereign risk indicators, one can disentangle the inherent contagiousness and vulnerability of the interdependent structure. We use three different sets of indicators for comparison. $BankDtD$ and $SovDtD$ are our primary indicators. The detailed presentation of our results is based on these primary indicators which take into account both the market and balance sheet based information. For comparison, we use secondary market indicators - $SovSPR$ and $BankEQU$, together with derivative markets measures - $SovCDS$ and $BankCDS$ - for each individual country. An increase in interdependence across all markets will be considered as a robust estimate of our interconnection measures.

4.1. Principal components analysis (PCA)

To measure the commonality among the sovereign and banking sector risk indices, we use Principal Component Analysis (PCA), a technique in which the risk of all institutions (individual sovereigns and their banking sector) is decomposed into orthogonal factors of decreasing explanatory power. PCA is used to reduce the dimensionality of a data set, increasing interpretability while minimising information losses. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables (see Muirhead (1982) for detailed exposition).

Since PCA seeks to maximize the variance and so is sensitive to scale differences in the variables, we first normalize the data and work with correlations rather than covariance between the original variables. The explanatory power of the first three PCs are shown in Figure 6. The graph suggests that, on average, the first three PCs explain more than 90% of the total variation of DtD risk indices at all time periods, but the importance of individual component varies drastically across time.

[Figure 6 about here.]

The first principal component is very dynamic and captures between 43% to 93% of the variation in risk and it might reasonably be interpreted as global volatility and general macroeconomic uncertainty. Starting from a low level of roughly 45%, it starts to increase rapidly in 2008. We detect a very rapid increase in the first half of 2008, followed by a gradual upward movement till the second quarter of 2009. We observe the highest interconnection between indices in 2009-Q2, when the first PC accounts for roughly 93% of the total variation. This period coincides with the adverse market development across the global financial markets encompassing both the Lehman Brothers and the AIG defaults, followed by the bailout of the six main Irish banks. Very soon afterwards, Greece declared the true nature of its fiscal deficits. From beginning 2009-Q3, the explanatory power of the first PC started to come down, falling as low as 49% by the end of 2011. In the last ten quarters, it has stabilized around 57% with minor variations. However, note that this level is roughly 12% points higher than its pre-crisis level.

We see a similar trend in the second and third PCs that could be associated, respectively, to country-specific factors and to the risk of a break-up of the Eurozone (see Battistini et al. (2014)). Most of the gains in the explanatory power of the first PC came from an equal reduction in the explanatory power of second and third PCs. The cumulative explanatory power also increased for the first three component in times of the global financial crisis and together they were able to explain roughly 97% of the variation at the peak of the crisis. Table 10 tabulates the percentage variation explained by the first three PCs for the full sample, pre-crisis period and crisis period. The choice of pre-crisis and crisis period is exogenous based on previous studies. As can be seen, the first and second components show better explanatory power in the pre-crisis period and explain 90% of the total variation compared with the crisis period (72%). The results are in-line with the findings of Beirne and Fratzscher (2013), who showed that idiosyncratic differences in the economic fundamentals explain a substantially higher share of the movements and cross-country differences in sovereign risk post-2008 crisis than in the pre-crisis period.

[Table 10 about here.]

Table 11 documents the proportion of the variance in each original risk index accounted for by the first three factors (calculated as the sum of the squared factor loadings). Comparing the pre-crisis and crisis period, we note that the first PC explained around 10 percent of the variance of each index in the pre-crisis period with very low variation within and across country indices (9% and 13%). However, estimates from the crisis period suggest huge variation (1% to 19%) during the crisis period. We find a very similar pattern of variation for the second PC as well. This provides additional evidence of decreasing interconnection in the crisis period.

[Table 11 about here.]

4.1.1. Comparison with CDS and Yield-Returns

Comparing this with *SovCDS* and *BankCDS*, we observe that CDS spreads are driven across the board with a large underlying factor. On average, the first PC drives more than 80% of the variation. However, since late 2012, the role of the first PC has decreased and the role of the second PC has grown. This provides suggestive evidence of the increasing role of country fundamentals in risk measures in the post-crisis landscape. The trend is also very similar to what we observe in the case of DtD, in which increasing higher weight are given to the second and third PC in total variation. Looking at the interconnection (Part II: Table 11),[20] the crisis period estimates suggest increasing variation across countries in the explanatory power of first three PCs. This divergence is especially pronounced for Ireland and Greece compared with the rest of the countries in our sample.

[Figure 7 about here.]

For PCA results based on *SovSPR* and *BankEQU*, we observe multiple peaks in the explanatory power of the first PC. The first peak is observed in the second half of 2009 (coinciding with the confirmation of irregularities in the Greek public finance statistics) while the second peak coincided with the increasing spreads for Spain and Italy in the second half of 2011 and early 2012. The explanatory power of the first PC rises from roughly 60% to 90% at the peaks. The gain in its explanatory power comes at the expense of the second PC, providing suggestive evidence that these indices are extremely prone to market sentiment. Results based on interconnection (Part III: Table 11), suggest that in the pre-crisis period, the explanatory power for the first three PCs is quite consistent across countries. However, in the post-crisis period, we observe high variations, especially for Irish sovereign yield and the Portuguese banking sector.

4.2. Interconnection based on dynamic Granger causality

A dynamic measure of interconnection based on linear Granger causality-tests is implemented to quantify the magnitude and directionality of linkages between banking and sovereign risk measures. As it is well know, the concept of Granger causality was introduced by Granger (1969) and Sims (1972) and 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.

Tests of Granger causality typically use the same lags for all variables, posing a potential problem since Granger-causality tests are sensitive to lag length. In this paper we use Hsiao (1981)'s sequential method to test for causality in order to determine the optimal lag structure for each variable, combining Akaike's final predictive error (FPE) and the definition of Granger causality.[21]

[20] Due to data limitations, we have PCA results for sovereign and banking sector CDS spreads for the crisis period only.

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

Based on this analysis, to understand the time-varying nature of bank-sovereign linkages for individual countries, we adopt an eclectic approach in order to directly investigate changes in the existence and the intensity of causality between banking and sovereign risk. To that end, we apply a dynamic approach to assess the evolving nature of the Granger causal linkages and to detect episodes of significant and transitory increases in the pairwise Granger causal relationships. Thus, we look for episodes with evidence of an enhancement in the information content of one series that significantly improves the explanatory power of the future evolution of the other series, suggesting a strengthening of their interdependence.

To summarize, in Figures 8, 9 and 10 we plot the evolution of dynamic Granger causality for each individual country based on different risk measures. These graphs provide us with a view of the time-varying bi-directional influence between sovereign and banking risks for each peripheral euro area country and constitute our indicator of causality intensification based on time-varying Granger-causality analysis. It illustrates the changes in the directions and magnitudes over time.

[Figure 8 about here.]

[Figure 9 about here.]

[Figure 10 about here.]

In Table 12 we summarize the causality intensification episodes for our full sample period. Note that if the difference is positive and statistically significant at the 1% level (i.e., above the critical line) 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. Note that in the cases of the banking sector equity index and sovereign yield spreads, we do not detect any causality intensification episodes, either from bank to sovereign or from sovereign to bank.

[Table 12 about here.]

Looking at dynamic Granger causality using DtD data for the case of Greece, we find no evidence of bank-sovereign linkages. We observe complete de-linkage in banking and sovereign stress from the very beginning of our sample period. These results are supported by the evidence of the sovereign yield spread and bank equity index data, where we observe a similar trend. The results of the CDS spreads suggest bank-sovereign linkages developing in late 2011 and early 2012, coinciding with the beginning of Greek debt restructuring episode.

In the case of Ireland, we see growing Granger causal linkage from banks to the sovereign in late 2007 and early 2008. However, in late 2008, we see a sudden reversal with a sharp drop in the interconnection between banks and the sovereign. Given the sudden nature of market events in Ireland, we find no supporting evidence of risk transfer from banks to the sovereign, even with yield spread and bank equity index data. For the late 2011 period, we detect a renewed development of the sovereign to bank nexus in CDS spread data. For Italy, in the pre-crisis period, we find no directional linkages; however, from mid-2009, we see the development of uni-directional linkages from sovereign to banks with multiple peaks in late 2009 and early 2011. The CDS spread based analysis shows no such linkages. Yield spread and banks equity index data suggest complete de-linkage between banks and sovereign risk.

As we have serious data limitations in case of Portugal, our analysis using DtD starts only from the beginning of the global financial crisis. We observe high uni-directional risk transfer from sovereign to banks in late 2008 and mid-2011. The analysis based on CDS spreads suggests the existence of bi-directional linkages in late 2010 and early 2011. The analysis based on yield spreads and bank equity index suggests no linkages for the entire period. For the case of Spain, we observe episodes of risk transfer from banks to the sovereign in late 2009 and early 2010 periods. However, from early 2011, we see evidence of risk transfer from the sovereign to banks. The period of 2010Q2-2012Q1 supports the existence of doom loop between the sovereign and banks. Analysis based on CDS spreads also supports the development of bi-directional sovereign-bank linkages in 2012Q3. However, the yield spread and bank equity index based analysis suggests no linkages between banks and sovereign risks.

Table 12 shows episodes of causality intensification and allows to compare results across different risk indices. We find that the analysis based on DtD indicates episodes of causality intensification in both directions only for Spain pointing to an adverse feedback loop between sovereigns and banks and corroborating, for this country, the findings by Singh et al. (2016), who also detected it using $SovSPR$ and $BankDtD$ data. Several reasons might explain the bi-directional relationship between the two sectors (banks and sovereigns) only for Spain. First, some authors [Hellwig (2017) among them] contend that while Greece, Portugal, and perhaps Italy, registered a traditional sovereign debt crisis, Ireland and Spain experienced a traditional real-estate and banking crisis. Second, other authors (see Fratzscher and Rieth (2018)) point out that in the case of Ireland, Greece and Portugal, all three sovereigns were bailed out and that might have broken the link between domestic banks and sovereigns as bank risks on the balance sheets of these sovereigns was forwarded to other sovereigns. Third, when comparing the two countries (Ireland and Spain) that experienced a traditional banking crisis, Cline (2014) claims that, while Ireland took on excess debt and risks while rescuing failed banks or stimulating the economy, in Spain private debt and a growth slowdown powerfully affected the government too. This could account for the low sovereign-bank correlation found for Ireland in Angelini et al. (2014) while that for Spain was much higher suggesting a somehow special sovereign-bank relationship in the latter case.[22] Finally, regarding the Spanish experience, Fratzscher and Rieth (2018) note that larger bailout packages for the banking sector seems to imply tighter links between banks and sovereigns whilst Berges and Echevarria (2018a) conclude that, while foreign investors' exacerbated volatility

[22]Furthermore, the so-called "bad banks" established in Ireland (National Asset Management Agency, NAMA) and Spain (Sareb) diverged significantly in terms of financial performance and success in divesting their impaired assets (Muehlbronner and Lemay (2015)). NAMA was created earlier and was also more advanced that Sareb in selling the assets on its balance sheet. This performance led the investors to consider that NAMA was no longer a material contingent liability for the Irish government, while Sareb's poor financial performance did not reduced the likelihood of further capital injections from the Spanish government.

by reducing their holdings of Spanish government debt, domestic banks reacted in the opposite manner, and therefore, had a stabilising impact on the country's public debt markets. Moreover, in the Spanish case, the domestic banks' investments in Spanish sovereign debt occurred at a time when there was a steep decrease in the demand for credit amongst Spanish companies and households (Berges and Echevarria (2018b)). These securities' earnings, which took the form of interest income and capital gains, propped up the banks' income statements during times of financial stress. Finally, in the case of Portugal and Italy, we only find evidence of unidirectional risk transfer from sovereign to banks.

Analyses based on CDS spreads suggest a risk transfer mainly from banks to sovereigns for Greece, Portugal, and Spain mainly in late 2010 and early 2011. Only in the case of Ireland do we find evidence of risk transfer from sovereigns to banks (2010Q3). The yield spreads and bank equity returns data support the absence of linkages between banks and sovereigns.

4.2.1. Exploring channels of risk transmission

Given that CCA claim methodology captures both market and accounting metrics affecting risk, in this subsection, we explore the channels of risk transmission between sovereigns and banks.[23] To that end, we first decompose the DtD indicators into two components by assessing the change in DtD conditional on volatility and on capital structure (market capital and distress barrier). The first component captures market participants risk appetite, whilst the second is used as a proxy of the risk related to the balance sheet composition (the leverage ratio). Therefore, we calculate how much DtD will vary if we change only the volatility and assume everything else constant. This is defined as the contribution of volatility (market participants risk appetite) to change in DtD. Likewise, a similar measure is calculated by taking volatility constant, while changing the market capital and the distress barrier, being considered as the relative contribution of change in leverage (risk related to the balance sheet composition). Subsequently, we analyse whether there exist causal linkages in each country from sovereign to bank risk and vice-versa by analysing the dynamic Granger-causality relationships through each of the two components of the DtD indicators.

[Table 13 about here.]

Table 13 offers the average estimated contribution of each component during the sample period under study. As can be seen, while for the sovereign DtD indicators balance sheet factors contribution is around 85% and risk appetite only represents 15%, for banks DtD indicators we find the opposite results. Risk appetite accounts for 86% of the total bank DtD risk while balance sheet factors only account for 14%. These results suggest that the sovereign indicator is much more fundamental-driven than the banking indicator, which seems to be more influenced by market sentiments.

Regarding the dynamic Granger-causality analysis applied to DtD decomposition, the results (not shown here to save space, but available from the authors upon request) further

[23] We are very grateful to an anonymous referee for suggesting the analysis in this subsection.

support the findings presented in the previous subsection. In particular, for Italy we detect the existence of a causal relationship from banks to sovereigns during 2010Q4, for Portugal we find evidence of causality running from banks to sovereigns during 2008Q4, and for Spain we find the presence of a causal relationship from banks to sovereigns during the sub-period 2009Q3-2010Q1 and from sovereign to banks during sub-periods 2007Q3 and 2008Q4 and 2011Q3-2013Q1, being all these episodes driven by the risk appetite component. Moreover, for Greece we undercover the existence of a new causal relationship from banks to sovereigns during 2007Q3 through the balance sheet connection.

4.3. Diebold-Yilmaz's connectedness index

In this subsection, we apply Diebold-Yilmaz's methodology for assessing connectedness (Diebold and Yilmaz (2009, 2012, 2014)) among various banking and sovereign risk indicators under study. These connectedness measures are based on forecast error variance decompositions from vector auto-regressions. The variance decomposition matrix gives us an intuitively appealing connectedness measure, that is, what percentage of the future uncertainty in variable i results from the shocks in variable j.

The full-sample connectedness are presented in Table 14. The ij^{th} entry of the upper-left 6×6 submatrix gives the estimated ij^{th} pair-wise directional connectedness contribution to the forecast error variance of risk indicator i from innovations to risk indicator j. Hence, the off-diagonal column sums (labelled "Contribution to others") and row sums (labelled "Contribution from others") give the total directional connectedness to all others from i and from all others to i respectively. The bottom row (labelled "Net contribution from others") gives the difference in total directional connectedness (to-from). Finally, the bottom-right element (in boldface) is total connectedness.

[Table 14 about here.]

As can be seen, the diagonal elements (own connectedness) are among the largest individual elements in Table 14, ranging from 18.83% ($SovCDS$) to 43.06% ($SovSPR$) in the case of Greece, from 14.86% ($BankCDS$) to 48.88% ($BankEQU$) in the case of Ireland, from 21.55% ($BankEQU$) to 40.89% ($BankDtD$) in the case of Italy, from 20.11% ($BankEQU$) to 44.95% ($SovDtD$) in the case of Portugal, and from 14.76% ($BankCDS$) to 29.81% ($SovSPR$) in the case of Spain. Interestingly, the own connectedness is smaller than most of the total directional connectedness FROM others, reflecting that these indicators are relatively dependent on each other; that is to say, shocks that affect a particular indicator spread on the other indicators.

The total connectedness of the risk indicators varies between 67.45% in the case of Ireland (indicating that 32.55% of the variation is due to idiosyncratic shocks) to 78.42% in Spain (suggesting that 21.58% of the variation is due to idiosyncratic shocks). This result is in line with the value of 78.30% obtained by Diebold and Yilmaz (2014) for the total connectedness between US financial institutions, but lower than the value of 97.2% found by Diebold and Yilmaz (2012) for international financial markets.

Figure 11 plots the country-wise net directional connectedness between various risk indices. The plots suggest that, in the case of Greece, $SovSPR$ and $BankCDS$ are net triggers of shocks while *SovDtD* and *BankEQU* are net diffusers of shocks. For Ireland, we find that *SovDtD* and *BankDtD* are net receivers of shocks and for Italy, *SovDtD*, *BankDtD*, and *BankEQU*. In the case of Portugal, the sovereign risk indicators (*SovCDS* and *SovSPR*) are found to be net transmitters of shocks while *SovDtD*, *BankCDS*, and *BankEQU* are net receivers. Finally, in the case of Spain, our results indicate that *SovDtD*, *BankDtD*, and *BankCDS* are net diffusers of shocks.

Comparing across countries, *SovDtD*s and *BankDtD* show the least connectedness with other sovereign and bank risk indicators respectively. This may be suggestive evidence of the different information content of these indicators based on sovereign and bank balance sheet information. All risk measures are well connected in each individual country in our study, suggesting the presence of a common underlying factor. *SovSPR* turns out to be the best connected among all sovereign and bank risk indices. *SovDtD* and *BankDtD* are net receivers in each country, suggesting that the increased risk is being driven away from market-based uncertainty to the idiosyncratic risk factors based on the sovereign and banking sectors balance sheet vulnerabilities.

[Figure 11 about here.]

5. Concluding remarks

This paper provides some additional evidence on the sovereign-bank risk nexus by assessing the interconnections and their time-varying nature for peripheral distressed euro area countries. To that end, in addition to the traditional banking and sovereign risk indicators based on the secondary market (sovereign yield spreads and banking sector equity return) and the derivatives market (banking sector average CDS spreads and sovereign CDS spreads), we compute a contingent claim model-based distance-to-default (DtD) measure for banks and sovereigns and apply three complementary econometric techniques to rigorously and exhaustively quantify the directional intensity of the interdependence between those banking and sovereign risk measures.

Our results suggest strong interconnection and co-movement between country-level banking and sovereign risk indicators, corroborating the previous finding in the literature (e.g., Acharya et al. (2014); Kallestrup et al. (2016)). We also find evidence of an increasing role of idiosyncratic risk factors driving the evolution of all risk indices in the post-crisis period, thus supporting the claims by Beirne and Fratzscher (2013) that the sensitivity of financial market participants to fundamental differences increased during the crisis. Country-wise analysis of time-varying bi-directional linkages using dynamic Granger-causality suggests the development of a bank-sovereign doom loop in Spain corroborating for this country the findings of Acharya et al. (2014), Fratzscher and Rieth (2018) and Singh et al. (2016). An analysis based on Diebold-Yilmaz's connectedness index shows the continuous presence of *SovDtD* and *BankDtD* as net receivers of shocks, suggesting that the increased risk is being driven away from market-based uncertainty to the idiosyncratic risk factors, which are better captured by the contingent claim based *DtD* indices. The results also provide a deeper understanding of the interaction of sovereign and bank risks through new *DtD* risk indicators, since based on this indicators probability of default can be computed as well as the expected losses given defaults (see Gray and Malone (2008)). Finally, our results suggest that market participants risk appetite was the main the channel of risk transmission between sovereigns and banks for the countries under study during the sample period.

Our findings have significant policy implications. Both non-zero risk weights of sovereign debt on bank balance sheets and limiting exposure to sovereigns would make banks more resilient (Lenarčič et al. (2016)), so the adoption of all the remaining Commission proposals on Banking Union (including on risk reduction, the European Deposit Insurance Scheme and a common backstop for the Single Resolution Fund) could help to reduce stress diffusion from bank to sovereigns. Furthermore, Commission proposal for an enabling framework for European Sovereign bond-backed securities (SBBS) for the euro area or European Safe Bonds (ESBies, a union-wide safe asset without joint liability (Brunnermeier et al. (2016)) could generate more safe assets that can reduce the risk transmission from sovereigns to banks.

In view of the robust evidence of the bank-sovereign nexus in peripheral euro-area countries, we plan to extend our research with an examination of the determinants of increasing/decreasing linkages based on different channels of interconnection, as discussed in Section 2. As membership of the monetary union can have a considerable influence on the banks' and sovereign risk in euro-area countries (see De Grauwe (2012); De Grauwe and Ji (2013), examining the role of fiscal support, central bank interventions and banking union in the sovereign-bank nexus is also in our short-term research agenda. Finally, in a future extension of the paper, we also plan to undertake a comparison between peripheral and central euro area countries to assess possible differentiated patterns in the sovereign-bank nexus.

Acknowledgement

We are very grateful to the seminar participants at the University of Barcelona for helpful comments and suggestions, to Fernando Fernández-Rodríguez for his assistance with the research, to the Comision Nacional del Mercado de Valores for kindly providing the sovereign debt volatility dataset and to Analistas Financieros Internacionales for kindly providing the CDS, yields and credit rating dataset. One of the authors thanks the Department of Economics at the University of Barcelona for their hospitality. The opinions expressed in this paper are those of the authors, and they do not reflect in any way those of the institutions to which they are affiliated. Responsibility for any remaining errors rests with the authors.

Funding

This work was supported by the Instituto de Estudios Fiscales [grant IEF 151/2017], the Bank of Spain [grant PR71/15-20229] and the Spanish Ministry of Economy and Competitiveness [grant ECO2016-76203-C2-2-P].

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Appendix A. Merton model equations for pricing contingent claims

Let us denote the observable value of the junior claims and its volatility by V_J and σ_J respectively and the fixed payment due at the end of the period T as S. If we assume this simple capital structure for the entity and ignore market imperfections (like dividend payouts, short selling restrictions, etc.), then at time t $(0 \leq t \leq T)$, the value of the entity's assets will be,

$$A(t) = S(t) + V_J(t) \tag{A.1}$$

If we assume that the entity's asset value follows geometric Brownian motion, then

$$dA(t) = \mu_A(t)\ A(t)\ dt + \sigma_A(t)\ A(t)\ dW$$

where A is value of the asset, σ_A its volatility, μ_A drift and dW is a Wiener process.

Because at the end of the period, senior creditors will receive their payment first while whatever remains will go to junior claim holders, junior claims can be seen as a call option on the entity's asset. Therefore, using the Black-Scholes option pricing theory analogically, the value of junior claims will be

$$V_J(t) = A(t)\ N(d_1) - S\ e^{-r(T-t)}\ N(d_2) \tag{A.2}$$

Using Ito's formula one can show

$$\sigma_J(t) = (\frac{A(t)}{V_J(t)})\ (\frac{\partial V_J(t)}{\partial A(t)})\ \sigma_A(t) \tag{A.3}$$

where $d_1 = \frac{log(\frac{A(t)}{S}) + (r - 0.5\sigma_A(t)^2)(T-t)}{\sigma_A(t)\sqrt{T-t}}$, $d_2 = d_1 - \sigma_A(t)\sqrt{T-t}$ and r is the risk-free interest rate at time t.

Thus, to find the unobservable value and volatility of the asset, we solve the non-linear system of equations A.4 and A.5. The system offers a single value for $A(t)$ and $\sigma_A(t)$.

$$f_1(V_J(t), \sigma_J(t)) = A(t)\ N(d_1) - S\ e^{-r(T-t)}\ N(d_2) - V_J(t) = 0 \tag{A.4}$$

$$f_2(V_J(t), \sigma_J(t)) = \frac{A(t)}{V_J(t)}\ N(d_1)\sigma_A(t) - \sigma_J(t) = 0 \tag{A.5}$$

Table 1: Description of bank and sovereign risk indicators

Variable	Description	Frequency	Source
BankDtD	Banks average *DtD* based on the *DtD* of a sample of banks headquartered in each country. The list of banks used in the calculation are shown in Table 3. For detailed methodology, please refer to Singh et al. (2015).	Quarterly	Author's calculation
SovDtD	Sovereign *DtD*. For detailed methodology, please refer to Singh et al. (2018).	Quarterly	Author's calculation
BankCDS	Banks average CDS based on 5Y bank CDS (on senior unsecured bonds) of all banks headquartered in a particular country for which CDS data is available in Datastream. For a complete list of bank, please refer to Table 4.	Quarterly	Datastream
SovCDS	5Y benchmark CDS spreads for individual countries.	Quarterly	Datastream
BankEQU	Banking sector equity index based on the average returns of all publicly traded banks in each individual country.	Quarterly	Datastream
SovSPR	Difference between the 10 year benchmark yield of a country over Germany.	Quarterly	Eurostat

Table 2: Description of variables used in the computation of *BankDtD*s

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 3: List of banks (by country)

Country	Bank name	ISIN
Greece	National Bank of Greece SA	GRS003003019
Greece	Piraeus Bank SA	GRS014003008
Greece	Eurobank Ergasias SA	GRS323003004
Greece	Alpha Bank AE	GRS015013006
Greece	Marfin Investment Group	GRS314003005
Greece	Attica Bank SA-Bank of Attica SA	GRS001003003
Greece	General Bank of Greece SA	GRS002003010
Ireland	Depfa Bank Plc	IE0072559994*
Ireland	Irish Bank Resolution Corp. Ltd.	IE00B06H8J93*
Ireland	Permanent TSB Plc	IE0004678656*
Ireland	Bank of Ireland	IE0030606259
Ireland	Allied Irish Banks plc	IE0000197834
Italy	*UniCredit SpA*	IT0004781412
Italy	Intesa Sanpaolo	IT0000072618
Italy	Banca Monte dei Paschi di Siena SpA	IT0001334587
Italy	Unione di Banche Italiane Scpa	IT0003487029
Italy	Banco Popolare Società Cooperativa	IT0004231566
Italy	Mediobanca SpA	IT0000062957
Italy	Banca popolare dell'Emilia Romagna	IT0000066123
Italy	Banca Popolare di Milano SCaRL	IT0000064482
Italy	Banca Carige SpA	IT0003211601
Italy	Banca Popolare di Sondrio Societa Cooperativa per Azioni	IT0000784196
Italy	Credito Emiliano SpA-CREDEM	IT0003121677
Italy	Credito Valtellinese Soc Coop	IT0000064516
Italy	Banca popolare dell'Etruria e del Lazio Soc. coop.	IT0004919327
Italy	Credito Bergamasco	IT0000064359
Italy	Banco di Sardegna SpA	IT0001005070
Italy	Banco di Desio e della Brianza SpA	IT0001041000
Italy	Banca Ifis SpA	IT0003188064
Italy	Banca Generali SpA	IT0001031084
Italy	Banca Intermobiliare di Investimenti e Gestioni	IT0000074077
Italy	Banca Popolare di Spoleto SpA	IT0001007209
Italy	Banca Profilo SpA	IT0001073045
Italy	Banca Finnat Euramerica SpA	IT0000088853
Portugal	Montepio Holding SGPS SA	PTFNB0AM0005*
Portugal	Banco Comercial Português, SA	PTBCP0AM0007
Portugal	Banco Espirito Santo SA	PTBES0AM0007
Portugal	Banco BPI SA	PTBPI0AM0004
Portugal	BANIF, SA	PTBAF0AM0002
Spain	*Banco Bilbao Vizcaya Argentaria SA*	ES0113211835
Spain	*Banco Santander SA*	ES0113900J37
Spain	Caixabank, SA	ES0140609019
Spain	Bankia, SA 7	ES0113307021
Spain	Banco de Sabadell SA	ES0113860A34
Spain	Banco Popular Espanol SA	ES0113790226
Spain	Caja de Ahorros del Mediterraneo	ES0114400007
Spain	Bankinter SA	ES0113679I37
Spain	Renta 4 Banco, S.A.	ES0173358039

Notes: ISIN stands for the International Securities Identification Number. An asterisk (*) indicates companies delisted during the study period. SIFI are indicated in italics (based on Bank of International Settlements G-SIBs as of November 2014).

Table 4: List of banks with CDS spreads available in Datastream (by country)

Country	Bank name	ISIN
Greece	National Bank of Greece SA	GRS003003019
Greece	Eurobank Ergasias SA	GRS323003004
Greece	Alpha Bank AE	GRS015013006
Ireland	Depfa Bank Plc	IE0072559994*
Ireland	Irish Bank Resolution Corp. Ltd.	IE00B06H8J93*
Ireland	Permanent TSB Plc	IE0004678656*
Ireland	Bank of Ireland	IE0030606259
Ireland	Allied Irish Banks plc	IE0000197834
Italy	*UniCredit SpA*	IT0004781412
Italy	Intesa Sanpaolo	IT0000072618
Italy	Banca Monte dei Paschi di Siena SpA	IT0001334587
Italy	Unione di Banche Italiane Scpa	IT0003487029
Italy	Banco Popolare Società Cooperativa	IT0004231566
Italy	Mediobanca SpA	IT0000062957
Italy	Banca Popolare di Milano SCaRL	IT0000064482
Portugal	Banco Comercial Português, SA	PTBCP0AM0007
Portugal	Banco Espirito Santo SA	PTBES0AM0007
Portugal	Banco BPI SA	PTBPI0AM0004
Spain	*Banco Bilbao Vizcaya Argentaria SA*	ES0113211835
Spain	*Banco Santander SA*	ES0113900J37
Spain	Caixabank, SA	ES0140609019
Spain	Banco de Sabadell SA	ES0113860A34
Spain	Banco Popular Espanol SA	ES0113790226
Spain	Caja de Ahorros del Mediterraneo	ES0114400007
Spain	Bankinter SA	ES0113679I37

Notes: ISIN stands for the International Securities Identification Number. An asterisk (*) indicates companies delisted during the study period. SIFI is indicated in italics (based on Bank of International Settlements G-SIBs as of November 2014).

Table 5: Summary statistics of banking sector risk measures

Country	Mean	Standard Deviation	Minimum	Median	Maximum	Skewness	Kurtosis	SE	N
Average banking sector DtD measure ($BankDtD$)									
Spain	4.58	1.80	2.00	4.42	8.50	0.41	-0.90	0.30	35
Greece	2.35	1.22	0.81	1.87	5.28	0.61	-0.89	0.21	35
Ireland	2.69	2.08	0.49	1.75	7.51	0.87	-0.70	0.35	35
Italy	4.20	1.52	1.96	3.89	7.72	0.26	-1.01	0.26	35
Portugal	3.96	2.06	1.45	3.21	9.58	0.90	-0.07	0.35	35
Average banking sector credit default swap spreads ($BankCDS$)									
Spain	300.94	157.74	41.99	288.76	549.46	0.11	-1.30	32.89	23
Greece	964.18	757.44	152.05	841.43	2400.79	0.60	-1.05	161.49	22
Ireland	515.82	584.15	6.80	340.70	2025.05	1.05	-0.01	98.74	35
Italy	148.74	155.76	12.87	85.43	493.92	1.03	-0.36	26.33	35
Portugal	306.98	383.41	14.48	99.28	1365.38	1.20	0.23	64.81	35
Average banking sector equity index level ($BankEQU$)									
Spain	257.71	78.91	100.00	243.67	404.41	0.01	-0.64	13.34	35
Greece	188.69	137.56	15.52	154.56	512.95	0.68	-0.51	23.25	35
Ireland	101.39	63.93	6.72	123.86	188.40	-0.31	-1.53	10.81	35
Italy	128.82	42.73	67.26	120.04	219.96	0.48	-0.82	7.22	35
Portugal	145.61	61.90	49.91	125.87	271.27	0.59	-0.61	10.46	35

Notes: The $BankDtD$ is a measure the number of standard deviations the banking sector assets are away from its default barrier. Hence, by construction, this is unitless. $BankCDS$ are measured in basis points. $BankEQU$ are unitless and are in levels.

Table 6: Correlations between banking sector risk measures

	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT
	Average banking sector ***DtD*** **(*BankDtD*)**					**Banks average CDS spreads** **(*BankCDS*)**					**Banking sector equity index** **(*BankEQU*)**				
ES	1	0.72	0.86	0.75	0.73	1	0.92	0.82	0.94	0.90	1	0.65	-0.34	0.37	0.44
GR	0.72	1	0.84	0.81	0.88	0.92	1	0.73	0.95	0.94	0.65	1	0.05	0.87	0.62
IR	0.86	0.84	1	0.78	0.77	0.82	0.73	1	0.80	0.91	-0.34	0.05	1	0.26	0.38
IT	0.75	0.81	0.78	1	0.84	0.94	0.95	0.80	1	0.91	0.37	0.87	0.26	1	0.67
PT	0.73	0.88	0.77	0.84	1	0.90	0.94	0.91	0.91	1	0.44	0.62	0.38	0.67	1

Note: ES, GR, IR, IT and PT stand for Spain, Greece, Ireland, Italy and Portugal, respectively.

Table 7: Summary statistics of sovereign risk measures

Country	Mean	Standard Deviation	Minimum	Median	Maximum	Skewness	Kurtosis	SE	N
Sovereign Distance-to-default (*SovDtD*)									
Spain	17.72	7.36	5.23	17.52	32.38	0.03	-1.28	1.24	35
Greece	14.39	10.12	1.43	14.25	31.85	0.11	-1.59	1.71	35
Ireland	17.38	8.47	3.76	16.71	35.22	0.18	-1.04	1.43	35
Italy	18.88	7.54	5.73	20.25	31.39	-0.30	-1.13	1.27	35
Portugal	10.94	6.67	2.66	9.15	23.93	0.49	-1.21	1.39	23
Sovereign credit default swap spreads (*SovCDS*)									
Spain	171.86	112.55	18.79	175.41	402.16	0.37	-1.02	23.47	23
Greece	4411.58	6219.48	20.32	794.91	14904.36	0.93	-1.05	1296.85	23
Ireland	345.35	226.63	125.28	271.33	841.86	0.64	-1.03	51.99	19
Italy	168.87	118.58	19.58	141.86	415.01	0.69	-0.77	24.73	23
Portugal	386.25	375.76	28.99	286.05	1170.3	0.89	-0.66	80.11	22
Sovereign yield spreads (*SovSPR*)									
Spain	1.37	1.57	0.01	0.67	5.29	0.87	-0.64	0.27	35
Greece	5.60	7.16	0.19	1.86	26.52	1.21	0.40	1.21	35
Ireland	2.19	2.49	-0.04	1.52	8.54	0.91	-0.41	0.42	35
Italy	1.43	1.40	0.14	0.85	4.88	1.03	-0.23	0.24	35
Portugal	2.76	3.52	0.00	0.77	11.18	1.15	-0.04	0.59	35

Table 8: Correlations between different sovereign risk measures

	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT
	Sovereign *DtD* ($SovDtD$)					**Sovereign CDS spreads** ($SovCDS$)					**Sovereign yield spreads** ($SovSPR$)				
ES	1	0.92	0.87	0.93	0.87	1	0.73	0.65	0.95	0.89	1	0.96	0.80	0.96	0.91
GR	0.92	1	0.87	0.81	0.91	0.73	1	0.03	0.73	0.55	0.96	1	0.85	0.94	0.96
IR	0.87	0.87	1	0.75	0.70	0.65	0.03	1	0.58	0.82	0.80	0.85	1	0.79	0.88
IT	0.93	0.81	0.75	1	0.71	0.95	0.73	0.58	1	0.89	0.96	0.94	0.79	1	0.93
PT	0.87	0.91	0.70	0.71	1	0.89	0.55	0.82	0.89	1	0.91	0.96	0.88	0.93	1

Note: ES, GR, IR, IT and PT stand for Spain, Greece, Ireland, Italy and Portugal, respectively.

Table 9: Country-wise cross-correlations between sovereign and banking risk indicators

Greece	*BankDtD*	*BankCDS*	*BankEQU*	*SovCDS*	*SovDtD*	*SovSPR*
BankDtD	1	-0.83	0.84	-0.69	0.81	-0.77
BankCDS	-0.83	1	-0.80	0.72	-0.81	0.95
BankEQU	0.84	-0.80	1	-0.69	0.92	-0.78
SovCDS	-0.69	0.72	-0.69	1	-0.63	0.69
SovDtD	0.81	-0.81	0.92	-0.63	1	-0.80
SovSPR	-0.77	0.95	-0.78	0.69	-0.80	1

Ireland	*BankDtD*	*BankCDS*	*BankEQU*	*SovCDS*	*SovDtD*	*SovSPR*
BankDtD	1	0.03	0.67	-0.19	0.50	-0.05
BankCDS	0.03	1	0.30	0.91	-0.59	0.90
BankEQU	0.67	0.30	1	0.18	0.21	0.15
SovCDS	-0.19	0.91	0.18	1	-0.72	0.92
SovDtD	0.50	-0.59	0.21	-0.72	1	-0.67
SovSPR	-0.05	0.90	0.15	0.92	-0.67	1

Italy	*BankDtD*	*BankCDS*	*BankEQU*	*SovCDS*	*SovDtD*	*SovSPR*
BankDtD	1	-0.43	0.42	-0.47	0.61	-0.44
BankCDS	-0.43	1	-0.83	0.96	-0.84	0.98
BankEQU	0.42	-0.83	1	-0.83	0.72	-0.84
SovCDS	-0.47	0.96	-0.83	1	-0.83	0.97
SovDtD	0.61	-0.84	0.72	-0.83	1	-0.82
SovSPR	-0.44	0.98	-0.84	0.97	-0.82	1

Portugal	*BankDtD*	*BankCDS*	*BankEQU*	*SovCDS*	*SovDtD*	*SovSPR*
BankDtD	1	-0.49	0.24	-0.54	0.47	-0.55
BankCDS	-0.49	1	-0.58	0.97	-0.80	0.97
BankEQU	0.24	-0.58	1	-0.62	0.46	-0.54
SovCDS	-0.54	0.97	-0.62	1	-0.78	0.98
SovDtD	0.47	-0.80	0.46	-0.78	1	-0.82
SovSPR	-0.55	0.97	-0.54	0.98	-0.82	1

Spain	*BankDtD*	*BankCDS*	*BankEQU*	*SovCDS*	*SovDtD*	*SovSPR*
BankDtD	1	0.01	0.06	0.04	0.20	0.09
BankCDS	0.01	1	-0.90	0.96	-0.88	0.94
BankEQU	0.06	-0.90	1	-0.88	0.82	-0.88
SovCDS	0.04	0.96	-0.88	1	-0.84	0.96
SovDtD	0.20	-0.88	0.82	-0.84	1	-0.82
SovSPR	0.09	0.94	-0.88	0.96	-0.82	1

Table 10: Principal component analysis results based on *SovDtD* and *BankDtD* indices

Principal Component	Percentage Explained	Total	Percentage Explained	Total	Percentage Explained	Total
	Full sample		**Pre-crisis period (2004Q4-2008Q3)**		**Crisis period (2008Q4-2013Q2)**	
First	0.7932	0.7932	0.7226	0.7226	0.5101	0.5101
Second	0.0833	0.8766	0.1744	0.8970	0.2128	0.7229
Third	0.0472	0.9238	0.0491	0.9462	0.1302	0.8531

Table 11: Interconnection based on principal component analysis

Part I: Based on ***SovDtD*** **and** ***BankDtD***									
	Full-sample			**Pre-crisis (2004Q4-2008Q3)**			**Crisis period (2008Q4-2013Q2)**		
	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3
BankDtD - Spain	0.09	0.40	0.42	0.11	0.22	0.35	0.01	0.27	0.27
SovDtD - Spain	0.12	0.23	0.23	0.13	0.19	0.19	0.18	0.19	0.24
BankDtD - Greece	0.12	0.12	0.14	0.09	0.24	0.27	0.19	0.22	0.23
SovDtD - Greece	0.12	0.20	0.27	0.12	0.26	0.27	0.13	0.14	0.33
BankDtD - Ireland	0.11	0.28	0.36	0.11	0.18	0.47	0.02	0.39	0.44
SovDtD - Ireland	0.11	0.13	0.44	0.12	0.25	0.26	0.02	0.31	0.52
BankDtD - Italy	0.11	0.14	0.46	0.13	0.18	0.18	0.09	0.11	0.53
SovDtD - Italy	0.10	0.35	0.42	0.10	0.30	0.30	0.19	0.19	0.19
BankDtD - Portugal	0.11	0.13	0.26	0.09	0.18	0.71	0.17	0.17	0.24
Part II: Based on ***SovCDS*** **and** ***BankCDS***									
	Full-sample			**Pre-crisis (2004Q4-2008Q3)**			**Crisis period (2008Q4-2013Q2)**		
	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3
BankCDS - Spain	-	-	-	-	-	-	0.12	0.12	0.26
SovCDS - Spain	-	-	-	-	-	-	0.12	0.13	0.14
BankCDS - Greece	-	-	-	-	-	-	0.12	0.13	0.17
SovCDS - Greece	-	-	-	-	-	-	0.05	0.40	0.54
BankCDS - Ireland	-	-	-	-	-	-	0.07	0.27	0.65
SovCDS - Ireland	-	-	-	-	-	-	0.07	0.36	0.36
BankCDS -Italy	-	-	-	-	-	-	0.11	0.18	0.18
SovCDS -Italy	-	-	-	-	-	-	0.11	0.14	0.28
BankCDS - Portugal	-	-	-	-	-	-	0.12	0.15	0.16
SovCDS - Portugal	-	-	-	-	-	-	0.11	0.13	0.25
Part III: Based on ***SovSPR*** **and** ***BankEQU***									
	Full-sample			**Pre-crisis (2004Q4-2008Q3)**			**Crisis period (2008Q4-2013Q2)**		
	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3
BankEQU - Spain	0.01	0.58	0.58	0.12	0.18	0.26	0.12	0.15	0.25
SovSPR - Spain	0.14	0.15	0.20	0.14	0.17	0.17	0.13	0.13	0.14
BankEQU - Greece	0.11	0.23	0.24	0.10	0.20	0.33	0.12	0.14	0.19
SovSPR - Greece	0.14	0.16	0.19	0.13	0.17	0.33	0.12	0.16	0.16
BankEQU - Ireland	0.00	0.13	0.68	0.03	0.26	0.52	0.09	0.23	0.23
SovSPR - Ireland	0.12	0.20	0.21	0.15	0.16	0.19	0.05	0.32	0.62
BankEQU - Italy	0.12	0.14	0.19	0.02	0.28	0.37	0.11	0.18	0.25
SovSPR - Italy	0.14	0.15	0.20	0.14	0.16	0.30	0.13	0.13	0.14
BankEQU - Portugal	0.07	0.11	0.33	0.03	0.27	0.31	0.02	0.40	0.83
SovSPR - Portugal	0.14	0.16	0.19	0.15	0.15	0.21	0.12	0.17	0.20

Notes: The table documents the proportion of the variance of each individual credit risk index accounted for by the first one, two and three principal component (cumulative) for the full sample, pre-crisis and crisis period respectively. *BankDtD* and *SovDtD* represent the average banking sector and sovereign credit risk based on contingent claims analysis as documented in Section 3. The sovereign credit risk of Portugal is only available starting 2007Q3 and so is not included in the calculation. For the sake of comparison, the crisis periods also exclude the Portuguese sovereign credit risk in PCA calculation. *BankCDS* and *SovCDS* represent the average banking sector CDS and sovereign CDS as observed in the market. The CDS data for the full sample starts at 2008Q4. Therefore for CDS, we report PCA analysis only for the crisis period. *BankEQU* and *SovSPR* represents the average returns based banking sector index and sovereign yield spreads as documented in Section 3.

Table 12: Episodes of causality intensification

	Based on *BankDtD* **and** *SovDtD*	
Period	Banks to Sovereign	Sovereign to Banks
2008Q3		Portugal
2009Q4	Spain	
2010Q3		Italy
2011Q2		Spain
	Based on *BankCDS* **and** *SovCDS*	
Period	Banks to Sovereign	Sovereign to Banks
2010Q3		Ireland
2010Q4	Portugal	
2011Q1	Portugal	
2011Q3	Greece	
2011Q4	Greece	
2012Q4	Spain	

Notes: This table shows the episodes of Granger-causality intensification (contagion) and the corresponding time period for the peripheral euro area countries. We do not detect any episodes of short-term causality intensification for analysis with sovereign yield spreads (*SovSPR*) and banking sector equity indices (*BankEQU*).

Table 13: Channels of risk transmission

Average contribution to sovereign *DtD***s (%)**					
	Greece	Ireland	Italy	Portugal	Spain
Risk appetite	25.01	11.37	13.91	9.94	13.71
Balance sheet	74.99	88.63	86.09	90.06	86.29
Average contribution to banks *DtD***s (%)**					
	Greece	Ireland	Italy	Portugal	Spain
Risk appetite	87.8	85.07	88.95	77.4	88.9
Balance sheet	12.2	14.93	11.05	22.6	11.1

Table 14: Total connectedness between banking and sovereign risk indicators

Spain	*SovDtD*	*SovCDS*	*SovSPR*	*BankDtD*	*BankCDS*	*BankEQU*	**Contribution from others**
SovDtD	14.88	21.66	23.52	11.49	11.53	16.93	85.12
SovCDS	11.86	27.52	28.52	4.42	12.69	14.99	72.48
SovSPR	11.92	27.35	29.81	4.64	12.41	13.88	70.19
BankDtD	10.08	16.14	23.08	21.20	15.67	13.82	78.80
BankCDS	10.54	24.49	27.58	8.48	14.76	14.15	85.24
BankEQU	15.53	22.85	20.91	8.41	10.98	21.33	78.67
Contribution to others	80.11	80.35	80.57	63.84	81.09	77.58	
Net contribution	-5.01	7.86	10.38	-14.96	-4.16	-1.10	**Total = 78.42**
Greece	*SovDtD*	*SovCDS*	*SovSPR*	*BankDtD*	*BankCDS*	*BankEQU*	**Contribution from others**
SovDtD	24.65	8.73	20.63	8.01	12.18	25.79	75.35
SovCDS	0.98	18.83	22.54	25.09	31.70	0.86	81.17
SovSPR	3.64	13.00	43.06	11.33	21.05	7.92	56.94
BankDtD	5.41	19.25	19.81	26.72	26.81	2.01	73.28
BankCDS	4.07	6.95	52.30	11.69	19.97	5.01	80.03
BankEQU	19.04	4.85	33.02	4.61	8.83	29.65	70.35
Contribution to others	57.34	73.70	77.50	69.45	83.43	58.38	
Net contribution	-18.01	-7.46	20.56	-3.83	3.40	-11.97	**Total = 72.85**
Ireland	*SovDtD*	*SovCDS*	*SovSPR*	*BankDtD*	*BankCDS*	*BankEQU*	**Contribution from others**
SovDtD	34.41	26.39	22.58	6.00	2.34	8.29	65.59
SovCDS	12.35	29.92	28.53	14.25	3.77	11.18	70.08
SovSPR	13.48	16.34	31.79	3.18	17.01	18.20	68.21
BankDtD	4.01	23.13	15.79	35.44	7.33	14.28	64.56
BankCDS	8.55	20.25	29.97	8.45	14.86	17.93	85.14
BankEQU	0.27	3.63	24.23	1.86	21.13	48.88	51.12
Contribution to others	52.92	75.00	79.21	48.76	77.64	58.84	
Net contribution	-12.68	4.91	11.00	-15.79	-7.50	7.72	**Total = 67.45**
Italy	*SovDtD*	*SovCDS*	*SovSPR*	*BankDtD*	*BankCDS*	*BankEQU*	**Contribution from others**
SovDtD	22.67	16.37	16.08	9.96	16.88	18.04	77.33
SovCDS	7.94	24.17	24.63	3.22	24.94	15.09	75.83
SovSPR	9.26	23.69	24.90	2.40	24.68	15.06	75.10
BankDtD	20.32	6.91	5.09	40.89	7.04	19.75	59.11
BankCDS	8.61	23.95	24.83	2.52	25.00	15.08	75.00
BankEQU	14.48	18.60	17.31	9.30	18.76	21.55	78.45
Contribution to others	72.77	78.74	77.93	40.13	78.69	79.39	
Net contribution	-4.55	2.91	2.84	-18.99	3.69	0.94	**Total = 73.47**
Portugal	*SovDtD*	*SovCDS*	*SovSPR*	*BankDtD*	*BankCDS*	*BankEQU*	**Contribution from others**
SovDtD	44.95	14.36	11.51	7.33	6.49	15.37	55.05
SovCDS	11.43	22.06	27.31	17.72	15.28	6.21	77.94
SovSPR	14.30	21.36	26.52	16.61	14.76	6.45	73.48
BankDtD	5.39	23.37	23.13	32.27	7.45	8.39	67.73
BankCDS	20.81	16.46	20.06	9.96	25.44	7.27	74.56
BankEQU	12.86	21.68	18.88	14.69	11.78	20.11	79.89
Contribution to others	59.04	81.51	79.19	67.26	68.67	68.48	
Net contribution	3.98	3.57	5.71	-0.46	-5.89	-11.41	**Total = 71.44**

Figure 1: Direct linkages between sovereign and financial institutions

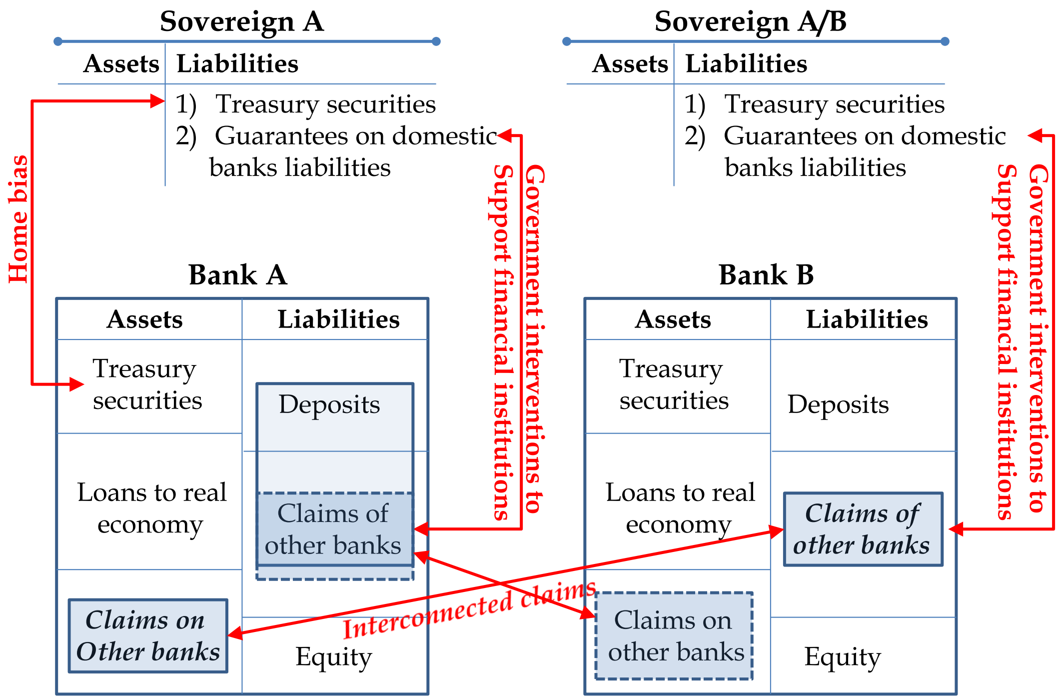
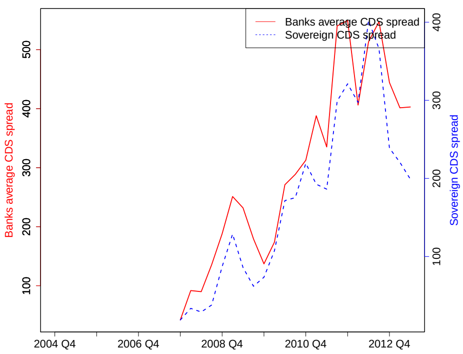
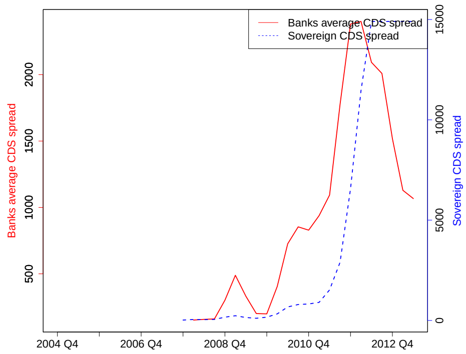


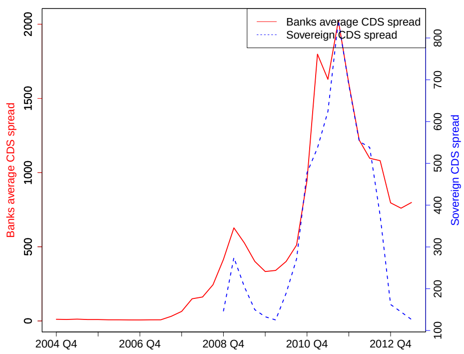
Figure 2: Banking sector average CDS spreads vs Sovereign CDS spreads



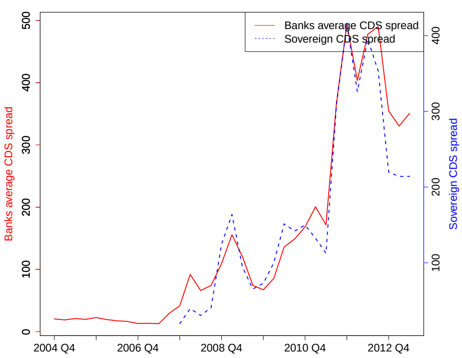
(a) Spain



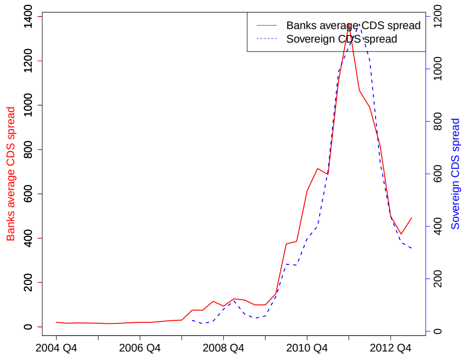
(b) Greece



(c) Ireland



(d) Italy



(e) Portugal

Figure 3: Sovereign balance sheet

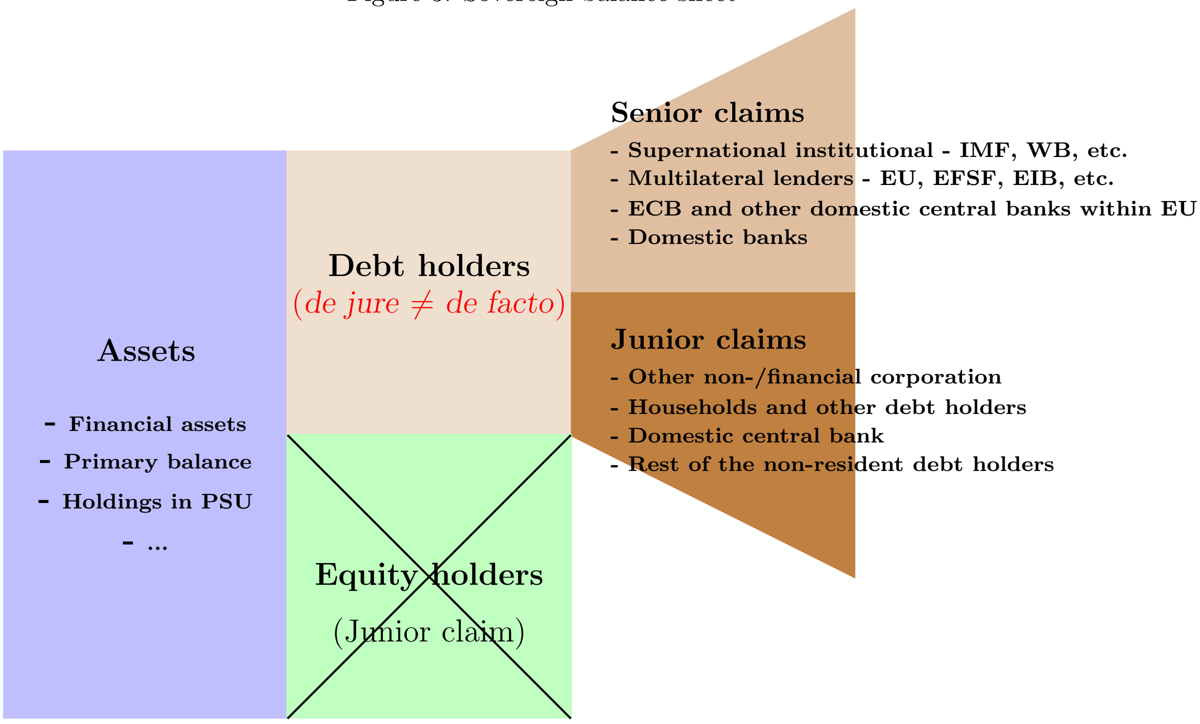
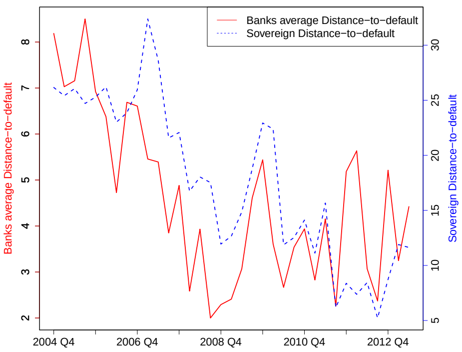
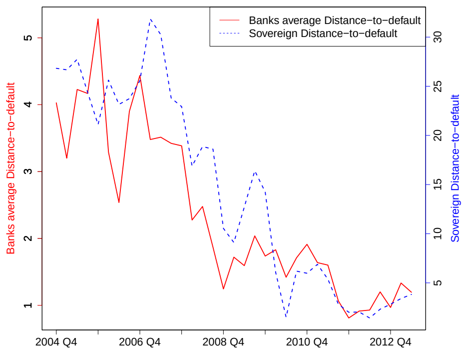


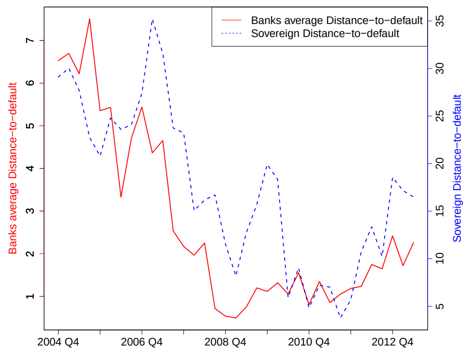
Figure 4: Banking sector average DtD ($BankDtD$) vs Sovereign DtD ($SovDtD$)



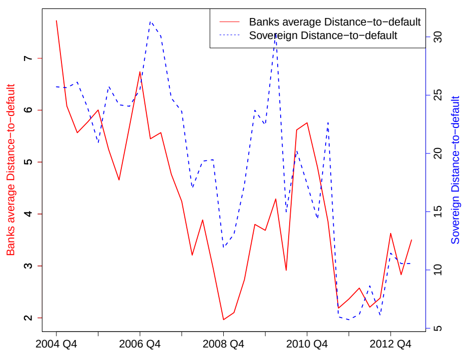
(a) Spain



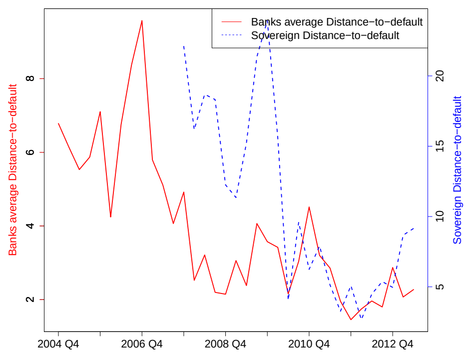
(b) Greece



(c) Ireland

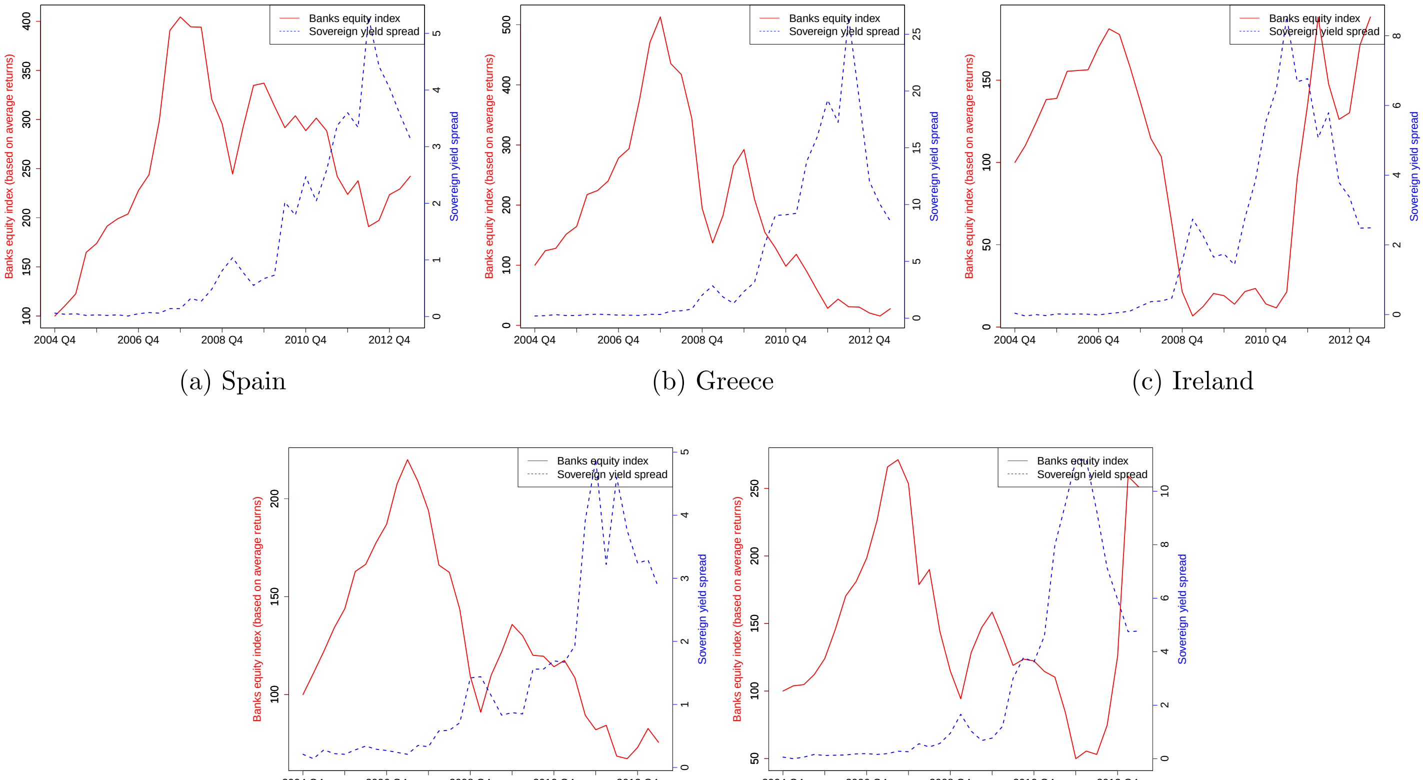


(d) Italy



(e) Portugal

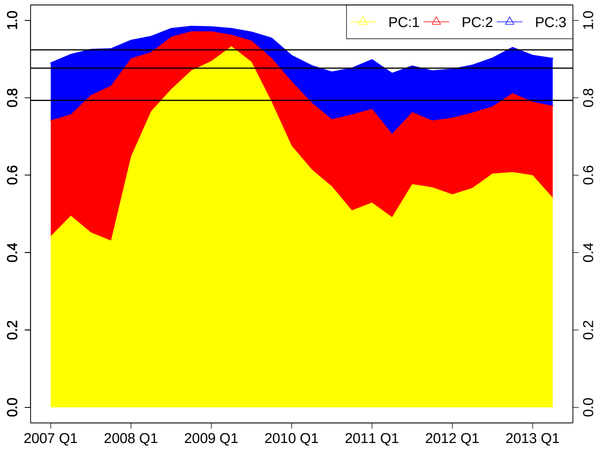
Figure 5: Banking sector equity index ($BankEQU$) vs Sovereign yield spreads ($SovSPR$)



(a) Spain (b) Greece (c) Ireland

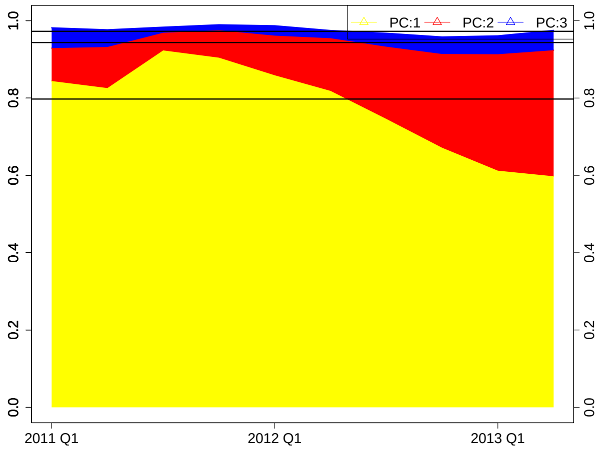
(d) Italy (e) Portugal

Figure 6: PCA based on the normalized indices of *SovDtD* and *BankDtD* for peripheral euro area countries (2007Q1-2013Q2)

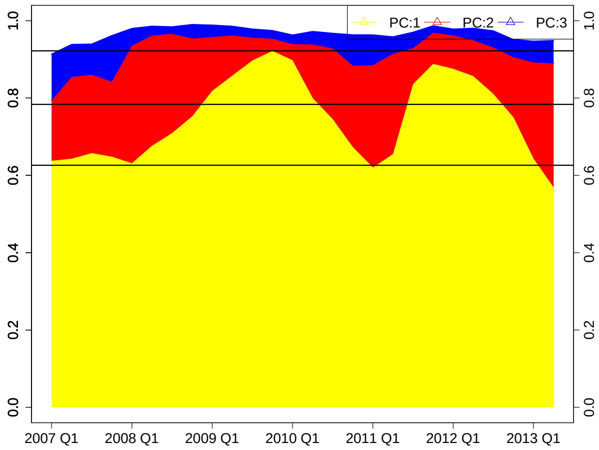


Notes: The figure plots the Cumulative Risk Fraction based on PCA of quarterly sovereign and banking sector credit risk indices based on ten quarter rolling window estimates. The yellow, red and blue areas correspond to the fraction of total variance explained by the first, the second and the third principal component respectively. The horizontal lines represent the same fraction using full-sample estimates.

Figure 7: PCA based on alternative sovereign and banking sector risk indices for peripheral euro area countries



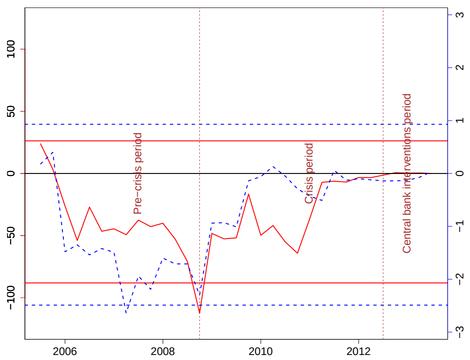
(a) Based on Sovereign and Banking sector CDS (2011Q1-2013Q2)



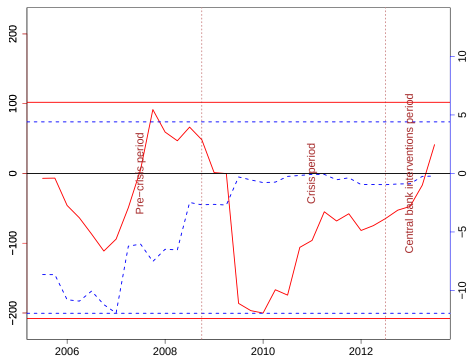
(b) Based on sovereign yield spreads and banking sector equity index (2007Q1-2013Q2)

Notes: Figure (a) plots the Cumulative Risk Fraction based on PCA of quarterly sovereign and average banking sector CDS indices based on ten quarter rolling window estimates. Figure (b) plots the Cumulative Risk Fraction based on PCA of quarterly sovereign yield spreads and banking sector equity index based on ten quarter rolling window estimates. The yellow, red and blue areas correspond to the fraction of total variance explained by the first, the second and the third principal component respectively. The horizontal lines represent the same fraction using full-sample estimates.

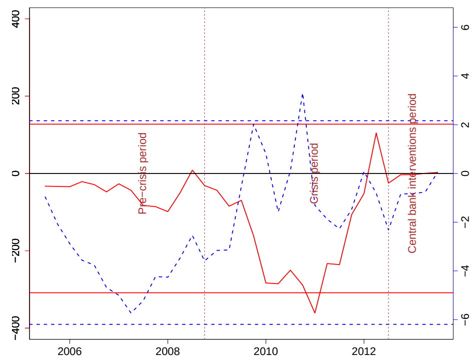
Figure 8: Bi-directional bank-sovereign linkages using dynamic Granger causality (based on sovereign and banking sector DtD indices)



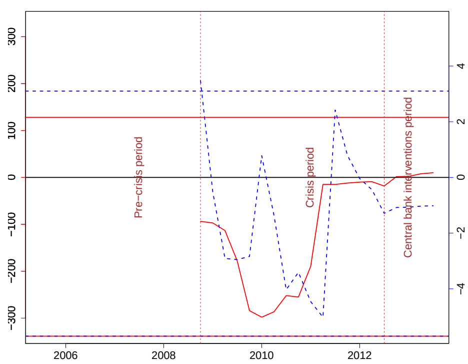
(a) Greece



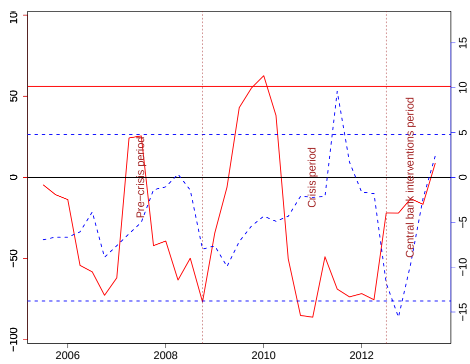
(b) Ireland



(c) Italy



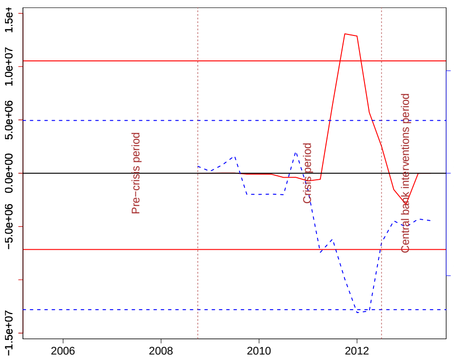
(d) Portugal



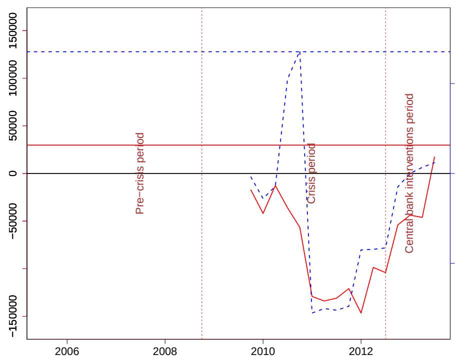
(e) Spain

Notes: The blue dotted line represents dynamic Granger causality from sovereign to banks and that the solid red line represents dynamic Granger causality from banks to sovereign.

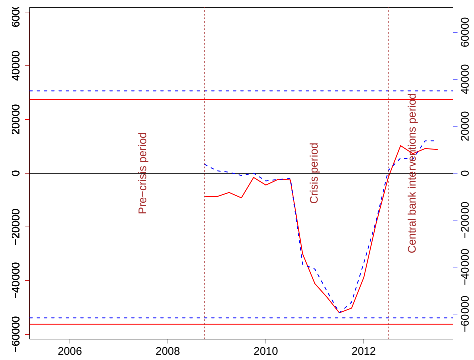
Figure 9: Bi-directional bank-sovereign linkages using dynamic Granger causality (based on sovereign and banking sector CDS indices)



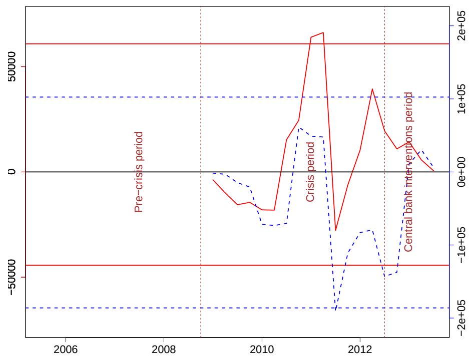
(a) Greece



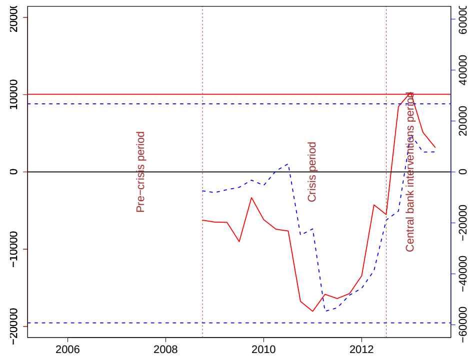
(b) Ireland



(c) Italy



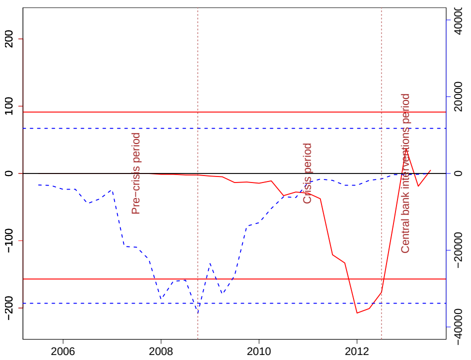
(d) Portugal



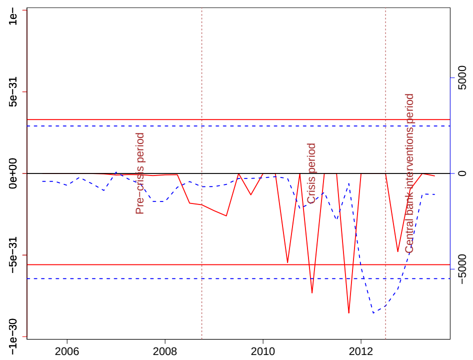
(e) Spain

Notes: The blue dotted line represents dynamic Granger causality from sovereign to banks and that the solid red line represents dynamic Granger causality from banks to sovereign.

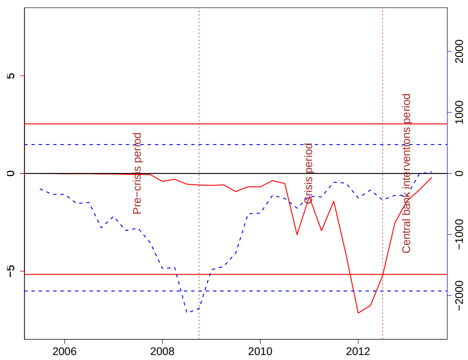
Figure 10: Bi-directional bank-sovereign linkages using dynamic Granger causality (based on sovereign yield spreads and banking sector equity index)



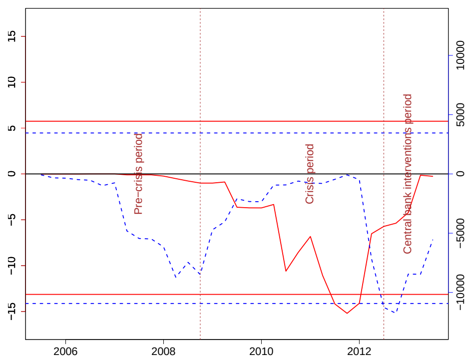
(a) Greece



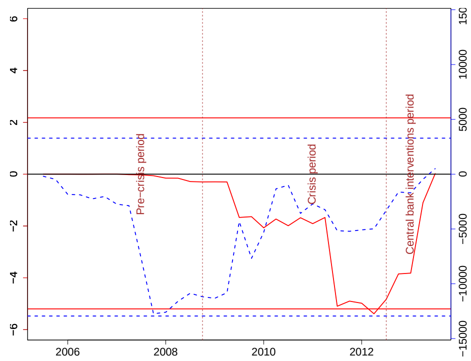
(b) Ireland



(c) Italy



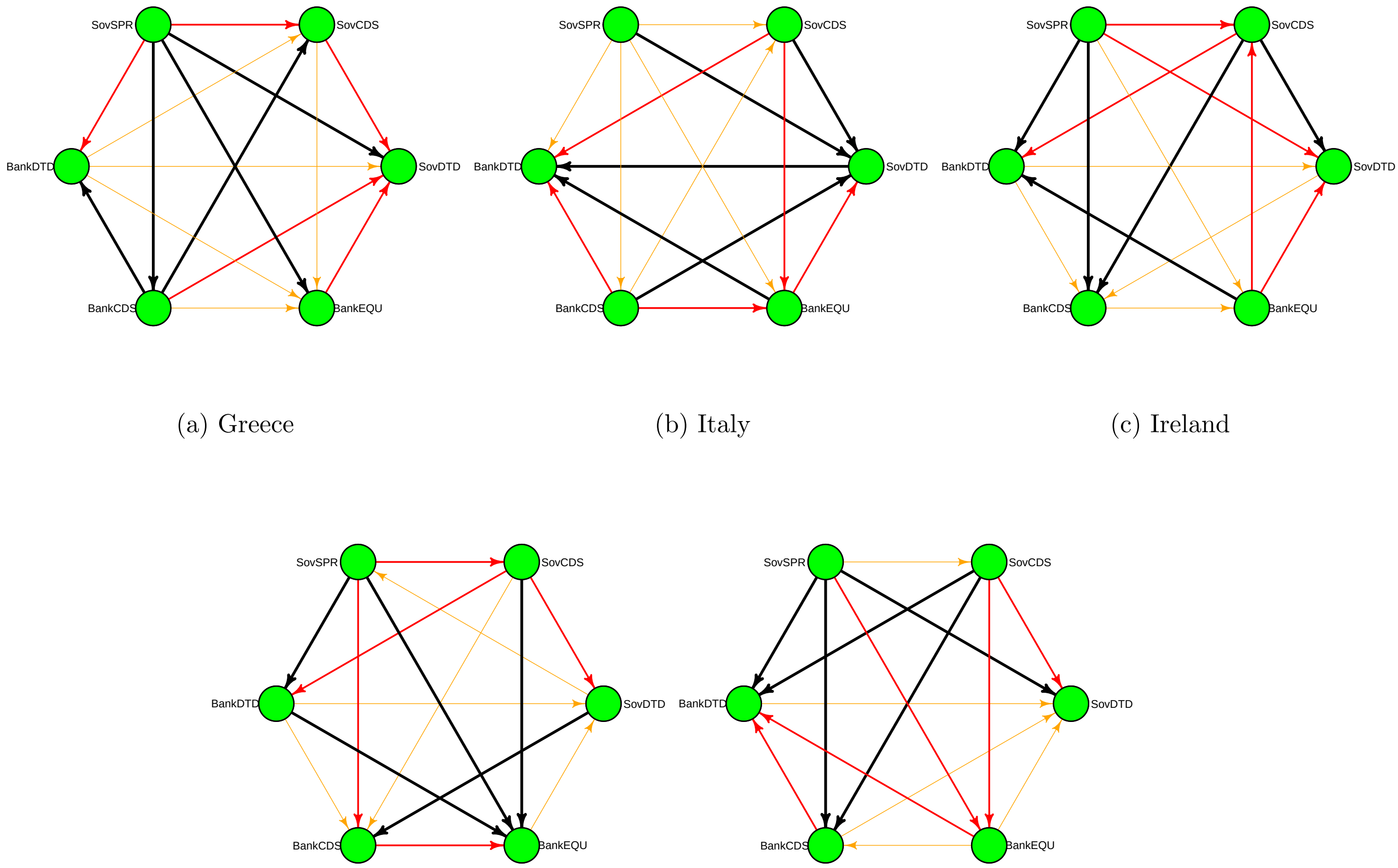
(d) Portugal



(e) Spain

Notes: The blue dotted line represents dynamic Granger causality from sovereign to banks and that the solid red line represents dynamic Granger causality from banks to sovereign.

Figure 11: Country-wise net pairwise directional connectedness between sovereign and banking sector risk indicators



(a) Greece (b) Italy (c) Ireland

(d) Portugal (e) Spain

Notes: To reflect the intensity of the relationship, we use black, red and blue links for very strong, medium and weak intensity respectively. For each country, we first order the computed net directional connectedness values from the highest to the lowest and find the two points that divide the ordered distribution into three parts, each containing a third of the population. $SovDtD$, $SovCDS$, and $SovSPR$ stand for sovereign DtD, CDS and yield spread respectively. $BankDtD$, $BankCDS$, and $BankEQU$ stand for banking sector average DtD, average CDS and average returns based equity index respectively.