UNIVERSITAT DE BARCELONA

Bank and Sovereign Risk: The Case of European Economic and Monetary Union

Manish Singh

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PhD in Economics | Manish Singh

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For
my mother, Sheela,
whose candid love and patience,
I admire
&
Madhu didi,
with you,
I always feel like I have just been born

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Barcelona in March, 2018
Manish Kumar Singh

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1 Introduction

1.1 Motivation

"The early 1980s were a time of large budget deficits and increasing ratios of government debt to GDP for many of the OECD countries, prompting concerns that the fiscal policies which led to such outcomes were not only unwise, but also unsustainable. Assessing wisdom is not easy, however, and surely not an exercise which can or should be reduced to the construction and examination of a few indicators. Assessing sustainability, on the other hand, is a much less ambitious task and one for which indicators are well suited."

Olivier Blanchard et al., 1990

"Debt sustainability assessment: Mission impossible"

Charles Wyplosz, 2011

On September 15, 2008, I was hired as Counterparty Credit Risk Analyst at the Legal, Risk and Credit division of Deutsche Bank. It was the same day that the American bank Lehman Brothers filed for bankruptcy. Within the next fifteen days, two more American banks - Washington Mutual and Wachovia collapsed, while Goldman Sachs and JP Morgan Chase changed their status to bank holding companies. By the end of the month, Irish banking system came to a halt. Ireland's government promised to underwrite the entire Irish banking system, a pledge that they were ultimately unable to uphold.

Next month began with the collapse of Iceland's three biggest commercial banks - Glitnir, Kaupthing, and Landsbanki. To protect the British deposits, the UK used anti-terror legislation to freeze the assets of the banks' UK subsidiaries. Unable to stop the panic, the British government ultimately bailed out several banks, including the Royal Bank of Scotland, Lloyds TSB, and HBOS. In the coming weeks, I saw the near nationalization/recapitalization of all major banks in Germany, France, the Netherlands and Belgium. Some of the world's largest and most prominent institutions failed or nearly failed during this global financial crisis. Regulators around the world extended credit, guaranteed debt, and injected capital to mitigate the situation.

In the coming months, the focus shifted from banks to sovereigns, who have started to, explicitly or implicitly, guarantee large portions of banks liabilities. The mood became grim after George Papandreou's socialist government was elected in Greece in late 2009, and revealed that the hole in Greece's finances was double of what was previously feared. Greece was immediately downgraded to junk and was later bailed out by the troika (the International Monetary Fund (IMF), the European Central Bank (ECB) and the European Commission), signalling the start of the Eurozone debt crisis proper. While the US started on the road to recovery, the European banking sector continued to face difficulties. Ireland and Portugal were subsequently bailed out in 2011, while Spain and Italy were breathing only with the help and support from the ECB (in 2012, Spain received financial assistance to recapitalize its banking sector).

The political events that unfolded in the next couple of years especially in Europe were even more exciting. Countries that were euphoric about joining the euro area (some even fudged their account to prove their willingness), became extremely distraught. Snap elections and referendums became the norm for decision making. Even the ardent supporters and founding members of European Union started discussing the possibility of an exit route. Grexit, Gexit, and Brexit were openly debated in media and public forums. I never imagined that a banking crisis originated across the Atlantic would send such shock waves that would destabilize the very core of the European Union.

This thesis is an attempt on my part to understand the events that unfolded in the euro area in the last ten years. At its very core was a banking crisis originated in late 2008 in the USA. The resulting aftermath took everyone's attention and engulfed the entire world finance. However, what captivated my attention was how little focus had been placed on understanding and measuring risk build-up within bank or sovereign finances. This dissertation comprising four essays specifically focuses on the banking and sovereign credit risk measurement and their linkages across time. I strongly feel that the key issue for research-based policymaking is measurement. Regulators around the world must look for tools to monitor the build-up of risks and analyse the negative externalities imposed by different market participants or various transmission channels on the entire system.

This thesis makes two serious contributions. The first is the measurement of bank and sovereign risk even when market based information on credit risk becomes unreliable or tainted with government or regulatory interventions. Under those circumstances, contingent claims analysis' methodology can be applied to estimate a forward-looking banking and sovereign credit risk measure which is flexible enough to be modified to provide short, medium or long term term creditworthiness of banks and sovereigns in euro area countries. The second major contribution is the examination of bank-sovereign linkages using our proposed indicators as measure of credit risk.

Studies prior to us have usually relied on event study analysis, where a short time window around the event was utilized with market based credit risk measures to prove the validity of bank-sovereign nexus. However, their reliance on market-based indices that lacked the required credibility as independent credit risk measures did not give complete plausibility to their results. Using contingent claims analysis as baseline framework for measuring risk in tail risk scenarios, we are able to address some of those concern. A dynamic approach to test the time-varying relationship using short-term fluctuations in the explanatory power of banks and sovereigns credit risk and comparing the results with other market-based risk indices, provide a robust estimate for bank-sovereign linkages.

1.2 Summary of the thesis

This thesis consists of four self-contained but related papers trying to uncover different aspects of banking and sovereign risk in the member countries of European Economic and Monetary Union (EMU). From a methodological point of view, they all have in common the contingent claims model from the theory of finance, which is used to value call options on a stock.

The first paper, *Bank risk behaviour and connectedness in EMU countries*, studies the structural differences in banking sector and financial regulations at country level to measure and analyse the banking sector risk behaviour. Deviating from the current view, which in our opinion is excessively focused on Systemically Important Financial Institutions (SIFIs), we introduce a micro approach to emphasise the role of smaller financial institutions in build-up of risk. The paper starts with a discussion of the reasons that are needed to consider this choice. Contingent claims analysis model is employed to calculate the risk of individual banks which is then aggregated at country level. The remaining of the paper tries to highlight the information content of country level banking risk indices. It is shown that if banking sector risk is calculated at country level using a bigger sample of banks, it can provide a simple, convenient and intuitive forward looking risk measure. The risk measures differentiate countries based on the structural differences in their financial sectors and show strong correlations with national and regional market sentiment indicators. They outperform the regulatory risk measures based at the European level and the causal linkages run from them to the latter indicators, suggesting better information content. And even though they have high correlations, causality and connectedness tests reveal no systemic component.

The second paper, *Sovereigns and banks in the euro area: a tale of two crises*, attempts to quantify the directional intensity of sovereign-bank linkages in the euro area countries. To this end, we borrow the indicator of banking sector risk in each country from the first paper, and use a traditional measure of sovereign risk (10-year government yield spreads over Germany). The paper starts with the review of channels via which banks and sovereigns are linked in a vicious cycle. We apply a dynamic approach to testing for Granger causality between the two measures of risk in each country, allowing us to check for episodes of significant and abrupt increase in short-run causal linkages. The empirical results indicate that episodes of causality intensification vary considerably in both directions over time and across the different EMU countries. The directionality suggests the presence of causality intensification, mainly from banks to sovereigns, in the crisis periods. Our findings also present empirical evidence about the existence of an adverse feedback loop between sovereigns and banks in some euro-area countries.

The third paper, *Incorporating creditors' seniority into contingent claim models: Application to peripheral euro area countries*, develops and uses a seniority structure of sovereign's creditors to analyse the impact of sectoral distribution of debt on the sovereign credit risk. Specifically, this paper highlights the role of multilateral creditors (i.e., the ECB, IMF, ESM etc.) and their preferred creditor status in explaining the sovereign default risk of peripheral euro area (EA) countries. Incorporating lessons from 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 EA countries in severe crisis episodes. This new priority structure of creditors, together with the contingent claims methodology, is then used to derive a set of sovereign credit risk indicators. In particular, the sovereign distance-to-default indicator, proposed in this paper (which includes both accounting metrics and market-based measures) aims to isolate sovereign credit risk by using information from the public sector balance sheets to build it up. Analysing and comparing it with traditional market-based measures of sovereign risk suggests that the measurement and predictive ability of credit risk measures can be vastly improved if we account for the changing composition of sovereigns' balance sheet risk based on creditors' seniority.

In the last paper, *Revisiting the sovereign-bank linkages: Evidence from contingent claims analysis*, we reconsider the sovereign-bank nexus as discussed in the second paper to check the robustness of our findings. Using the banking sector risk indicator developed in our first paper, together with the sovereign risk index build in the third paper we re-inspect the bank-sovereign linkages. We use three different statistical measures of interconnection based on principal components analysis, Granger causality network and Diebold-Yilmaz's connectedness index. We also compare our results with alternative specifications using existing market-based indicators of banking and sovereign risk. Our results suggest strong connectedness and co-movement between country-level banking and sovereign risk indicators. 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 'wake-up call hypothesis' 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 our second paper. Connectedness analysis also suggest that increasingly the risk is being driven away from market-based uncertainty to the idiosyncratic risk factors, which are better captured by the contingent claim based indices.

2 Bank risk behaviour and connectedness in EMU countries

SUMMARY

Given the structural differences in banking sector and financial regulation at country level in European Economic and Monetary Union (EMU), this paper tries to estimate the banking sector risk behavior at country level. Based on contingent claim literature, it computes "Distance-to-default (DtD)" at bank level and analyses the aggregate series at country level for a representative set of banks over the period 2004-Q4 to 2013-Q2. The indices provide an intuitive, forward-looking and timely risk measure having strong correlations with national/regional market sentiment indicators. An underlying trend exists but causality tests suggest no systemic component. Cross-sectional differences in DtD suggests fragility in EMU countries 12-18 months prior to the crisis and better predictive ability than the regulatory index based on large and complex banking institutions at European level. Furthermore, we explore the reasons for this divergence using VAR estimates.

Keywords: contingent claim analysis, Distance-to-default, banking risk
JEL Code: G01, G13, G21, G28

A joint work with Prof. Marta Gomez-Puig and Prof. Simon Sosvilla-Rivero based on this chapter has been published as - Singh, M. K., Gómez-Puig, M., Sosvilla-Rivero, S. (2015). Bank risk behavior and connectedness in EMU countries. *Journal of International Money and Finance* 57, 161-184.

2.1 Introduction

The 2007-08 financial crisis and the subsequent European sovereign debt crisis have exacerbated the need to understand and monitor the bank risk behavior. Renewed attention is being focused at the global scale to enhance and extend risk measurement methodologies. The eurozone is no exception and the twin objective of the European Central Bank (ECB) - price and financial system stability - places a strong emphasis on Systemically Important Financial Institutions (SIFI) but relies on individual countries' central banks to supervise smaller financial institutions.

This paper deviates from this current and in our view excessive focus and attention on detecting and monitoring risk at European banking level. We take a step backward and introduce a micro approach to document and monitor the buildup of banking sector risk at country level. Based on contingent claims literature, we calculate "Distance-to-default (DtD)" at bank level and analyze the aggregate series at country level for a representative set of banks over the period 2004-Q4 to 2013-Q2. Conceivably, if regulators pay greater attention to country-specific buildups of risk and their connectedness, they might take actions earlier to mitigate the extent and impact of future crisis.

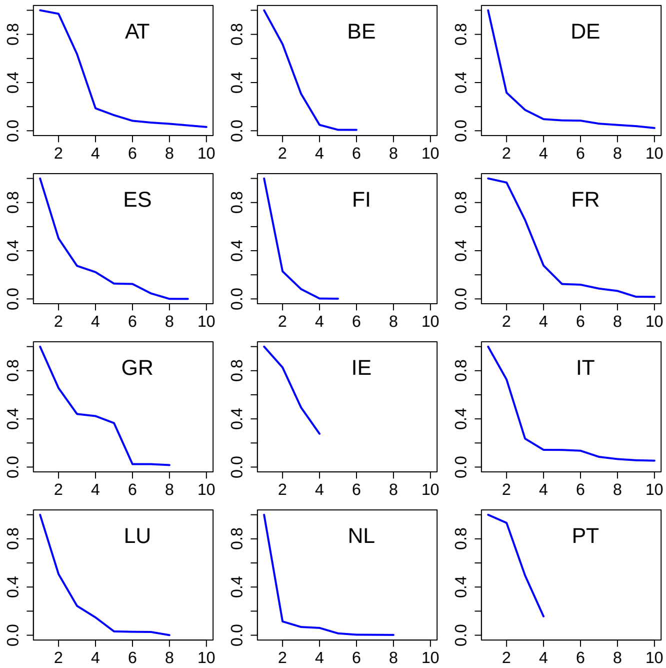
There are many reasons for this choice. First, the structure of the banking sector within EMU countries varies considerably. In the case of Germany, Finland and the Netherlands, total banking sector assets are relatively concentrated, while in Italy, Greece, France and Austria, they are distributed quite equitably. Figure 2.1 summarizes this information by plotting the relative size of banking firms (by total assets in 2010) in individual EMU countries, where the total asset of the biggest bank in a particular country is normalized to one. Excessive asset concentration lowers regulatory cost but makes countries vulnerable to the actions of individual institutions.

Second, countries economic dependence on the banking sector varies drastically.[1] Consider the case of Luxembourg, where the total financial assets under management is roughly 25 times the Gross Domestic Product (GDP) at current prices while, in Greece, Italy and Finland, this multiple is less than three (Figure 2.2a). In some countries, all financial services are provided by banks, while in others there are specialized mortgage, pension and insurance companies. Given the existence of deposit insurance at the national level, governments implicitly or explicitly guarantee bank deposits; which in times of stress, can transfer huge contingent liabilities onto sovereign's balance sheets and bailing out may lead to the weakening of government's own position.

Third, the excessive home bias in European banks' asset portfolios (Figure 2.2b)

[1] We consider total asset managed by banking firms as a proxy for relative economic dependence.

Figure 2.1: Size distribution of banks in each EMU country



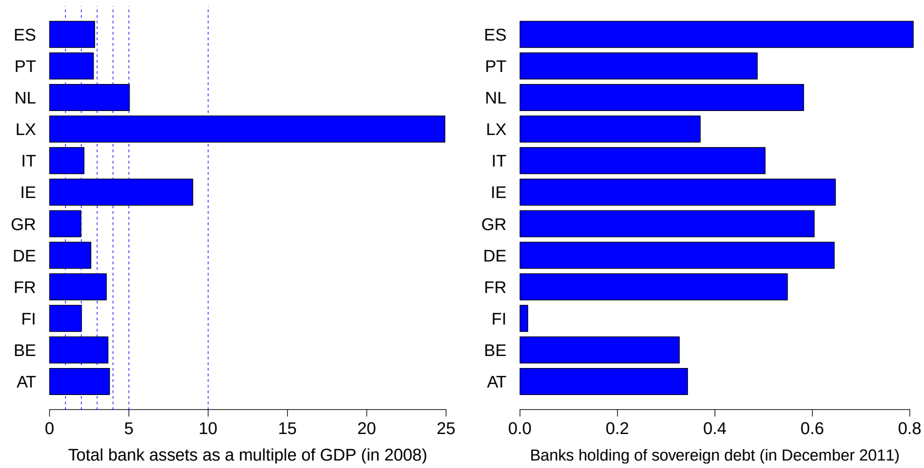
Notes: The figure shows the relative size of individual banks (by total assets in 2010) in each EMU country in 2010. For simplicity, the total asset of the biggest bank in each country is normalized to one. AT: Austria, BE: Belgium, ES: Spain, DE: Germany, FI: Finland, FR: France, GR: Greece, IE: Ireland, IT: Italy, NL: The Netherlands, PT: Portugal, EMU: European Economic and Monetary Union. Source: Bankscope.

creates a vicious circle for risk transfer between banks and sovereigns, which creates perverse economic and political incentives for government to save domestic banks. The existence of financial regulation at national level provides governments with the means to pursue their own national interests. Also noteworthy is the home bias in the private investors portfolio (Belke and Schneider (2013)) which aggravates this problem further. Neighborhood effects, close connectedness with certain countries and cross country differences in bailout strategy also motivate the monitoring of bank risk at country level.

Given this background, the main objective of the paper is to document the evolution of country level banking risk indices. The central questions addressed here are: (1) Does this risk measure provide useful information on the buildup of risk?; (2) Does it render utile insights into market sentiments?; (3) Can it perform better than regulatory measure of prudential risk?; and (4) Is there strong dependence among countries banking sector?

As it turns out, country level DtDs are simple, convenient and intuitive forward

Figure 2.2: Economic dependence and home bias



(a) MFI total assets as multiple of GDP

(b) Banks' holding of its own sovereign bonds (as % of total notional outstanding)

Notes: MFI: Monetary Financial Institution as classified by Organization for International Co-operation and Development (OECD). Datasource: OECD, National Central Banks, European Bank Authority stress test 2011 and Eurostat.

looking risk measures. The level of DtD differentiates countries based on the structural differences in their financial sectors and shows strong correlations with national and regional market sentiments. The improved informational content helps it outperform the regulatory risk measures based at European level and the causal linkages run from aggregate country level DtDs to Euro wide regulatory indicators. The country level DtDs do show very high correlations but causality and connectedness tests reveal no systemic component. This supports our argument of the need to measure risk indices at country level.

This paper contributes to the literature in several ways: (1) we use a novel bottom-up approach to understanding systemic risk buildup in the banking sector and risk-shifting behavior in EMU countries; (2) we use one of the most comprehensive representative databases for the EMU financial sector; (3) we do not neglect the banking sector of smaller countries, which may not be relevant at EMU level but will be relevant at country level; and (4) to our knowledge, this is the first paper which tries to establish a link between country-specific buildup of financial risk with euro-wide aggregate risk indicators and national and regional market sentiments.

The rest of the paper is organized as follows. Section 2.2 reviews the prior literature that used different frameworks to understand bank fragility and justifies our selection of DtD as banking risk indicator. Section 2.3 describes the sample data used to construct, analyze and calibrate the individual and aggregate DtD series. Section 2.4 first documents the behavior of returns, volatility and DtD for each EMU country; it then analyses these behaviors jointly and presents some cross-sectional econometric analysis to gauge the predictive ability and market association of the country-specific DtD indicators. Section 2.5 documents the connectedness among country level banking risk. Section 2.6 draws conclusions.

2.2 Choice of risk indicator

Based on the survey of the existing risk measure techniques, we employed three basic criteria for indicator selection. It should: (1) identify the existing balance sheet fragility; (2) incorporate uncertainty using forward looking market measure; and (3) provide quantifiable risk indicators to assess relative creditworthiness (Gapen et al. (2005)). A comprehensive literature survey suggest that most of bank risk indicators can be classified into two broad categories.

The first or the traditional approach to assess the risk of a firm are based on the pure balance sheet data (see Altman (1968), Altman and Katz (1976), Kaplan and Urwitz (1979), Ohlson (1980), Zmijewski (1984), Blume et al. (1998) among others). Key accounting ratios are identified and using multivariate discriminant or multinomial choice models, firm's default probability is estimated. However the consensus on the accuracy and stress prediction ability of these indicators are relatively low.

These models have generally been criticized on three grounds: (1) the absence of a underlying theoretical model; (2) the timeliness of the information;[2] and (3) the lack of uncertainty and forward-looking component. The selected methodologies also introduce sample selection bias, generating inconsistent coefficient estimates (e.g., Shumway (2001), Chava and Jarrow (2004), Thomas et al. (2012)).

The second approach is pure market based. These are indices determined directly in the market place (e.g. stock prices, aggregate realized volatility, aggregate market leverage, turbulence (a measure of excess volatility relative to market), liquidity ratios and credit condition (e.g., credit default swaps)). Most of these measures lack an underlying theoretical framework but the timely availability and continuous incorporation of information helps improve the relative performance and predictive ability in some cases (see Agarwal and Taffler (2008), Campbell et al. (2011), Gropp et al. (2006), Jorion (2006), Vassalou and Yuhang (2004)).

[2]These models use information from financial statements which are based on past performance and are available only at a quarterly or an annual frequency; thus, they fail to capture changes in the financial conditions of the borrowing firm.

In between these measures lies the contingent claims based model (CCA) of Merton (1974) which provides a theoretical underpinning and answers some of these criticisms. The basic model is based on the priority structure of balance sheet liabilities and uses the standard Black-Scholes option pricing formula to value the junior claims as call option on firms' value with the value of senior claims as default barrier. The structural underpinning and the combination of market-based and accounting information helps obtain a comprehensive set of financial risk indicators, e.g: DtD, probabilities of default, credit spreads, etc.

Additionally, this measure captures the current period instability (using volatility), a forward-looking component (using stock prices) and balance sheet mismatch (using capital structure), in accordance with our requirements. It has been widely applied to assess the ability of corporates, banks and sovereigns to service their debt. Banking applications follow CCA by interpreting a bank's equity as a call option on its value given the limited liability of shareholders. This approach was further refined by Vasicek (1984) and Crosbie and Bohn (2003) and is applied professionally in Moody's KMV to predict default.

The DtD approach has been widely cited and reviewed by the International Monetary Fund (IMF), European Central Bank (ECB) and Office of Federal Research (OFR) as a tool for enhancing bank risk analysis. A number of applications of this approach have been studied to analyze different dimensions of risk. Several papers have examined the usefulness of DtD as a tool for predicting corporate and bank failure (Jessen and Lando (2015), Koutsomanoli-Filippakia and Mamatzakis (2009), Qia et al. (2014), Kealhofer (2003), Oderda et al. (2003), Vassalou and Yuhang (2004), Gropp et al. (2006), Harada et al. (2010), Thomas et al. (2012)). They have found DtD to be a powerful measure to predict bankruptcy and rating downgrades. Comparative analysis of DtD (Hillegeist et al. (2004), Campbell et al. (2008), Bharath and Shumway (2008), Vassalou and Yuhang (2004), Jessen and Lando (2015) and Agarwal and Taffler (2008)) also suggests that DtD can be a powerful proxy to determine default.

2.2.1 Calculation methodology

The foundation for this model lies with the structural model of default developed by Black and Scholes (1973) and Merton (1974). Since equity is a junior claim to debt, it can be modeled and calculated as a standard call option on the assets with exercise price equal to the value of risky debt (also known in the literature as distress barrier or default barrier).

The model uses no arbitrage conditions and assumes a frictionless market. The stochastic process generating the firm's assets return are described by the diffusion process with a constant variance per unit time (σ_A). Following standard literature, we assume that financial distress and bankruptcy are costless.[3] A firm has a simple capital structure with N shares of common stock with market capital E and zero coupon bonds with a face value of D with time to maturity T. The estimation methodology is as follows.

We use the value conservation equation:

$$A = E + De^{-rT} \tag{2.1}$$

Given the assumption of assets distributed as a Generalized Brownian Motion, the application of the standard Black-Scholes option pricing formula (Black and Scholes (1973)) yields the closed-form expression:

$$E = AN(d_1) - e^{-rT}DN(d_2) \tag{2.2}$$

where r is the risk-free rate under risk-neutrality, and $N(*)$ is the cumulative normal distribution. The values of d_1 and d_2 are expressed as:

$$d_1 = \frac{ln(\frac{A}{D}) + (r + 0.5\sigma_A^2)T}{\sigma_A\sqrt{T}} \tag{2.3}$$

$$d_2 = d_1 - \sigma_A\sqrt{T} \tag{2.4}$$

The Merton model uses an additional equation that links the asset volatility σ_A to the volatility of the bank's equity σ_E by applying Ito's Lemma:

$$\sigma_E = N(d_1)\frac{A}{E}\sigma_A \tag{2.5}$$

Using Eqs. 2.2 and 2.5, we obtain the implied asset value A and volatility σ_A, by inverting the two relationships. Once numerical solutions for A and σ_A are found, the T periods ahead DtD is calculated as:

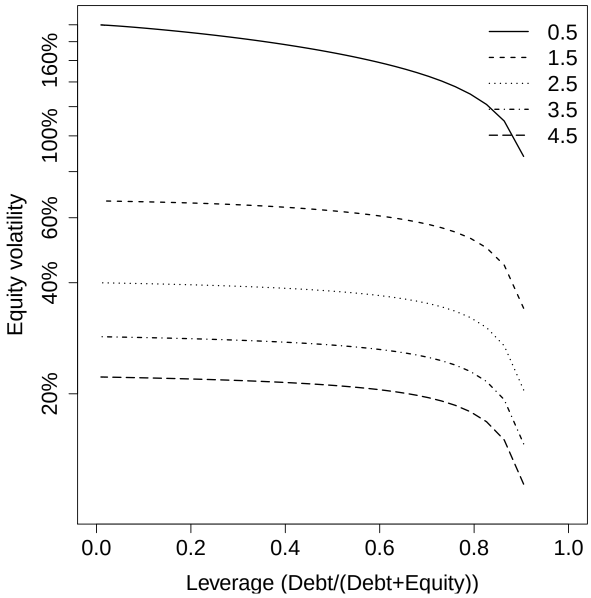
$$DtD = \frac{A - D}{\sigma_A A} \tag{2.6}$$

DtD can be interpreted as the number of standard deviations the value of a firm's asset is away from its default barrier. This standardization across firm size and volatility can be used to rank firms in terms of their relative credit worthiness. The three key inputs in calculating the DtD (market capitalization, debt, and the volatility of equity) implies that it can be influenced by the leverage ratio (debt/(equity + debt)) and volatility of the firm. A higher value of DtD can be obtained either be-

[3] Here we assume that equity market price will reflect the cost of bankruptcy.

cause the leverage of the firm is low or because the volatility is low or both (Figure 2.3).

Figure 2.3: ISO-DtD curves



Notes: The lines represent different values of DtD for varying combinations of leverage and equity volatility.

As can be noted, at a fixed level of volatility and low levels of leverage, DtD changes are small and insignificant for changes in leverage; while for a constant level of leverage, DtD shows much sharper drops for changes in equity volatility. This implies that more than leverage, it is equity volatility that has a greater influence in driving large changes in DtD (Thomas et al. (2012)). Note that here we do not intend to improve the performance of this risk measure technique but aim to use it more effectively in order to capture the banking sector fragility. This approach will help supplement the existing methodologies that failed to capture vulnerabilities prior to this crisis.

2.3 Data

The sample selection methodology is as follows: First, an exhaustive list of all listed and delisted monetary financial institutions is selected from Bankscope[4] database (as on 10^{th} February 2014). We obtain a total of 199 firms in western Europe. Secondly, only firms whose shares were publicly listed and traded between the last

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

quarter of 2004 till the second quarter of 2013 and are headquartered in EMU countries are selected. Finally, credit institutions which are pure-play insurance, pension or mortgage banks are removed. To formalize this decision, we use Datastream as an additional source of information. The major reason for this exclusion is the difference in liability structure and business model compared to banks. However it does not mean that they are less risky to the financial system.

This choice also ensures that the selected banks share the same accounting currency. However, it does not mean that they have a similar exchange rate risk profile, since the level of foreign currency exposure will depend on their respective asset profiles. The market-based data include daily observations of risk-free interest rates, daily stock price and total outstanding share in public. The list of variables and data sources are summarized in Table 2.1.

Table 2.1: Description of variables

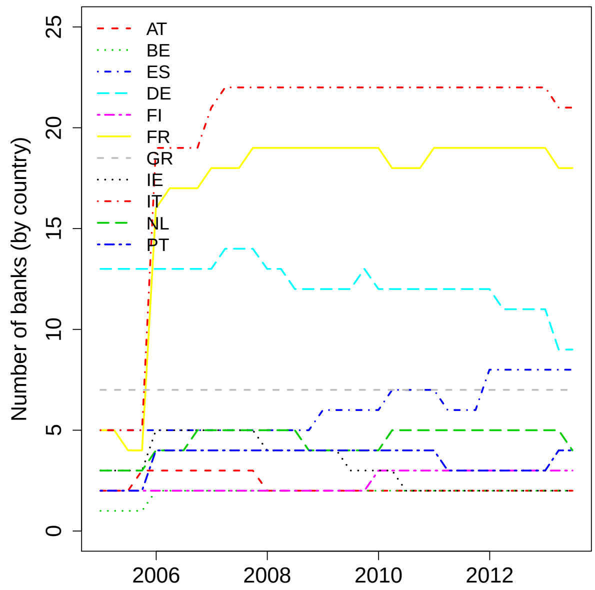
Balance sheet variables		
Variable	Description	Source
Total assets	As reported in annual/interim reports	Bankscope (Code 2025)
Short-term liabilities	Deposits and short term funding	Bankscope (Code 2030)
Total equity	As reported in annual/interim reports	Bankscope (Code 2055)
Daily market based variables		
Variable	Description	Source
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

Firms which were listed, delisted, nationalized or suffered any other relevant corporate actions are considered in the data set until they stopped trading on public exchanges. Due to the varying number of corporate actions every quarter, the number of firms in the sample changes over time, both for the full sample and for individual countries (Figure 2.4) though the core banks remains the same over time. They have an aggregate weight of 78% at the beginning of 2006 and of 86% at the end of it 2013-Q2. Therefore, we honestly do not think that changes in the bank sample composition over time may have a relevant impact on the forecasting properties of the dataset. The comprehensive list of firms used in this analysis is summarized in Table 2.2.[5] This detailed list of firms represents one of the best references for the

[5]The period for which each firm was traded is also available but is not presented here in order to

EMU banking sector.

Figure 2.4: No of banks used every period for each country



Computation of individual DtD: DtD is not measured directly; it is recovered implicitly from the balance sheet and market price of firm's liabilities. For our analysis we compute DtD at quarterly frequency. In practical terms, this means that the balance sheet information has to be modified from its original quarterly, half-yearly, or in few cases, yearly frequencies using cubic spline interpolation. Also the real debt contracts are not all written with a single terminal date. To overcome this problem, a common procedure used by Moody's KMV (Vasicek (1984)) and also employed here, is to adopt a one year horizon ($T = 1$), but to weight longer term debt (maturity > 1 year) at only 50% of face value. The debt barrier (D) will then be equal to the face value of short-term liabilities plus half of the long-term liabilities. Equity value of the firm (E) is computed as the quarterly average of daily market capitalization (number of common shares x share prices) while quarterly historical volatility based on daily log-returns is taken as equity volatility (σ_E). The individual DtD is then calibrated using the procedure outlined in Section 2.

Aggregating DtD series: In practice, the extension of DtD series as a system wide indicator has two major difficulties: (1) At what level should they be aggregated? Since we aim to focus on country level risk measurement in EMU, we would aggregate the DtD at country level; and (2) How can individual banks' data be aggregated as a system-wide representation? Here we follow Saldias (2013), Harada

save space. This information is available from the authors upon request.

Table 2.2: List of banks (by country)

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

Notes: Parenthesis contains the ISIN (International Securities Identification Number), an asterisk (*) mark represents companies which got delisted during the study period. SIFI are indicated in italics (based on Bank of International Settlements G-SIBs as of November 2014).

and Ito (2008) and Harada et al. (2010), and take the simple cross-sectional equal-weighted average at each point in time for all banks headquartered in a particular country as the aggregated risk measure. The simple average DtD for country i at time t is represented by $aDtD_{i,t}$:

$$aDtD_{i,t} = (1/N)\sum_{j=1}^{N} DtD_{j,t} \tag{2.7}$$

where $DtD_{j,t}$ is the individual DtD for firm j at time t having headquarter in country i.

This aggregation approach offers relative risk measures and is very attractive in terms of policy advice. However, this methodology has two major drawbacks. First, it ignores the latest modifications in DtD measurements to improve its relative performance (see Jessen and Lando (2015), Gray and Malone (2008) and Saldias (2013)). Since our focus is not on performance improvement of DtD, we took the most basic and intuitive measure to understand bank risk. Secondly, it does not incorporate the joint distribution properties (see Gray et al. (2007), Gray and Jobst (2010), Duggar and Mitra (2007), Gray et al. (2010) and Jobst and Gray (2013)). Since our aim here is to evaluate the underlying linkages among country level risk, we do not incorporate a priori dependence structure among banking institutions in our aggregation technique.

Country-level $aDtD$: To visualize the country-wise banking risk behavior, we plot the $aDtD$ for individual EMU countries (Figure 2.5). As can be seen, the level of $aDtD$ differs considerably across countries. The series together show a trend and the variability across time is high. The pre-crisis level of $aDtD$ is high (above 4) for almost all countries with Greece, Austria and Ireland at the lower end. During the crisis period, all countries saw corrections in $aDtD$ with Ireland, the Netherlands, Austria and Greece showing huge drops in $aDtD$ level. Post 2007-08, the graph also suggest that the level of $aDtD$ remain low for most of the countries suggesting that it is able to catch the trend and fluctuations during the current crisis.

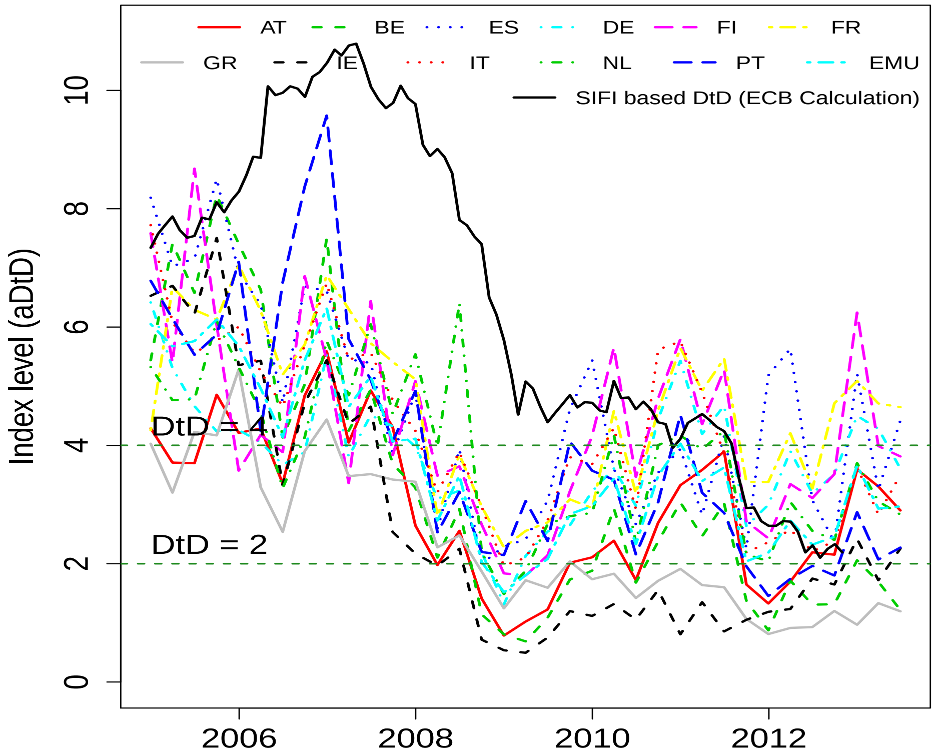
2.4 Analysis

2.4.1 Does $aDtD$ provide information regarding risk buildup?

As banking stress indicators, we compare the evolution of $aDtD$ with banking sector equity and volatility indices.[6] Figure 2.6 plots $aDtD$, bank equity index and

[6] The country wise bank equity index is based on average logarithmic returns of all publicly traded banking firms headquartered in a particular country and are normalized to 100 for all countries at the beginning of the last quarter in 2004. The volatility is equal weighted annualized equity price volatility based on the standard deviation of daily logarithmic returns of the previous quarter.

Figure 2.5: Country level $aDtD$



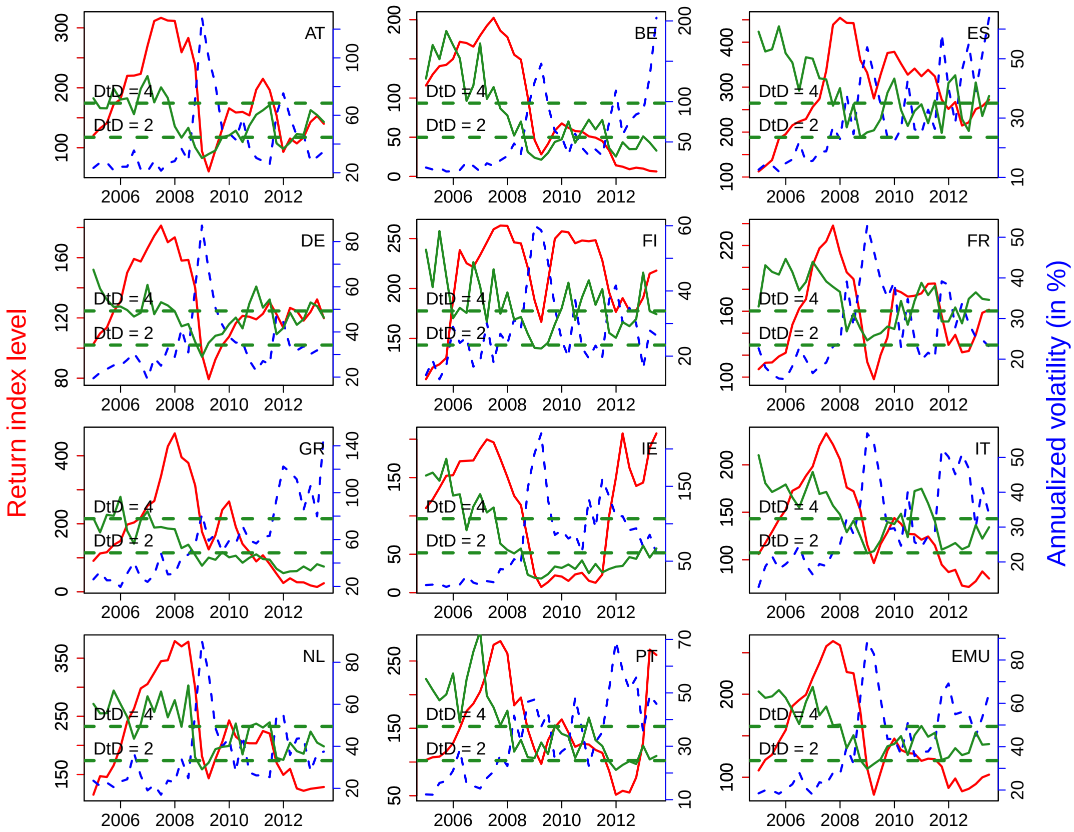
volatility for each EMU country separately. The left axis represents the equity index level while the right axis represents the annualized volatility in percentage. The level of $aDtD$ is scaled to show the general trend and variation with time. The graphs suggest that $aDtD$ started deteriorating for most countries between 2006-07, except for France and the Netherlands. Notably, it started declining when bank index level showed an upward trend while volatility was quite stable.[7]

The returns level suggests that the bank equity prices have fallen substantially for all countries. The first period of rapid decline started around mid 2007, though some recovery was seen in 2009. The second period of decline started during the sovereign debt crisis at the end of 2009, and still continues for some countries. For almost half of the sample, the index level at the end of 2012 is below the index value at the end of 2004. Greece, Belgium, Ireland, Portugal and Italy witnessed the highest drop while Finland and Austria were largely unaffected. In some countries (like Portugal and Ireland) the index level shows a dramatic recovery post crisis. These spikes are due to the sudden drop in sample size due to bank failures and are

This methodology creates an upward (downward) bias in the returns (volatility) indices due to bank failures and should be interpreted carefully.

[7] It also indicates strong correlations with the average volatility, which undermines its effectiveness.

Figure 2.6: Country-wise indices



The blue, green and red line represent volatility, $aDtD$ and equity index level respectively.

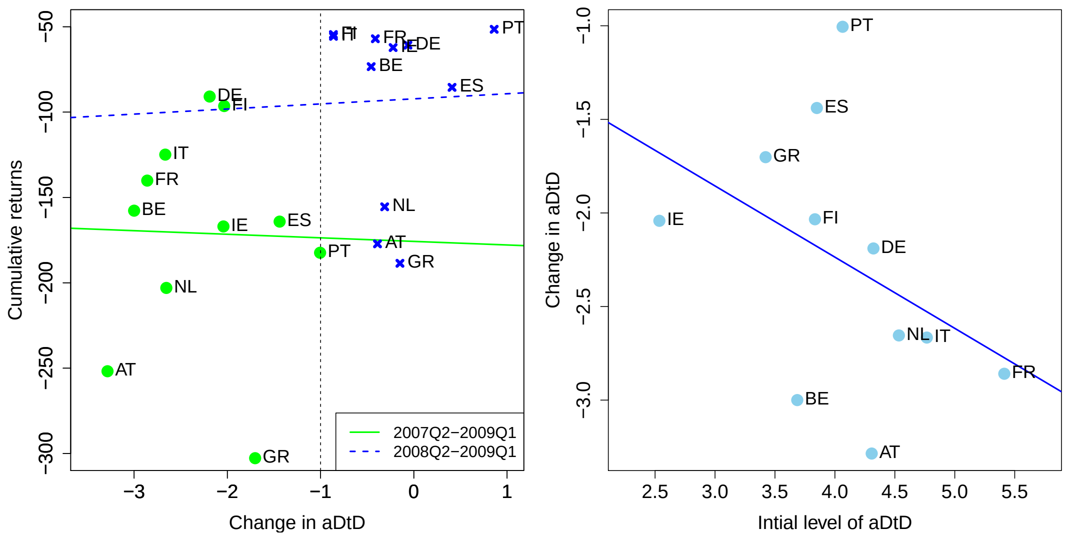
therefore more notable for small countries having fewer banks.

The volatility of small countries (Greece, Portugal, Ireland, the Netherlands, and Austria) is relatively high. Post 2009, the volatility dropped for most EMU countries but has not yet returned to its pre-crisis level. European sovereign debt crisis, loss of market confidence and the need for continuous monetary support to banking sector may be explanations for the relatively high average volatility in peripheral countries. Given the changes in the sample size in a few peripheral countries, the shift in the mean volatility level needs to be interpreted with caution.

Equity indices and $aDtD$ during the crisis: To compare the performance of equity indices with $aDtD$ during the crisis, we analyze the country-wise behavior of market returns with $aDtD$ during the financial crisis. As a predictive indicator of future health, we examine the possibility by comparing the cumulative returns from 2007-Q2 and 2008-Q2 to 2009Q1 with the fall in level of $aDtD$ indicator in each country. Figure 2.7a summarizes this information aptly. As can be seen, most of the fall in $aDtD$ occurred between 2007-Q2 and 2008-Q2, indicating a direct obvious prediction of vulnerability prior to the crisis. However, the total drop in returns shows no correlation with the drop in $aDtD$.

Do initial level of $aDtD$ matters?: Whether or not the initial level of $aDtD$ matters, we plot the initial level of $aDtD$ with the drop in $aDtD$ during the crisis (Figure 2.7b) and find a positive relationship. This suggests that higher initial levels of $aDtD$ experienced higher corrections during this period. The $aDtD$ for most EMU countries averaged between 4 to 5 prior to the crisis. During the crisis (between 2007-Q2 and 2009-Q1), it fell sharply for Austria, France and Italy while for Portugal, Spain and Greece, the corrections were lower than expected.

Figure 2.7: Equity index and aDtD during the crisis



(a) Cumulative returns vs DtD

(b) Scatter plot with trend line (2007-Q2 to 2009-Q1)

2.4.2 Does $aDtD$ render utile insights into market sentiments?

Here we explore the association of $aDtD$ with a selection of indicators covering broad market sentiments and sectoral bank indices collected from independent agencies, professional market data providers and other academic authors.

At country level: We consider six variables as proxy for market sentiment: a consumer confidence indicator (CCI), stock returns (RET), the credit rating (RAT), a fiscal stance indicator (FSI), stock volatility (VOL), rating (RAT) and an index of economic policy uncertainty (EPU). As for the national bank indices, we examine two sectoral equities indices covering banks and financial services (Table 2.3).

Table 2.4 shows that for the individual countries we find a positive association between $aDtD$, CCI and RET. In 7 out of 11 cases we detect a strong connection between our indicator and CCI, while for the RET we obtain a moderate or strong relationship in 6 out of 11. We also find a relatively moderate negative association with RAT and EPU and a strong negative correlation with VOL. For FSI we obtain mixed results. For the sectoral bank indices, regardless of the DtD indicator, our results suggest a moderate positive association with both DSBANKS and DSFIN. The findings suggest that $aDtD$s are capturing the underlying trends that generate differences in risk perceptions of national banking system.

Table 2.3: National financial indicators

	Market sentiment indicators	
Variable	Description	Source
Consumer Confidence Indicator (CCI)	This index is built up by the European Commission which conducts regular harmonized surveys of consumers in each country.	European Commission (DG ECFIN)
Stock Returns (RET)	Differences between logged stock indices prices of the last and the first day of the quarter for each country.	Datastream
Rating (RAT)	Credit rating scale built up from Fitch, Moodys, S&P ratings for each country. Following Blanco (2001), we built up a quarterly scale to estimate the effect of investor sentiment based on the rating offered by these three rating agencies.	Bloomberg
Index of Fiscal Stance (FSI)	This indicator compares a target level of the debt-GDP ratio at a given point in the future with a forecast based on the government budget constraint. It was built by Polito and Wickens (2011, 2012).	Provided by the authors
Stock Volatility (VOL)	Quarterly average of monthly standard deviation of the daily returns of each country's stock market general index	Datastream
Index of Economic Policy Uncertainty (EPU)	This index draws on the frequency of newspaper references to policy uncertainty; it was built for Germany, France, Italy, Spain and EMU by Baker et al. (2013).	www.policyuncertainty.com
	Sectoral bank indices	
Variable	Description	Source
DSBANKS	DataStream Equity Index-Banks	DataStream
DSFIN	DataStream Equity Index-Financial Services	DataStream

At regional (Eurozone) level: We did a similar exercise to understand the association between regional market sentiments and financial indicators with $aDtD$. We find a strong positive association between $aDtD$s and the regional consumer con-

Table 2.4: Correlations between $aDtD$s and national financial indicators

		Market sentiment indicators					Sectoral bank indices	
	CCI	RET	RAT	FSI	VOL	EPU	DSBANKS	DSFIN
AT	0.87	0.08	-	-0.55	-0.86	-	0.70	0.49
BE	0.80	-0.03	-0.34	-0.64	-0.94	-	0.58	0.90
DE	0.71	0.40	-	-0.83	-0.92	-0.51	0.44	0.53
ES	0.58	-0.03	0.22	-0.31	-0.69	-0.30	0.49	0.29
FI	0.53	0.05	-	0.17	-0.88	-	0.31	-
FR	0.76	0.56	-0.10	-0.64	-0.94	-0.71	0.47	0.90
GR	0.79	0.67	-0.60	0.65	-0.88	-	0.81	0.41
IE	0.87	0.75	-0.58	0.87	-0.83	-	0.82	0.24
IT	0.68	0.53	-0.61	0.04	-0.92	-0.64	0.60	0.66
NL	0.59	0.51	-	0.35	-0.87	-	0.70	0.66
PT	0.24	0.06	-0.34	-0.36	-0.95	-	0.21	0.23

fidence indicator and a strong negative relationship with regional economic policy uncertainty and regional financial market volatility. The associations with the indicator of credit quality in the EMU corporate market and regional fiscal stance are moderate and positive while their connection with regional interest rate volatility (1-year forward) is mixed. Regarding the regional sectoral bank indices, there is evidence of a strong association with $aDtD$s in most cases. Interestingly, the $aDtD$s in the peripheral countries strongly influence all EMU bank indices (both GIIPS[8] and non-GIIPS), suggesting a strong co-movement tendencies among banking indices.[9]

2.4.3 Can $aDtD$ perform better than regulatory measure of prudential risk?

We examine how country-wise $aDtD$ perform with respect to the European SIFI based aggregate banking risk indicator (ECB DtD) used by the European Central Bank. To check the better predictive ability of $aDtD$, we plot the ECBDtD together with $aDtD$ in Figure 2.5. The graphical evidence suggests that $aDtD$s do suggest the deteriorating market conditions in most peripheral EMU countries (Spain, Ireland, Greece and Italy) and some central countries (Germany, Belgium and Finland)

[8]Greece, Ireland, Italy, Portugal and Spain.

[9]Complete detail of regional indices and correlations are not attached to save space but are available upon request.

prior to the ECBDtD.[10]

An additional dimension of considering comprehensive list of banks for each country is the increased informational content. To test whether this has a significant effect, we create a time-series of average DtD of all EMU banks in our sample (*EMU-aDtD*) and explore its relationship with the EMU macroeconomic uncertainty indicators compiled by the European Central Bank (2013) from a set of diverse sources: (1) measures of uncertainty perceived by economic agents about the future economic situation based on surveys; (2) measures of uncertainty or of risk aversion based on financial market indicators; and (3) measures of economic policy uncertainty. As far as the EMU banking risk measure is concerned, we use the ECBDtD.[11]

Regarding the measures of uncertainty related to future economic outcomes, we use the degree of disagreement about the projections for activity between professional forecasters measured as the standard deviation of the projections from Consensus Economics for annual real GDP growth in the following calendar year (ECBANY), the average "aggregate uncertainty" from the ECB's Survey of Professional Forecasters (ECBBAVE), combining both disagreement between forecasters and individual uncertainty, and an indicator capturing the uncertainty of private households (ECBCHOU) and enterprises (ECBCBUS) based on the European Commission's Business and Consumer Surveys. Additionally, to account for the concerns for the stability of the euro we have used the indicator built up by Klose and Weigert (2012) which reflects the market expectation of the probability that at least one euro area country will have left the currency union by the end of 2013 (EUROINST).

To assess financial market uncertainty or risk aversion measures, we use an average of a set of financial market indicators (implied bond and stock market volatility,

[10]Further results (not shown here, but available from the authors upon request) suggest that default risk might be higher in the case of multinational rather than domestic oriented banks. ECB's calculation of DtD based on SIFIs also suggests that the level of aggregate DtD is low for SIFI. This is important, since multinational banks not only mean more interconnectedness, but also serve as buffer of regional shocks (Belke and Gros (2015)). Indeed, cross-border capital flows in the form of equity appear to be much more stable than those taking the form of credit, especially inter-bank credit. Moreover, credit booms and bust leave a debt overhang and losses can materialize only via insolvencies, whereas equity flows absorb automatically losses in case of a bust and provide the cross border owner with incentives to continue to provide financing. It follows that cross-border banks can absorb regional shocks. But large banks pose the 'too big to fail' problem and they would also propagate regional shocks, especially if they originate in large countries, to the entire area (Belke (2013), Belke and Gros (2015)).

[11]We are very grateful to Analistas Financieros Internacionales for kindly providing the credit rating dataset and Fernando Fernandez-Rodriguez for his research assistance. We thank Scott R. Baker, Raquel Lopez, Eliseo Navarro, Vito Polito, Michael R. Wickens and the European Cenral Bank for allowing us access to their datasets.

implied EUR/US dollar volatility and CDS spreads over government bond yields) and a number of systemic stress indicators (exchange rate volatility, equity market volatility, bond market volatility, money market volatility, financial intermediation and a composite systemic stress indicator) (ECBDAVE).

With respect to economic policy uncertainty, we use an index based on the newspaper coverage of policy-related economic uncertainty and the disagreement between forecasters with regard to the outlook for inflation and budget balances: These components are aggregated using weights of 50% for the former and 25% for each of the dispersion measures (ECBEAVE). Additionally, we make use of an indicator that combines all the individual sets of series by principal component analysis (ECBFPC). We select these measures of uncertainty because they show a significant negative correlation with key macroeconomic variables, such as quarterly growth rates of real GDP, total investment, private consumption and, in particular, total employment.

Table 2.5 summarizes the correlations of these ECB regulatory indicators with *EMU-aDtD*. As can be seen, we find a significant and negative association between our indicators of EMU banking risk based on DtD and the various measures of macroeconomic uncertainty, suggesting that higher banking risk (signaled by a reduction in DtD) will increase macroeconomic uncertainty and, as a consequence, adversely affect macroeconomic events.

Table 2.5: Cross correlation of EMU-aDtDs with ECB indicators

Macroeconomic uncertainty indicators	EMU-aDtD
ECBANY	-0.62
ECBBAVE	-0.66
ECBCHOU	-0.64
ECBCBUS	-0.53
ECBEAVE	-0.85
ECBFPC	-0.85
EUROINST	-0.94
Banking risk indicator	**EMU-aDtD**
ECBEDtD	0.67

To test the predictive ability of this indicator with respect to the regulatory indicators, we assessed the possible existence of Granger-causality. As can be seen in Table 2.6, with the sole exception of ECBCHOU, we find a significant unidirectional Granger-causality relationship running from our indicators of EMU banking risk to both the various measures of macroeconomic uncertainty and the banking risk indicator used by the ECB. This result gives further support to the hypothesized interconnection between DtDs and macroeconomic uncertainty and banking risk.

Table 2.6: Granger causality between EMU-aDtDs and ECB indicators

Macroeconomic uncertainty indicators			
Null Hypothesis	F-Stats	Prob.	Significant at
ECBANY does not Granger Cause EMU-aDTD	2.29	0.12	
ECBBAVE does not Granger Cause EMU-aDTD	0.28	0.76	
ECBCHOU does not Granger Cause EMU-aDTD	1.97	0.16	
ECBCBUS does not Granger Cause EMU-aDTD	1.39	0.27	
ECBEAVE does not Granger Cause EMU-aDTD	0.40	0.67	
ECBFPC does not Granger Cause EMU-aDTD	0.32	0.73	
EUROINST does not Granger Cause EMU-aDTD	6.18	0.04	5%
Banking risk indicators			
Null Hypothesis	F-Stats	Prob.	Significant at
ECBDtD does not Granger Cause EMU-aDtD	0.12	0.89	
Macroeconomic uncertainty indicators			
Null Hypothesis	F-Stats	Prob.	Significant at
EMU-aDtD does not Granger Cause ECBANY	5.08	0.01	5%
EMU-aDtD does not Granger Cause ECBBAVE	8.76	0.00	1%
EMU-aDtD does not Granger Cause ECBCHOU	0.64	0.53	
EMU-aDtD does not Granger Cause ECBCBUS	4.00	0.03	5%
EMU-aDtD does not Granger Cause ECBEAVE	2.93	0.07	10%
EMU-aDtD does not Granger Cause ECBFPC	7.51	0.00	1%
EMU-aDtD does not Granger Cause EUROINST	4.09	0.01	5%
Banking risk indicators			
Null Hypothesis	F-Stats	Prob.	Significant at
EMU-aDtD does not Granger Cause ECBDtD	6.53	0.0047	1%

Summary: Our empirical estimates using country level indices suggest that the country-wise $aDtD$ has better predictive ability than the market based measures (returns and volatility) and is strongly connected with market sentiments at national and regional level. The initial level of $aDtD$ matters and the drop is more significant for countries having higher $aDtD$. $aDtD$ also have strong correlations with regulatory measures of risk and has higher information content. The direction of causality runs from $aDtD$ to regulatory measures.

2.5 Connectedness among countries banking risk

In this section, we explore the linkages between $aDtD$ using a cross country connectedness measures. We use three ways to measure the connectedness: (1) Correlations; (2) Granger causality; and (3) Diebold-Yilmaz connectedness index (DYCI) based on the variance decomposition of forecast errors.

2.5.1 Correlation measures

To understand the co-movement properties, we use three correlation measures (parametric: Pearson, and non-parametric: Spearman and Kendell) in our analysis.[12] Since the Pearson measure is the most commonly used, we report our findings based on Pearson correlations only, but they are also robust based on other measures.

Table 2.7: Correlations among aggregate DtD indices

	AT	BE	ES	DE	FI	FR	GR	IE	IT	NL	PT
BE	0.83										
ES	0.70	0.83									
DE	0.79	0.66	0.65								
FI	0.71	0.63	0.66	0.78							
FR	0.88	0.83	0.67	0.75	0.62						
GR	0.74	0.89	0.72	0.51	0.53	0.69					
IE	0.78	0.93	0.86	0.62	0.63	0.74	0.84				
IT	0.84	0.84	0.75	0.81	0.74	0.76	0.81	0.78			
NL	0.79	0.79	0.65	0.69	0.65	0.72	0.78	0.71	0.80		
PT	0.77	0.84	0.73	0.58	0.58	0.70	0.88	0.77	0.84	0.67	
EMU	0.91	0.95	0.87	0.80	0.77	0.86	0.88	0.92	0.93	0.85	0.88

For each measure of correlations, we first estimate the pair-wise correlations between the $aDtD$ (Table 2.7). As can be seen, we find a strong correlation[13] between indices, which suggests a common risk factor. This may also be due to the small

[12] This avoids any bias arising from potential non-linear dependencies and confirms the robustness of our findings.

[13] We use the adjective “strong” when the absolute value of the correlation is above 0.8, “moderate” when it is between 0.7-0.8, and “weak” when it is between 0.6-0.7.

sample, which contains two crisis episodes. To understand the time varying correlation dynamics, we tested for correlations using pre-/post crisis windows and apply a signed rank test to evaluate the null hypothesis that the mean and median correlations are equal if we divide the time period in two half (pre and post 2009-Q4).

The results suggest that except Germany and Finland, all other countries shows very strong correlations with EMU average. This also suggest a common risk factor which we test in the next section. Belgium, Greece, Italy and Portugal have strong inter-linkages and connections across the board. Belgian banking sector shows strong connections with all EMU countries except Germany and the Netherlands. Germany is strongly connected with only Italy and moderately to France, Austria and Finland. For other peripheral countries, Germany has weak correlations.

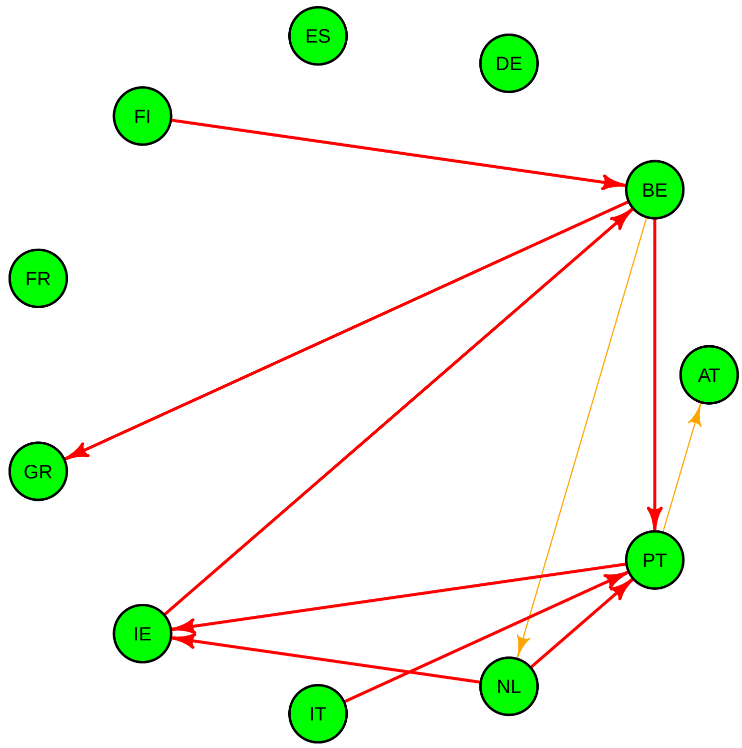
2.5.2 Granger causality

The graphic behavior of the countries' $aDtD$ series and correlation estimates suggests an underlying trend. It may be due to an increase in the systemic risk of global financial industry due to cross linkages, increased volatility or investment in correlated assets. To understand this spillover within the EMU banking sector, we run Granger causality tests for each pair-wise country $aDtD$s. We find very weak evidence of causality running from a particular country towards the rest of the countries (Figure 2.8), which suggests that the banking risk captured by countries' $aDtD$s remains idiosyncratic (suggestive evidence of no systemic component). To test the robustness of our results, we also did the analysis based on banks' market capital and asset based weighted average DtD. The results (not shown here to save space, but they are available from the authors upon request) render the same qualitative conclusions than in the case of using $aDtDs$.

2.5.3 Diebold-Yilmaz connectedness measure

To explore further the systemic underlying component among $aDtD$ indices, we use VAR (vector auto regression) methodologies based measure of connectedness. The connectedness is based on the decomposition of the forecast error variance, which is briefly described here. For a multivariate time series, the forecast error variance decomposition works as follows: First, we fit a standard vector autoregressive (VAR) model to the series; secondly, using series data up to, and including, time t, establish an H period ahead forecast (up to time $t+H$); and finally, decompose the forecast error variance for each component with respect to shocks from the same or other components at time t.

Figure 2.8: Linkages based on Granger causality tests



Notes: We show the most important directional causalities among the pairs of 11 countries' aDtDs. Red and orange lines represent significance at 10% and 5% level respectively.

Consider an N-dimensional covariance-stationary data-generating process (DGP) with orthogonal shocks:

$$x_t = \Theta(L)u_t, \Theta(L) = \Theta_0 + \Theta_1 L + \Theta_2 L^2 + ..., E(u_t, u_t^{'}) = I$$

Note that Θ_0 need not be diagonal. All aspects of connectedness are contained in this very general representation. Contemporaneous aspects of connectedness are summarized in Θ_0 and dynamic aspects in $\Theta_1, \Theta_2, ...$ Transformation of $\Theta_1, \Theta_2, ...$ via variance decompositions in needed to reveal and compactly summarize connectedness. Let us denote by d_{ij}^H the ij-th H-step variance decomposition component (i.e., the fraction of variable i's H-step forecast error variance due to shocks in variable j). The connectedness measures are based on the "non-own" or "cross" variance decompositions, $d_{ij}^H, i, j = 1, ..., N, i \neq j$.

Diebold and Yilmaz (2014) propose several connectedness measures built from pieces of variance decompositions in which the forecast error variance of variable

i is decomposed into parts attributed to the various variables in the system. Here we provide a snapshot of their connectedness index. They proposed a connectedness table such as Table 2.8 to understand the various connectedness measures and their relationships. Its main upper-left NxN block, that contains the variance decompositions, is called the "variance decomposition matrix," and is denoted it by $D^H = [d_{ij}]$ The connectedness table augments D^H with a rightmost column containing row sums, a bottom row containing column sums, and a bottom-right element containing the grand average, in all cases for $i \neq j$.

Table 2.8: Schematic connectedness table

	x_1	x_2	...	x_N	From others
x_1	d_{11}^H	d_{12}^H	...	d_{1N}^H	$\sum_{j=1,j\neq 1}^N d_{1j}^H$
x_2	d_{21}^H	d_{22}^H	...	d_{2N}^H	$\sum_{j=1,j\neq 2}^N d_{2j}^H$
..	..	...	..	..	
..	..	...	..	..	
x_N	d_{N1}^H	d_{N2}^H	...	d_{NN}^H	$\sum_{j=1,j\neq N}^N d_{Nj}^H$
To others	$\sum_{i=1,i\neq 1}^N d_{i1}^H$	$\sum_{i=1,i\neq 2}^N d_{i2}^H$		$\sum_{i=1,i\neq N}^N d_{iN}^H$	$\frac{1}{N}\sum_{i,j=1,i\neq j}^N d_{ij}^H$

The off-diagonal entries of D^H are the parts of the N forecast-error variance decompositions of relevance from a connectedness perspective. In particular, the *gross pairwise directional connectedness* from j to i is defined as follows:

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

Since in general $C_{i\leftarrow j}^H \neq C_{j\leftarrow i}^H$ the *net pairwise directional connectedness* from j to i, can be defined as:

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

Regarding the off-diagonal row sums in Table 2.8, they give the share of the H-step forecast-error variance of variable x_i coming from shocks arising in other variables (all other, as opposed to a single other), while the off-diagonal column sums provide the share of the H-step forecast-error variance of variable x_i going to shocks arising in other variables. Hence, the off-diagonal row and column sums, labeled "from" and "to" in the connectedness table, offer the total directional connectedness measures. In particular, *total directional connectedness* from others to i is defined as

$$C^H_{i\leftarrow\bullet} = \sum_{j=1, j\neq i}^{N} d^H_{ij}$$

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

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

We can also define *net total directional connectedness* as

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

Finally, the grand total of the off-diagonal entries in D^H (equivalently, the sum of the "from" column or "to" row) measures *total connectedness*:

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

For the case of non-orthogonal shocks the variance decompositions are not easily calculated as before because the variance of a weighted sum is not an appropriate sum of variances; in this case methodologies for providing orthogonal innovations like traditional Cholesky-factor identification may be sensitive to ordering. So, following Diebold and Yilmaz (2014), a generalized VAR decomposition (GVD), invariant to ordering, proposed by Koop et al. (1996) and Pesaran and Shin (1998) will be employed. The H-step generalized variance decomposition matrix is defined as $D^{gH} = [d^{gH}_{ij}]$, where

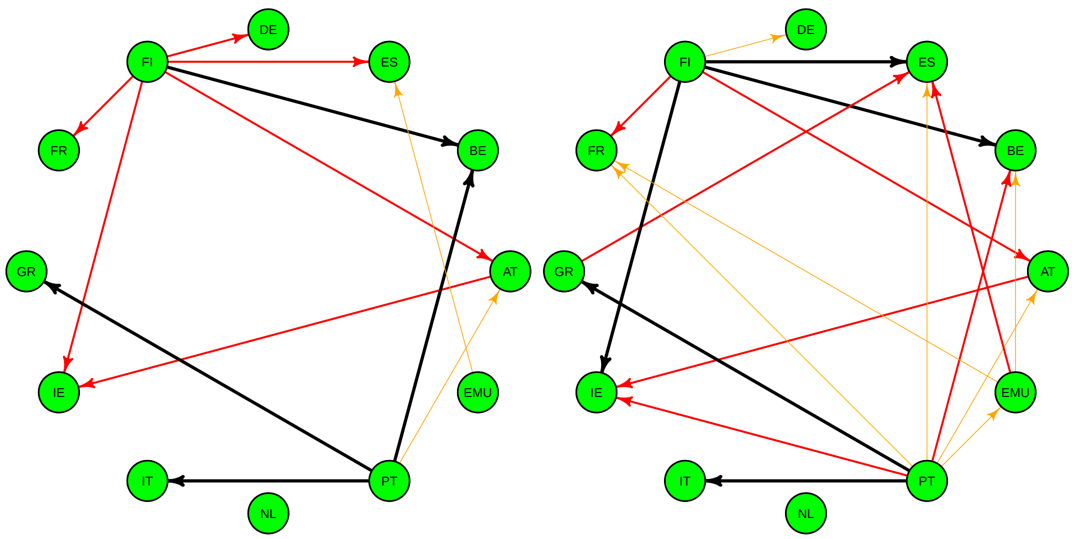
$$d^{gH}_{ij} = \frac{\sigma_{ij}^{-1} \sum_{h=0}^{H-1} (e_i^{'} \Theta_h \Sigma e_j)}{\sum_{h=0}^{H-1} (e_i^{'} \Theta_h \Sigma \Theta_h^{'} e_j)}$$

In this case, e_j is a vector with j^{th} element unity and zeros elsewhere, Θ_h is the coefficient matrix in the infinite moving-average representation from VAR, Σ is the covariance matrix of the shock vector in the non-orthogonalized-VAR, σ_{ij} being its j^{th} diagonal element. In this GVD framework, the lack of orthogonality makes it so that the rows of do not have sum unity and, in order to get a generalized connectedness index $\tilde{D}^g = [\tilde{d}^g_{ij}]$, the following normalization is necessary: $\tilde{d}^g_{ij} = d^g_{ij} / \sum_{j=1}^{N} d^g_{ij}$, where by construction $\sum_{j=1}^{N} \tilde{d}^g_{ij} = 1$ and $\sum_{i,j=1}^{N} \tilde{d}^g_{ij} = N$. The matrix $\tilde{D}^g = [\tilde{d}^g_{ij}]$ permits us to define similar concepts as defined before for the orthogonal case, that is, *total directional connectedness, net total directional connectedness and total connectedness.*

Tables 2.9 and 2.10 present the connectedness tables for $aDtD$ based on six months and one year horizon, along with the nonparametrically bootstrapped standard errors, while Figure 9 shows the most important directional connections among the pairs of 12 $aDtD$s based on the top three deciles. As can be seen, all the connectedness measures are statistically different from zero at least at the 5% level. To test the robustness of our results, we also did the analysis based on banks' market capital and asset based weighted average DtD. The results (not shown here to save space, but they are available from the authors upon request) render the same qualitative conclusions than in the case of using $aDtDs$.

The Netherlands show very weak connectedness while Germany and Italy shows linkages only with Finland and Portugal respectively. Spain, Belgium, Portugal and Austria have high connectedness with most EMU countries except for the Netherlands, Italy and Germany. Even for changing horizon, the results remain quite consistent. In most cases, the effects seem to dry out but the connectedness pair remain the same. Finally, we observe a value of 73.67% for the total connectedness between $aDtD$ in a horizon of 6 months and value 76.72% for a year, in line with the values of 78.3% obtained by Diebold and Yilmaz (2014) for US financial institutions.

Figure 2.9: Net directional connectedness among $aDtD$s



(a) Based on 6 months horizon (b) Based on 1 year horizon

Notes: We show the most important directional connections among the pairs of 12 countries' aDtDs. Black, red and orange lines represent the first, second and third deciles based on net pairwise directional connectedness derived from Tables 2.9 and 2.10.

Table 2.9: Connectedness among country-wise banking risk - aDtD

	Horizon 6 months												
Country	AT	BE	ES	DE	FI	FR	GR	IE	IT	NL	PT	EMU	From
AT	19.35**	3.76**	1.30*	4.95**	22.3**	5.40**	5.09**	4.76**	3.66**	3.77**	13.15*	12.42**	80.65**
	(0.73)	(0.18)	(0.45)	(0.24)	(1.12)	(0.31)	(0.99)	(1.01)	(0.98)	(0.18)	(5.11)	(2.12)	(1.24)
BE	6.50**	7.58**	5.72**	5.94**	18.18**	4.45**	9.81**	3.30**	6.00**	3.43**	17.13**	11.95**	92.42**
	(1.89)	(0.57)	(1.07)	(0.66)	(1.45)	(0.82)	(2.01)	(0.75)	(1.35)	(0.35)	(1.81)	(1.45)	(1.3)
ES	5.59**	4.14**	16.78**	3.52**	13.77**	4.51**	9.09**	4.65**	10.14**	6.01**	10.00**	11.81**	83.22**
	(1.32)	(1.21)	(0.45)	(0.23)	(2.11)	(0.67)	(2.11)	(1.12)	(1.62)	(1.13)	(1.22)	(1.57)	(1.12)
DE	8.22**	2.54**	1.63**	38.97**	14.19**	9.51**	7.12**	5.48**	5.62**	1.10**	0.58**	5.04**	61.03**
	(0.91)	(0.48)	(0.22)	(0.66)	(0.71)	(0.52)	(0.84)	(0.73)	(0.45)	(0.23)	(0.15)	(0.78)	(1.91)
FI	12.77**	3.57**	2.39*	5.72**	33.04**	4.54**	3.97**	3.85**	8.15*	3.12**	6.18*	12.70**	66.96**
	(2.54)	(0.98)	(0.99)	(0.47)	(1.12)	(1.01)	(0.74)	(0.84)	(0.51)	(0.42)	(2.44)	(1.34)	(1.71)
FR	10.2**	3.38**	1.45**	14.28**	14.95**	27.47**	4.37**	5.41**	2.82**	5.33**	2.23**	8.13**	72.53**
	(1.77)	(0.55)	(0.22)	(0.76)	(0.69)	(0.55)	(0.51)	(0.58)	(0.37)	(0.54)	(0.51)	(1.11)	(1.48)
GR	4.77*	3.91*	3.79*	6.58**	6.77*	2.98**	28.52**	1.55**	4.13**	5.19*	24.74**	7.07**	71.48**
	(1.89)	(1.55)	(1.41)	(1.26)	(2.77)	(0.61)	(0.47)	(0.32)	(0.42)	(1.91)	(1.54)	(1.45)	(1.98)
IE	13.42**	3.84**	2.88*	10.71**	15.96**	10.95**	2.69**	15.06**	5.18**	4.38*	6.67**	8.26**	84.94**
	(4.15)	(0.99)	(1.11)	(2.46)	(2.93)	(3.16)	(0.34)	(0.26)	(0.55)	(1.61)	(1.03)	(1.03)	(1.74)
IT	4.68**	4.89**	6.76**	5.43**	10.28**	2.28**	3.99**	2.23**	20.16**	6.21*	18.98**	14.12**	79.84**
	(1.12)	(1.34)	(0.43)	(0.78)	(1.54)	(0.81)	(0.52)	(0.43)	(0.49)	(1.71)	(1.14)	(2.11)	(1.63)
NL	5.45**	2.85**	3.12**	1.57**	6.95**	6.14**	5.22**	0.85*	9.37**	42.32**	5.39*	10.77**	57.68**
	(0.97)	(0.69)	(0.31)	(0.24)	(0.45)	(0.28)	(0.63)	(0.35)	(1.12)	(0.35)	(2.13)	(1.28)	(1.34)
PT	4.85*	4.40**	4.16**	4.8**	4.54*	1.20**	4.56**	0.96**	6.52**	2.50*	51.65**	9.87**	48.35**
	(1.98)	(1.55)	(0.14)	(1.29)	(1.77)	(0.17)	(0.34)	(0.14)	(0.26)	(0.99)	(0.32)	(1.42)	(1.18)
EMU	9.04**	5.51**	4.74**	4.39**	16.52**	4.93**	5.07**	3.31**	9.44**	6.35**	15.66**	15.06**	84.94**
	(1.02)	(0.56)	(0.88)	(0.65)	(1.11)	(0.79)	(0.89)	(0.99)	(1.28)	(0.87)	(1.12)	(0.15)	(0.78)
To	81.54**	84.95**	69.34**	63.54**	81.38**	67.47**	68.13**	70.7**	77.89**	52.83**	70.03**	88.16**	73.67**
	(1.77)	(1.36)	(1.61)	(1.43)	(1.37)	(1.29)	(1.73)	(1.19)	(1.88)	(1.64)	(1.45)	(0.91)	(0.41)

Bootstrapped standard errors are presented in parenthesis. ** and * indicate significance at the 1% and 5% levels, respectively.

Table 2.10: Connectedness among country-wise banking risk - aDtD

	Horizon 1 year												
Country	AT	BE	ES	DE	FI	FR	GR	IE	IT	NL	PT	EMU	From
AT	18.15**	3.91**	1.66*	4.70**	21.34**	4.67**	5.87**	4.35**	4.50**	4.31**	13.71**	12.84**	81.85**
	(0.99)	(0.31)	(0.57)	(0.2)	(1.31)	(0.37)	(0.94)	(0.91)	(1.15)	(0.21)	(4.08)	(1.72)	(1.39)
BE	7.34**	7.68**	3.98	5.09**	17.00**	3.34**	10.12**	3.31**	7.00**	4.04**	17.14*	13.96**	92.32**
	(1.49)	(0.62)	(0.87)	(0.75)	(1.57)	(0.41)	(2.15)	(0.68)	(0.95)	(0.31)	(1.52)	(1.24)	(1.75)
ES	6.81**	5.37**	9.81**	2.66**	16.15**	2.85**	12.03**	3.66**	9.14**	8.12**	10.93**	12.47**	90.19**
	(1.19)	(1.21)	(1.78)	(0.21)	(2.18)	(0.37)	(1.95)	(0.76)	(0.78)	(0.98)	(1.29)	(1.44)	(2.16)
DE	6.68**	3.71**	1.74**	32.04**	12.82**	6.68**	9.46**	3.96**	7.22**	1.49**	6.52**	7.67**	67.96**
	(0.85)	(0.31)	(0.55)	(0.51)	(1.53)	(0.74)	(0.77)	(0.65)	(0.41)	(0.25)	(1.49)	(1.03)	(1.37)
FI	12.47**	3.73**	2.03**	5.48**	30.61**	4.47**	4.93**	4.27**	8.81**	3.26**	6.20*	13.74**	69.39**
	(2.43)	(0.64)	(0.66)	(0.49)	(1.26)	(0.99)	(0.89)	(0.86)	(0.84)	(0.44)	(2.44)	(1.45)	(1.28)
FR	8.19**	4.71**	1.86**	11.02**	13.89**	19.95**	6.14**	3.34**	4.14**	6.11**	9.12**	11.54**	80.05**
	(1.61)	(0.66)	(0.45)	(0.73)	(0.97)	(0.54)	(0.61)	(0.42)	(0.67)	(0.61)	(1.61)	(1.25)	(1.39)
GR	7.71**	3.86*	1.51*	7.18**	8.71*	2.77**	29.04**	3.02**	1.87**	5.57*	23.03**	5.71**	70.96**
	(1.27)	(1.53)	(0.58)	(1.42)	(3.55)	(0.47)	(0.44)	(0.56)	(0.35)	(2.05)	(1.42)	(1.07)	(1.42)
IE	13.90**	5.12**	2.28**	9.76**	18.35**	5.00**	5.47**	11.37**	4.77**	3.64*	10.50**	9.85**	88.63**
	(2.33)	(1.03)	(0.89)	(2.13)	(1.77)	(1.03)	(0.56)	(0.39)	(0.51)	(1.24)	(0.97)	(1.18)	(1.26)
IT	6.26**	5.65**	4.54**	7.11**	14.99**	2.93**	5.36**	2.36**	16.47**	5.78*	16.10**	12.44*	83.53**
	(1.24)	(1.22)	(0.83)	(0.75)	(1.65)	(0.67)	(1.24)	(0.39)	(0.91)	(1.58)	(0.97)	(2.15)	(1.44)
NL	7.42**	3.69**	2.25	2.44	7.74**	8.80**	7.81**	1.43**	6.69**	38.76**	3.28*	9.66**	61.24**
	(0.75)	(0.73)	(0.72)	(0.53)	(1.68)	(0.51)	(0.63)	(0.21)	(1.12)	(0.52)	(1.28)	(1.42)	(1.57)
PT	5.80*	4.87**	2.54**	6.51**	6.13**	2.16**	5.46**	1.19**	3.82**	2.83*	50.67**	8.01**	49.33**
	(2.34)	(1.23)	(0.45)	(2.01)	(1.33)	(0.25)	(0.41)	(0.17)	(0.24)	(1.12)	(2.14)	(1.46)	(1.02)
EMU	10.17**	6.07**	3.17**	4.91**	17.69**	4.76**	6.60**	3.19**	7.70**	5.49**	15.45**	14.82**	85.18**
	(1.41)	(0.71)	(0.56)	(0.59)	(1.14)	(0.84)	(0.92)	(0.84)	(1.21)	(0.84)	(0.93)	(0.47)	(1.41)
To	83.64**	86.85**	73.75**	67.61**	83.49**	70.83**	73.18**	74.98**	79.95**	56.64**	72.26**	88.83**	76.72**
	(1.91)	(1.41)	(1.33)	(1.12)	(1.48)	(1.25)	(1.42)	(1.24)	(1.55)	(1.66)	(1.57)	(1.11)	(0.51)

Bootstrapped standard errors are presented in parenthesis. ** and * indicate significance at the 1% and 5% levels, respectively.

2.6 Conclusion

By analyzing the behavior and fluctuations of a market based banking risk indicator for individual EMU countries, we find that $aDtD$ is an intuitive, simple and convenient forward looking risk measure. The level of $aDtD$ varies with country suggesting cross-sectional structural differences across the banking sector and captures trends as well as fluctuations in the financial markets. Analysis during the crisis period suggests better predictive ability (12-18 months prior to the crisis) for most of the EMU countries. The initial level of $aDtD$ matters but the change in $aDtD$ is more pronounced for countries with a higher initial level.

When compared with other regulatory risk and market sentiment measures, $aDtD$s shows better predictive ability and very high correlations. The strong association between $aDtD$s and regional (Eurozone) market sentiment (uncertainty)/sectoral banking indices also improves the explanatory power. The Granger causality test reveals the direction of causality running from $aDtD$s to Eurozone risk indicators (and not the other way round) suggesting better information content.

The correlations analysis suggests strong inter-linkages across country level banking stress but low inter-linkage between core and peripheral EMU countries. Taking s step further, we tested for a systemic component using Granger causality tests and found negative results. To better understand the dependence structure, we explored further by analyzing the connectedness using Diebold-Yilmaz Connectedness Index and found low connectedness among country level banking risk indices.

As the recent literature has highlighted huge connectedness among Systemically Important Financial Institutions (SIFI) and high degree of joint risk of default, our empirical estimates which uses country level indices suggest otherwise. The country-wise $aDtD$ has higher predictive ability and is strongly connected with market sentiments but the connectedness among the country-wise $aDtD$ is low. Suggesting that the inter-linkages may be higher for SIFI but for the country level banking sector, the connectedness is low. This result will be beneficial for understanding and augmenting a priori dependence structure in the computation of systemic risk.

So, there are various reasons for considering country-wise risk indicators alongside regional market and other risk measures. As the statistical theory suggests, when faced with two estimators for the same underlying variable, it is optimal to combine the two. Tracking country specific indices provide additional information related to the average risk level and their ability to forecast the risk buildup cannot be ignored. Following the systemic risk indicators based on large, complex EU-wide financial institution may delay the prediction of risk buildup.

DtD measures can also be extended beyond the banking context. The theoretical argument being a kind of option value of waiting under uncertainty can be extended to international trade literature to help understand the impact of uncertainty on investment, export, import and employment (see Belke and Gros (2001) for EMU case). Further extension can also help examine the interconnection between banking and sovereign risk in the euro area (Gómez-Puig et al. (2015)) and to explore if the Banking Union in the euro area can disentangling the risk of the EMU banks and their governments by influencing the risk pattern (Belke (2013), Belke and Gros (2015), De Groen (2015)).

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3 Sovereigns and banks in the euro area: a tale of two crises

SUMMARY

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

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

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3.1 Introduction

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

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

On the reverse, a banking crisis can also trigger a surge in sovereign risk. The impact on the public finances commonly comes from the recession and the fiscal expansion typically implemented to deal with it. A comprehensive analysis of the transmission channels of financial instability (or crisis) on a country's fiscal stance is presented by Eschenbach and Schuknecht (2002). These authors identify three major transmission channels of financial instability on a country's fiscal stance, namely (i) Direct bailout costs; (ii) Direct revenue effects; and (iii) Indirect effect via the impact on the real economy. Direct bailout costs focuses on the direct government support provided to distressed financial institutions in order to avoid a systemic financial crisis. The impact depends strongly on the form of government interven-

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

tions. The revenue effect impacts through the downward changes in asset prices driven by financial instability causing reduction in tax paid (household on wealth, corporate and sales taxes etc.). A reduction in real estate transactions (price and volume), slowdown in equity market and decrease in dividends also negatively impacts the fiscal revenue. The indirect effect works through the real economy where lower wages and higher unemployment triggers a reduction in personal income tax and social contributions while simultaneously increasing the unemployment payments. Subsequent increase in government debt and higher interest payments both exacerbates the effect.

Based on these linkages, some authors (Brunnermeier et al. (2011) and Reichlin (2013), among them) have described the development of a 'diabolic loop' as the major cause of the crisis in EMU countries. European banks, encouraged by the absence of any regulatory discrimination between bonds, held an excessive part of the national debt, which - far from being safe - fed never-ending speculation on the banks' solvency. In turn, sovereigns were in constant danger of having to rescue their banks, which, combined with the uncertainty regarding the kind of fiscal support they would receive from their European partners, increased the riskiness of their bonds. However, banks' exposure to the domestic sovereign debt had declined steadily for all EMU countries between the mid-1990s until the end of 2008 (see Figure 4(a) in Angelini et al. (2014)). In most EMU countries, end 2008 marks an inversion in this trend, where the banks began to increase their domestic sovereign debt holdings. This suggests that the increasing exposure was a consequence not the cause of the crisis although it may have contributed to exacerbating the crisis by intensifying the bank-sovereign nexus. Even though most of these authors[2] try to establish or assume the existence of a diabolic loop between bank and sovereign risk, to our knowledge there is a lack of empirical support to identify, trace and quantify the asymmetrical directional intensity of risk transfer. This paper tries to fill this gap in the literature where direction and intensity of risk transfer between banking and sovereign risk is being evaluated for individual countries for each quarter between 2005Q2-2013Q3.

In a parallel development, some authors (see, e.g. Shambaugh (2012)) have pointed out that the euro area is currently facing three interlocking crises (bank-

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

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

While there is a substantial amount of empirical literature exploring the determinants of either bank risk or sovereign risk in isolation, few papers to date have tried to empirically quantify the interdependence or even contagion between the sovereign and banking sectors. Exceptions are Alter and Schüler (2012), Gross and Kok (2013) and Alter and Beyer (2014), who applied different extensions of vector autoregressive (VAR) models; and De Bruyckere et al. (2013) who investigated the presence of contagion by computing excess correlation (over and above what one would expect from fundamental factors). However, though they use different methodologies, all these papers apply the same measure of banking and sovereign risk: credit default swap[3] (CDS) spreads on 5-year senior debt contracts, since these are known to be the most actively traded and therefore the most liquid. In this context, our paper makes the first major contribution to this branch of the literature by applying indicators of bank and sovereign risk that differ considerably from the ones used in previous literature. As far as we know, this is the first paper to use measures other than CDS spreads to quantify the directional intensity of risk transfer between banks and sovereigns in the euro area. Our selection offers three major advantages: (1) It extends the sample period of analysis incorporating a few pre-crisis years; (2) It allows the inclusion of countries for which CDS spreads are thinly traded or not available; and (3) It measures the relative creditworthiness of the banking sector of different countries based on the same parameters.

Our indicator of banking risk is based on the banks distance-to-default (DtD) as explained in Chapter 2. Specifically, the average DtD ($aDtD$) based on the simple average DtD of all banks headquartered in a particular country will be the proxy

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

of banking risk used in the analysis.[4] On the other hand, 10-year government yield spreads over Germany will be our measure of sovereign risk,[5] since they reflect the premium that investors demand in order to bear the sovereign risk.

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

Our results suggest that in the pre-crisis period, from early 2005 until the collapse of Lehman Brothers, 77% of the total episodes of causality intensification detected were from sovereigns to banks and coincided with a period of economic stagnation in EMU countries or with the beginning of a downturn in GDP growth in the euro area. After the last quarter of 2008, coinciding with the beginning of the financial

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

[5] Some authors contend that past CDS spreads improve the forecast quality of bond yield spreads (Palladini and Portes (2011), Fontana and Scheicher (2010)). However, CDS markets (in both the sovereign and the banking sectors) have been quite illiquid since late 2008, only one year before the onset of the euro sovereign debt crisis. This is one of the reasons we decided to make use of 10-year yield spreads over euro-denominated German government bonds instead of CDS (see Section 3.3.2), even though the 10-year yield is used in the case of Germany in order to include Germany in our analysis.

crisis and the implementation of government measures to support financial institutions, the direction of the causality intensification underwent a change. In this crisis period the majority of the causality intensification episodes (around 63% of the total) ran from banks to sovereigns. This finding is noticeable in the cases of France, Greece and Ireland where episodes of causality intensification are detected only in this direction. For the case of Germany, Portugal and the Netherlands they account for more than 70% of the episodes. Conversely, in Belgium and Finland causality intensification was mainly from sovereigns to banks, while in Spain, Italy and Austria there were similar numbers of episodes of causality intensification in both directions.

The rest of the paper is organized as follows. Section 3.2 reviews the linkages between sovereign and banking risk in EMU countries. Section 3.3 briefly explains the selection and creation of our banking and sovereign risk indicators. Section 3.4 explains our data selection methodology. The econometric methodology used in our analysis is presented in Section 3.5. Section 3.6 summarizes the main results and, finally, Section 3.7 offers some concluding remarks.

3.2 Sovereign/bank linkages

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

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

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

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

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

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

3.3 Assessing banking and sovereign risk

3.3.1 Bank risk indicator

To assess the banking sector risk in each EMU country, we use the country-wise banking sector $aDtD$ indicator. $aDtD$ can be interpreted as how many standard deviations the asset value of the banking sector is away from the debt threshold. The closer it is to zero, the closer the banking sector is to distress.

Why DtD over CDS spreads? First, they offer a longer history compared to CDS spreads (Figure 3.1). Indeed most of the banking CDS started trading in the latter half of 2005 and quality data was not available until late 2007 (in most of the cases the data is available starting December 2007). Also very few of them have remained liquid since the onset of US financial crisis. Thus, this choice of risk indicator will allow us to examine the interconnection between the risk in the sovereign and the banking sectors starting 2005 (more than three years before the beginning of the global financial crisis).

Second, it includes more banks in each country than those for which CDS data are available (better representativeness) and seem to perform better in crisis monitoring (see Chapter 2). To see whether this indicator exhibits a similar movement as CDS, we plot $aDtD$ and average CDS[6] for each country in our analysis separately (Figure 3.1). As can be seen, the $aDtD$ at country level mirrors the average CDS movement in all cases (deterioration in $aDtD$ corresponds to increase in average CDS, and vice versa).

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

3.3.2 Sovereign risk indicator

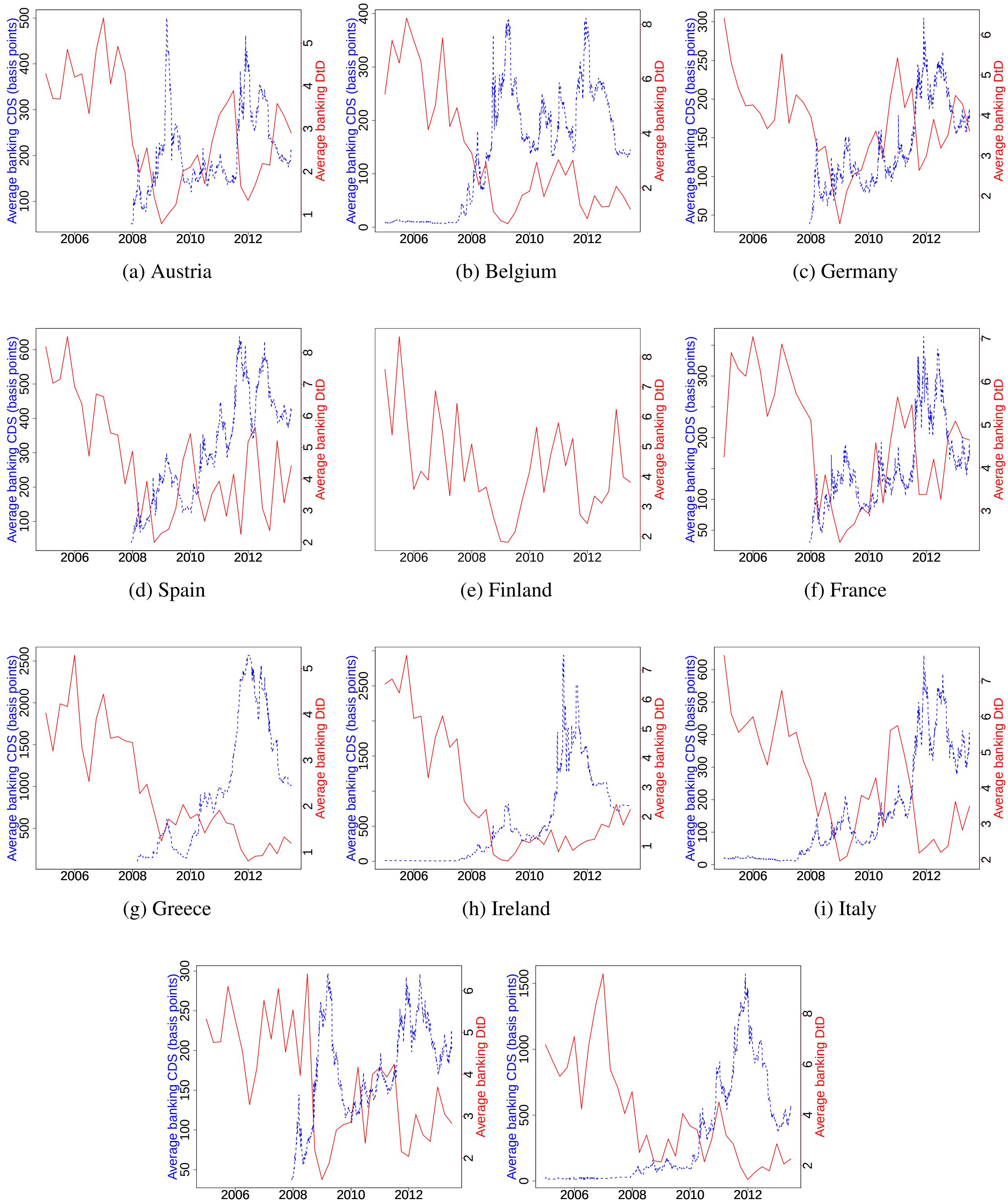
Ten-year sovereign bond yield spreads with respect to the German bund is the proxy used in this paper to measure sovereign risk, whilst the 10-year benchmark sovereign yield is used in the case of Germany.[8] Our sample contains eleven EMU countries, six central (Austria, Belgium, Finland, France, Germany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

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

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

[8] We decided to use the 10-year bund yields as a proxy for the risk-free benchmark; they are considered as such in many academic studies because German sovereign debt has enjoyed a high credit rating for some time now and its returns can be seen as a good proxy for risk-free asset returns. For the sake of simplicity, this convention is maintained in the paper. However, since this decision would mean the omission of Germany from the analysis, we use the 10-year yield as a proxy of the sovereign risk in the case of Germany. We think that it is relevant to include Germany in the analysis taking into account that since 2008 this country had a deteriorated banking system and government measures to support the banking system accounted for 25% of its GDP at the end of 2008 (see Table 3.5).

Figure 3.1: Country-wise banking sector $aDtD$ and average CDS spreads



(a) Austria (b) Belgium (c) Germany

(d) Spain (e) Finland (f) France

(g) Greece (h) Ireland (i) Italy

(j) The Netherlands (k) Portugal

Notes: CDS data is not available for Finnish banks. CDS data is at daily frequency while the $aDtD$ is calculated at quarterly frequency.

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

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

3.4 Data

3.4.1 Banking sector risk measure

We use the banks average DtD as the banking sector risk measure for individual countries. The sample selection methodology and computation of $aDtD$ is explained in Section 2.3.

3.4.2 Sovereign risk measure

Ten-year bond yield spreads with respect to the German bund (10-year yields in the case of Germany), which have been calculated from data drawn from Datastream, will be the proxy used in this paper to measure sovereign risk for all countries in the sample except for Germany. The 10-year yield is used in the case of Germany in order to be able to include this country in our analysis. We use quarterly data from 2004-Q4 to 2013-Q3 (i.e., T=36 observations).

3.4.3 Data anlaysis

Graphs in Figure 3.2 display the evolution of both sovereign and banking risk in the eleven countries in our sample during the crisis period: from 2004-Q4 to 2013-Q3. The right axis corresponds to the banking risk indicator ($aDtD$) and the left axis to the sovereign risk indicator (the 10-year sovereign yields spread or the 10-year yield).

3.5 Econometric methodology

The term 'contagion', generally used in contrast to 'interdependence', conveys the idea that after a shock there may be breaks or anomalies in the international transmission mechanism which arguably reflect switches across multiple equilibria, market panics unrelated to fundamentals, investors' herding, and the like. Contagion has been defined in many different ways in the literature,[9] including the transfer of any shock across countries (Edwards (2000)). Eichengreen and Rose (1999) and Kaminsky and Reinhart (1999) define it as the situation in which knowledge of crisis in one country increases the risk of crisis in another one.

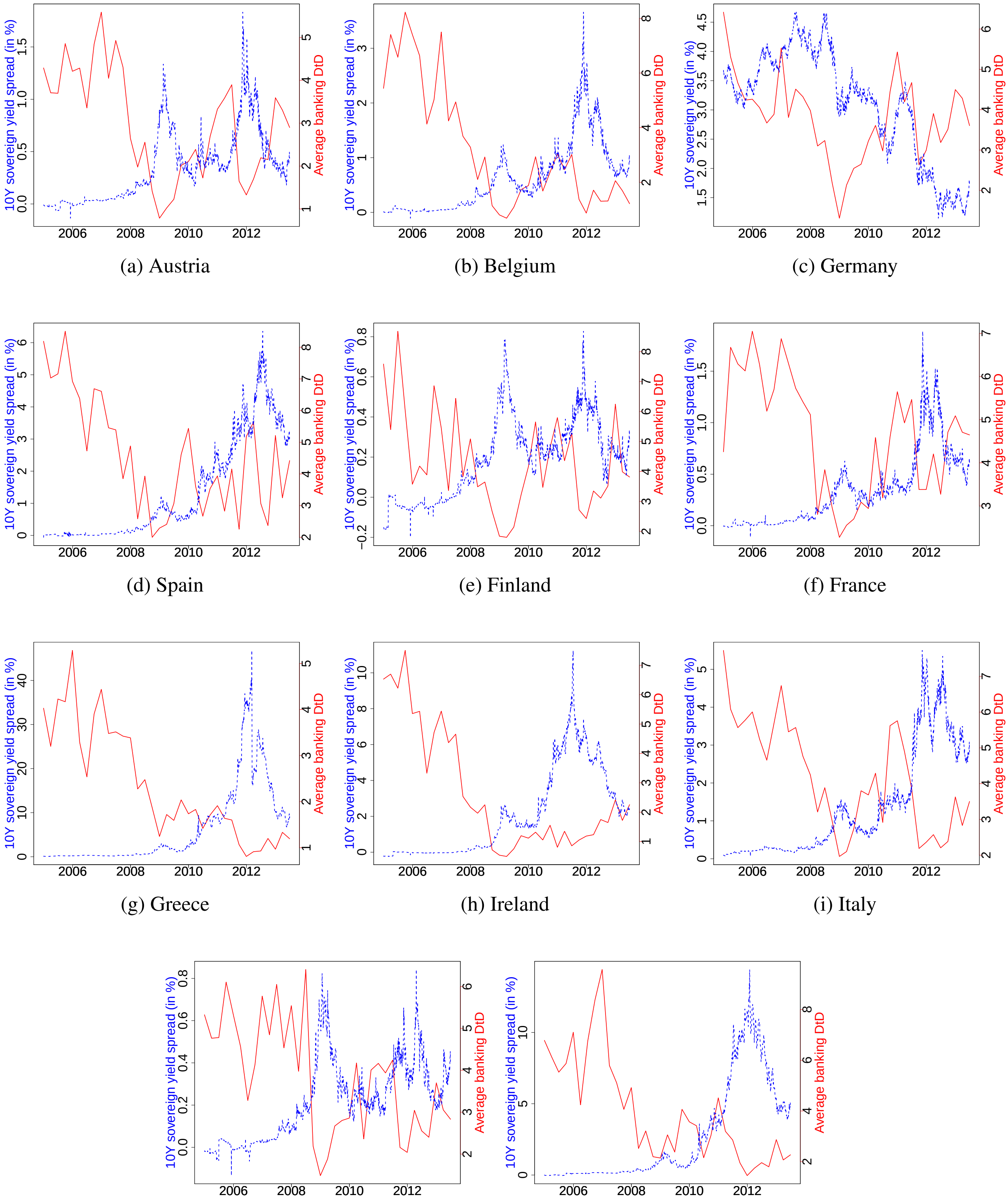
Much of the empirical work on measuring the existence of contagion is based on comparing correlation coefficients during a relatively stable period with a crisis or a period of turbulence (see, e.g., Forbes and Rigobon (2002) and Corsetti et al. (2005)). In fact, Forbes and Rigobon (2002) argue that 'contagion is a significant increase in cross-market co-movements after a shock.' These authors stress that this notion of contagion excludes a constant high degree of co-movement that exists in all states of the world since; in that case, markets would be just interdependent. This definition is sometimes referred to as 'shift-contagion' and this very sensible term clarifies that contagion arises from a shift in cross-market linkages, and also avoids taking a stance on how this shift occurs.[10]

Given the lack of consensus on contagion, in this study we adopt an eclectic approximation and directly investigate changes in the existence and the intensity of causality between banking and sovereign risk among a sample of eleven euro area countries. To that end, we follow a dynamic approach in order to assess the

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

[10] See Forbes and Rigobon (2001).

Figure 3.2: Country-wise banking sector $aDtD$ and 10Y sovereign yield spreads



(a) Austria (b) Belgium (c) Germany

(d) Spain (e) Finland (f) France

(g) Greece (h) Ireland (i) Italy

(j) The Netherlands (k) Portugal

Notes: Yield spread data is at daily frequency while the $aDtD$ is calculated at quarterly frequency. For Germany, we use the 10Y benchmark German bund yield.

evolving nature of the Granger causal linkages and to detect episodes of significant and transitory increases in the pair-wise Granger causal relationships. The intuition is that if the causal linkage intensifies during a period of turmoil relative to a period of tranquility, this intensification could identify episodes of significant propagation of shocks from one side to the other.

3.5.1 Testing procedure

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

Tests of Granger causality typically use the same lags for all variables. This poses a potential problem, since Granger-causality tests are sensitive to lag length.[11] In this paper we use Hsiao (1981) sequential method to test for causality to determine the optimal lag structure for each variable, combining Akaike's final predictive error (FPE, from now on) and the definition of Granger-causality.[12] Essentially, the FPE criterion trades off the bias that arises from under-parameterization of a model against a loss in efficiency resulting from its over-parameterization, removing the ambiguities of the conventional procedure.

Consider the following models,

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \epsilon_t \tag{3.1}$$

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \sum_{j=1}^{n} \gamma_j Y_{t-j} + \epsilon_t \tag{3.2}$$

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

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

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

1. Treat X_t as a one-dimensional autoregressive process (5), and compute its FPE with the order of lags m varying from 1 to m. Choose the order which yields the smallest FPE, say m,[13] and denote the corresponding FPE as FPE$_X$(m, 0).

2. Treat X_t as a controlled variable with m number of lags, and treat Y_t as a manipulated variable as in (6). Compute again the FPE of (6) by varying the order of lags of Y_t from 1 to n, and determine the order which gives the smallest FPE, say n, and denote the corresponding FPE as FPE$_X$(m,n).[14]

3. Compare FPE$_X$(m, 0) with FPE$_X$(m,n) (i.e., compare the smallest FPE in step 1 with the smallest FPE in step 2). If FPE$_X$(m,0) $>$ FPE$_X$(m,n), then Y_t is said to cause X_t. If FPE$_X$(m,0) $<$ FPE$_X$(m,n), then X_t is an independent process.

4. Repeat steps 1 to 2 for the Y_t variable, treating X_t as the manipulated variable.

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

$$\Delta X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \epsilon_t \tag{3.3}$$

$$\Delta X_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta Y_{t-j} + \epsilon_t \tag{3.4}$$

where Z_{t-1} is the lagged OLS residual of the cointegrating regression ($X_t = \mu + \lambda Y_t$), known as the error-correction term. Note that, if X_t and Y_t are I(1) variables, but they are not cointegrated, then β in (8) is assumed to be equal to zero.

In both cases (i.e., X_t and Y_t are I(1) variables, and they are or are not cointegrated), we can use Hsiao's sequential procedure substituting X_t with ΔX_t and Y_t with ΔY_t in steps 1 to 4), as well as substituting expressions (5) and (6) with equations (7) and (8). Proceeding in this way, we ensure efficiency since the system is congruent and encompassing (Hendry and Mizon (1999)).

As explained above, since the presence and intensity of Granger-causality may vary over time, we adopt a dynamic analysis to detect episodes of a significant,

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

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

short-run abrupt increase in the causal linkages. To assess the dynamic Granger-causality between sovereign and banking risk, we carry out rolling regressions using a window of four quarterly observations.[15] In each estimation, we apply the Hsiao (1981)'s sequential procedure outlined above to determine the optimum FPE (m, 0) and FPE (m, n) statistics in each case.

3.5.2 Application

As a first step, we tested the order of integration of the $aDtD$s, and the sovereign risk indicator by means of the Augmented Dickey-Fuller (ADF) tests. Then, following Cheung and Chinn (1997)'s suggestion, we confirmed the results using the Kwiatkowski et al. (1992) (KPSS) tests, where the null is a stationary process against the alternative of a unit root. The results, not shown here to save space but available from the authors upon request, decisively reject the null hypothesis of non-stationarity in the first regressions. They do not reject the null hypothesis of stationarity in the first differences, but strongly reject it in levels, in the second differences. So, they suggest that both variables can be treated as first-difference stationary. As a second step, we tested for cointegration between each of the 20 pair relationships using Johansen (1991, 1995)'s approach. The results suggest[16] the absence of long-run cointegration between the $aDtD$ and the sovereign risk indicator. Therefore, we tested for Granger-causality in first differences of the variables, with no error-correction term added (i. e., equations (7) and (8) with $\beta = 0$).

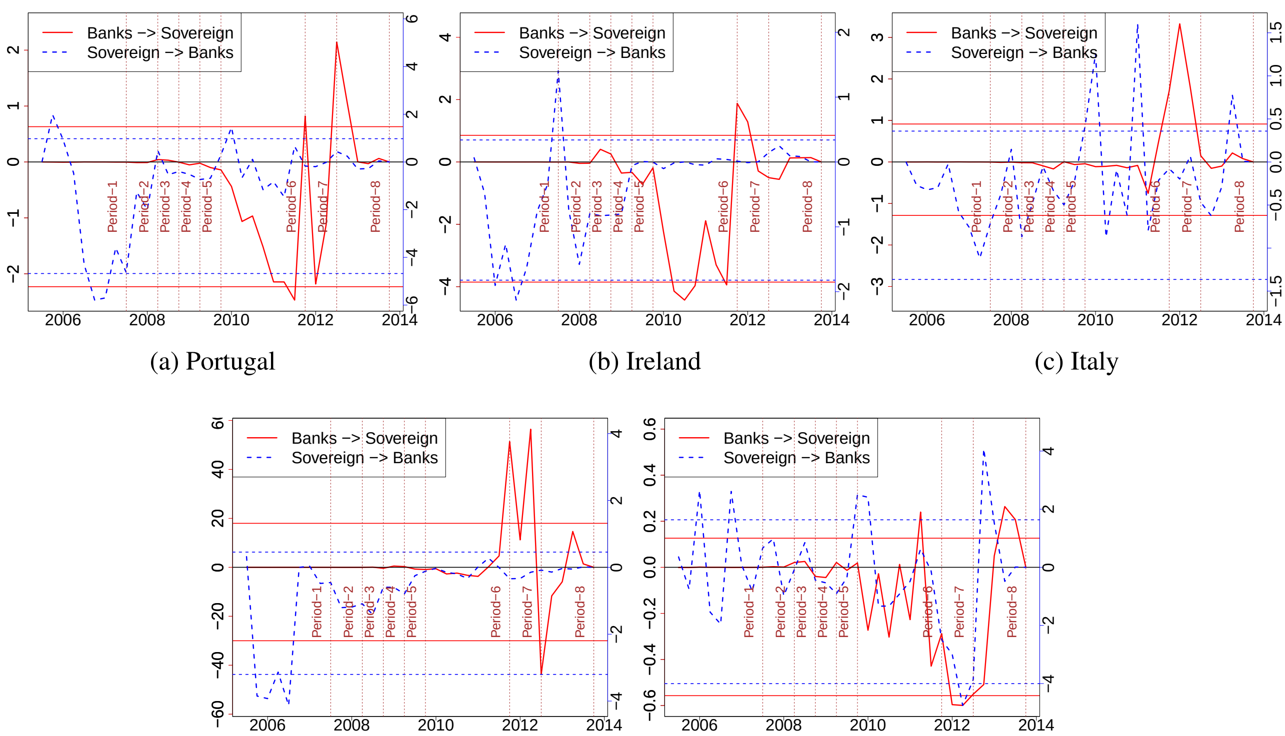
In Figures 3.3-3.4 we plot the evolution over time of the difference between FPE (m, 0) and FPE (m, n) statistics in each case. Therefore, these graphs provide us with a view of the dynamic bidirectional influence that exists between sovereign and banking risks for each EMU country and constitute our indicator of causality intensification based on time-varying Granger-causality analysis since it illustrates the changes in the directions and magnitudes over time. In Figure 3.3 we present the graphs corresponding to the five peripheral EMU countries included in the sample (Greece, Ireland, Italy, Portugal and Spain), whilst Figure 3.4 displays the graphs corresponding to the six central EMU countries in our sample (Austria, Belgium, Finland, France, Germany and the Netherlands).

Note that if the difference is positive and statistically significant at the 1% level in the case of, say, the banking to sovereign risk relationship, this indicates the

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

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

Figure 3.3: Time-varying causality between sovereign and banking risk in EMU peripheral countries, 2005:Q2-2013:Q3



(a) Portugal (b) Ireland (c) Italy

(d) Greece (e) Spain

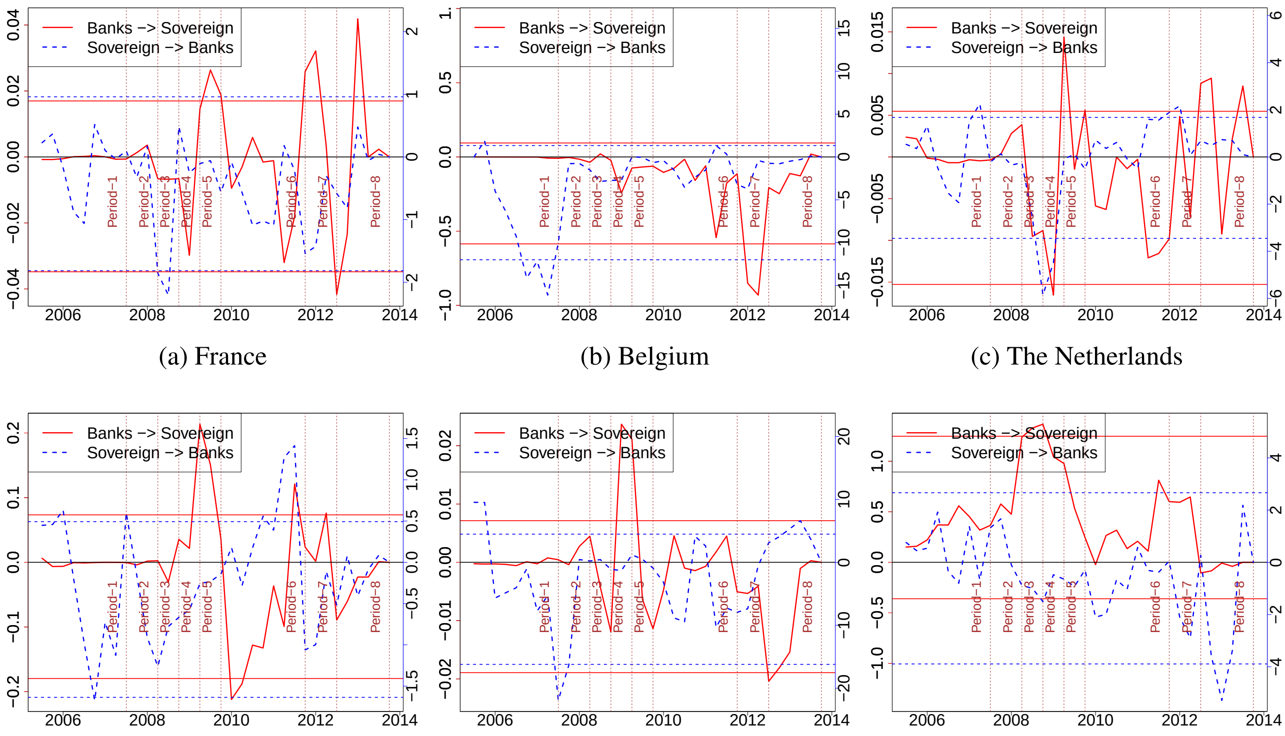
Note: We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past $aDtD$ series (Banks $\rightarrow$ Sovereign) and the differences between FPE obtained when estimating the $aDtD$ series using only the information contain in past $aDtD$ series and the FPE obtained using also the information contained in past sovereign spread series (Sovereign $\rightarrow$ Banks). We associate causality intensification from country banking risk towards sovereign risk with those episodes where the difference Banks $\rightarrow$ Sovereign (left axis) is positive and statistically significant at the 1% level, and causality intensification from sovereign risk towards country banking risk with those episodes where the difference Sovereign $\rightarrow$ Banks (right axis) is positive and statistically significant at the 1% level.

existence of a significant, transitory increase in the Granger-causality relationship running from country banking risk towards sovereign risk.

3.6 Results

In order to examine the time-varying behavior of causality between the two risks, we follow the Bank for International Settlements (2009), and divide the entire time

Figure 3.4: Time-varying causality between sovereign and banking risk in EMU core countries, 2005:Q2-2013:Q3



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

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

Note: We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past $aDtD$ series (Banks $\rightarrow$ Sovereign) and the differences between FPE obtained when estimating the $aDtD$ series using only the information contain in past $aDtD$ series and the FPE obtained using also the information contained in past sovereign spread series (Sovereign $\rightarrow$ Banks). We associate causality intensification from country banking risk towards sovereign risk with those episodes where the difference Banks $\rightarrow$ Sovereign (left axis) is positive and statistically significant at the 1% level, and causality intensification from sovereign risk towards country banking risk with those episodes where the difference Sovereign $\rightarrow$ Banks (right axis) is positive and statistically significant at the 1% level.

span (2005:Q2 to 2013:Q3)[17] into eight stages (stages 2 to 7 correspond to Bank for International Settlements (2009) stages 1 to 6). The first three stages before the Lehman collapse are considered as pre-crisis periods while the rest are classified as crisis periods. Table 3.1-3.2 reports the episodes of causality intensification, directionality and the involved countries.

We also search for episodes of causality intensification between banks and sovereigns

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

Table 3.1: Evolution of episodes of causality intensification: Pre-crisis period

Stages	Contagion	Direction	Peripheral	Central
First (2005:Q2-2007:Q2)	Yes	Sovereign to banks	Spain (2005:Q4) Spain (2006:Q3) Ireland (2007:Q2) Portugal (2005:Q3)	Austria (2005:Q4) Austria (2007:Q2) Belgium (2005:Q3) Finland (2005:Q2) Finland (2005:Q3) Netherlands (2007:Q1)
	No	Banks to sovereign	-	-
Second (2007:Q3-2008:Q1)	No	Sovereign to banks	-	-
	No	Banks to sovereign	-	-
Third (2008:Q2-2008:Q3)	No	Sovereign to banks	-	-
	Yes	Banks to sovereign	-	Germany (2008:Q2) Germany (2008:Q3)

using the important domestic banks in each individual country. For this purpose, we classified all banks into systemically important bank (SIB) and other national bank based on the list of global or domestic SIBs prepared by European Central Bank, Bank for International Settlements and Federal Reserve. Countries for which no SIB exist, we took the biggest bank in terms of total asset. Table 3.3 list the banks considered for this analysis while Figure 3.5 and 3.6 exhibit the time-varying causality between sovereign and SIBs risk in EMU peripheral and central countries, respectively and Table 3.4 present the detected episodes of causality intensification.

For the ease of understanding directionality with major market events, Figure 3.7 and 3.8 document the major crisis events for different EMU countries together with major policy actions coordinated at EU level. The interested reader may browse through Figures 3.7 and 3.8 to find evidence for particular countries or for concrete policy measures of her/his special interest and the respective detected causality intensification episodes in Tables 3.1, 3.2 and 3.4.[18]

[18]Note that, even though the results of the cointegration tests reject a long-run relationship between sovereign and banking risks for the countries under study, we do find evidence of causality intensification episodes between them, suggesting that each risk series contains useful information that is not present in the other which can help to explain the short-run evolution of the latter.

Table 3.2: Evolution of episodes of causality intensification: Crisis period

Stages	Contagion	Direction	Peripheral	Central
Fourth (2008:Q4 - 2009:Q1)	No	Sovereign to banks	-	-
	Yes	Banks to sovereigns	-	Austria (2009:Q1) Finland (2008:Q4) Finland (2009:Q1) Netherlands (2009:Q1)
Fifth (2009:Q2 - 2009:Q3)	Yes	Sovereign to banks	Spain (2009:Q3) Italy (2009:Q3)	-
	Yes	Banks to sovereigns	-	France (2009:Q2) France (2009:Q3) Netherlands (2009:Q3)
Sixth (2009:Q4 - 2011:Q3)	Yes	Sovereign to banks	Spain (2009:Q4) Italy (2009:Q4) Italy (2010:Q4) Portugal (2009:Q4)	Austria (2010:Q3) Austria (2011:Q1) Austria (2011:Q2) Belgium (2011:Q1) Finland (2010:Q3) Netherlands (2011:Q3)
	Yes	Banks to sovereigns	Spain (2011:Q1) Greece (2011:Q3) Ireland (2011:Q3) Italy (2011:Q3) Portugal (2011:Q3)	Austria (2011:Q2) France (2011:Q3)
Seventh (2011:Q4 - 2012:Q2)	Yes	Sovereign to banks	Spain (2012:Q2)	Netherlands (2011:Q4)
	Yes	Banks to sovereigns	Greece (2012:Q1) Ireland (2011:Q4) Italy (2011:Q4) Italy (2012:Q1) Portugal (2012:Q2)	Austria (2012:Q1) France (2011:Q4) Netherlands (2012:Q2)
Eighth (2012:Q3 - 2013:Q3)	Yes	Sovereign to banks	Italy (2013:Q1)	Finland (2012:Q4) Finland (2013:Q1)
	Yes	Banks to sovereigns	Spain (2013:Q1) Spain (2013:Q2) Portugal (2012:Q3)	France (2012:Q4) Netherlands (2012:Q3) Netherlands (2013:Q2)

3.6.1 Pre-crisis stages

The first stage, which ran from 2005:Q2 to 2007:Q2, was the period of relative stability before the beginning of the global financial crisis. The second stage began in

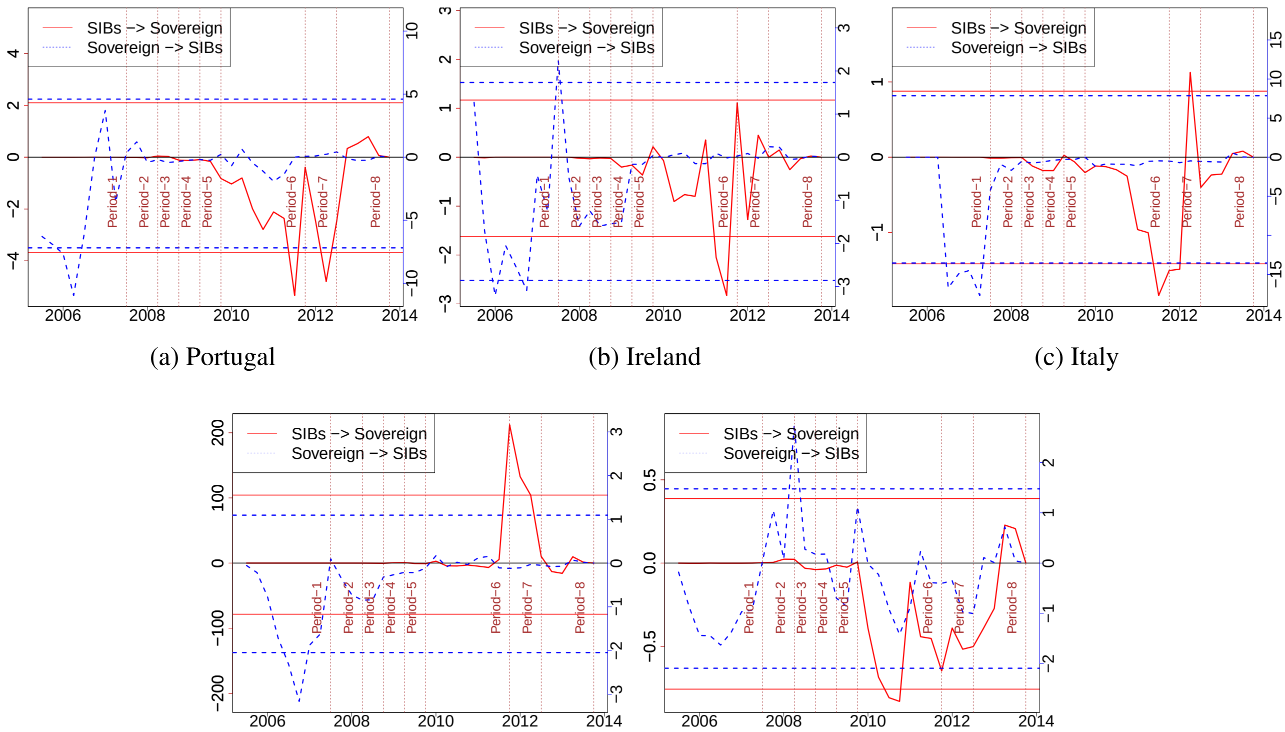
Table 3.3: List of SIBs in individual countries

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

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

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

Figure 3.5: Time-varying causality between sovereign and SIBs in EMU peripheral countries, 2005:Q2-2013:Q3



(a) Portugal (b) Ireland (c) Italy

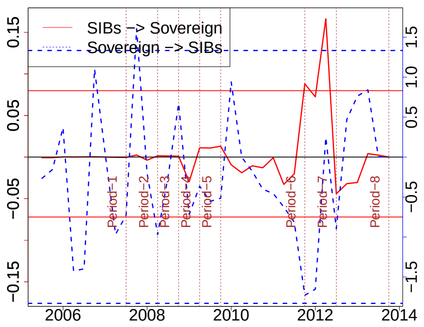
(d) Greece (e) Spain

Note: We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past DtDs series for SIBs (SIBs $\rightarrow$ Sovereign) and the differences between FPE obtained when estimating the $aDtD$ series for SIBs using only the information contain in past $aDtD$ series and the FPE obtained using also the information contained in past sovereign spread series (Sovereign $\rightarrow$ SIBs). We associate causality intensification from SIBs risk towards sovereign risk with those episodes where the difference SIBs $\rightarrow$ Sovereign (left axis) is positive and statistically significant at the 1% level, and causality intensification from sovereign risk towards SIBs risk with those episodes where the difference Sovereign $\rightarrow$ SIBs (right axis) is positive and statistically significant at the 1% level.

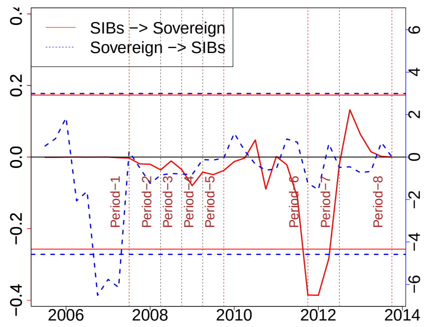
recession in the last quarter of 2008 when its GDP fell 2.1%).

Some important observations can be drawn from Figures 3.3-3.6 and Tables 3.1 and 3.4. Table 3.1 shows that during the first stage, before the financial crisis, causality intensification mainly took place from sovereigns to banks. We find evidence of at least one episode of causality intensification in this direction in seven out of the eleven cases studied, the exceptions being Greece, Italy, France and Germany. It is noticeable that these episodes are mainly concentrated in the second semester of 2005 and in the first semester of 2007, coinciding with a period of eco-

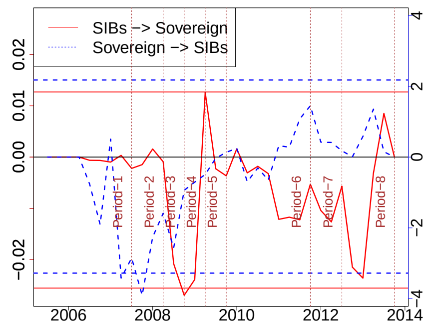
Figure 3.6: Time-varying causality between sovereign and SIBs in EMU core countries, 2005:Q2-2013:Q3



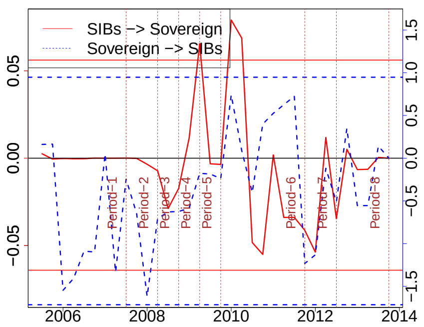
(a) France



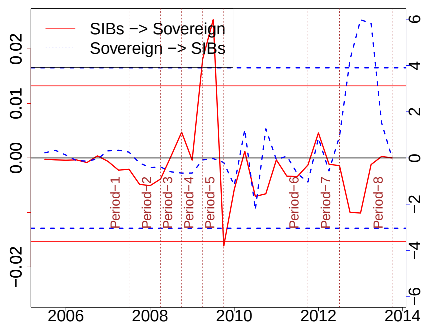
(b) Belgium



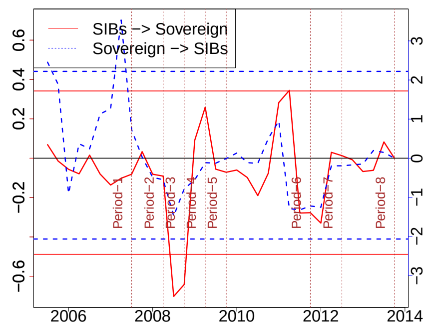
(c) The Netherlands



(d) Austria



(e) Finland



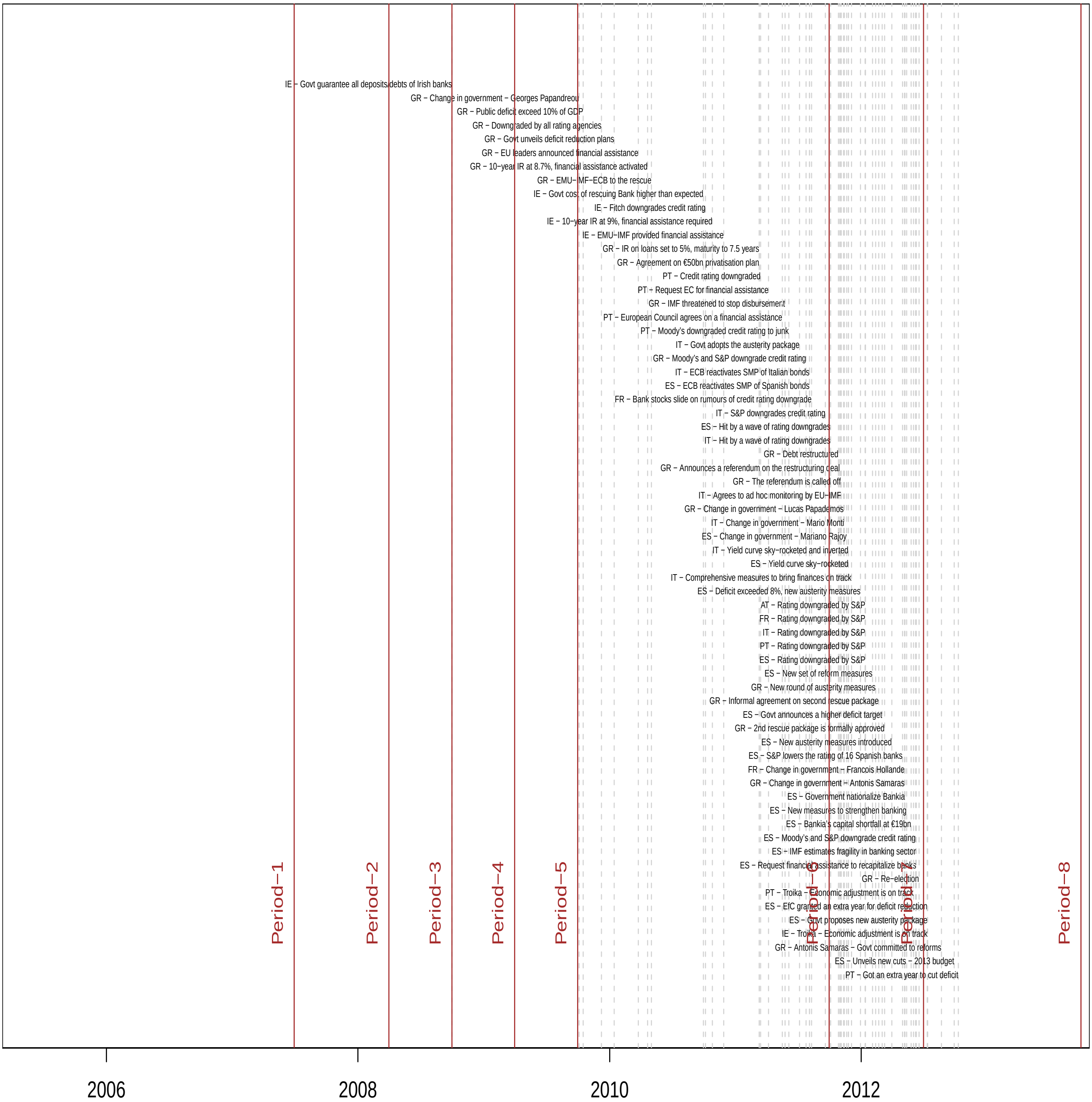
(f) Germany

Note: We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past $DtDs$ series for SIBs (SIBs $\rightarrow$ Sovereign) and the differences between FPE obtained when estimating the $aDtD$ series for SIBs using only the information contain in past $aDtD$ series and the FPE obtained using also the information contained in past sovereign spread series (Sovereign $\rightarrow$ SIBs). We associate causality intensification from SIBs risk towards sovereign risk with those episodes where the difference SIBs $\rightarrow$ Sovereign (left axis) is positive and statistically significant at the 1% level, and causality intensification from sovereign risk towards SIBs risk with those episodes where the difference Sovereign $\rightarrow$ SIBs (right axis) is positive and statistically significant at the 1% level.

nomic stagnation in EMU countries in the first case and with the beginning of a downturn in GDP growth from 2007 in the euro area, which after peaking in the last quarter of 2006 (3.7%) began to decrease until it reached negative values at the end of 2008.

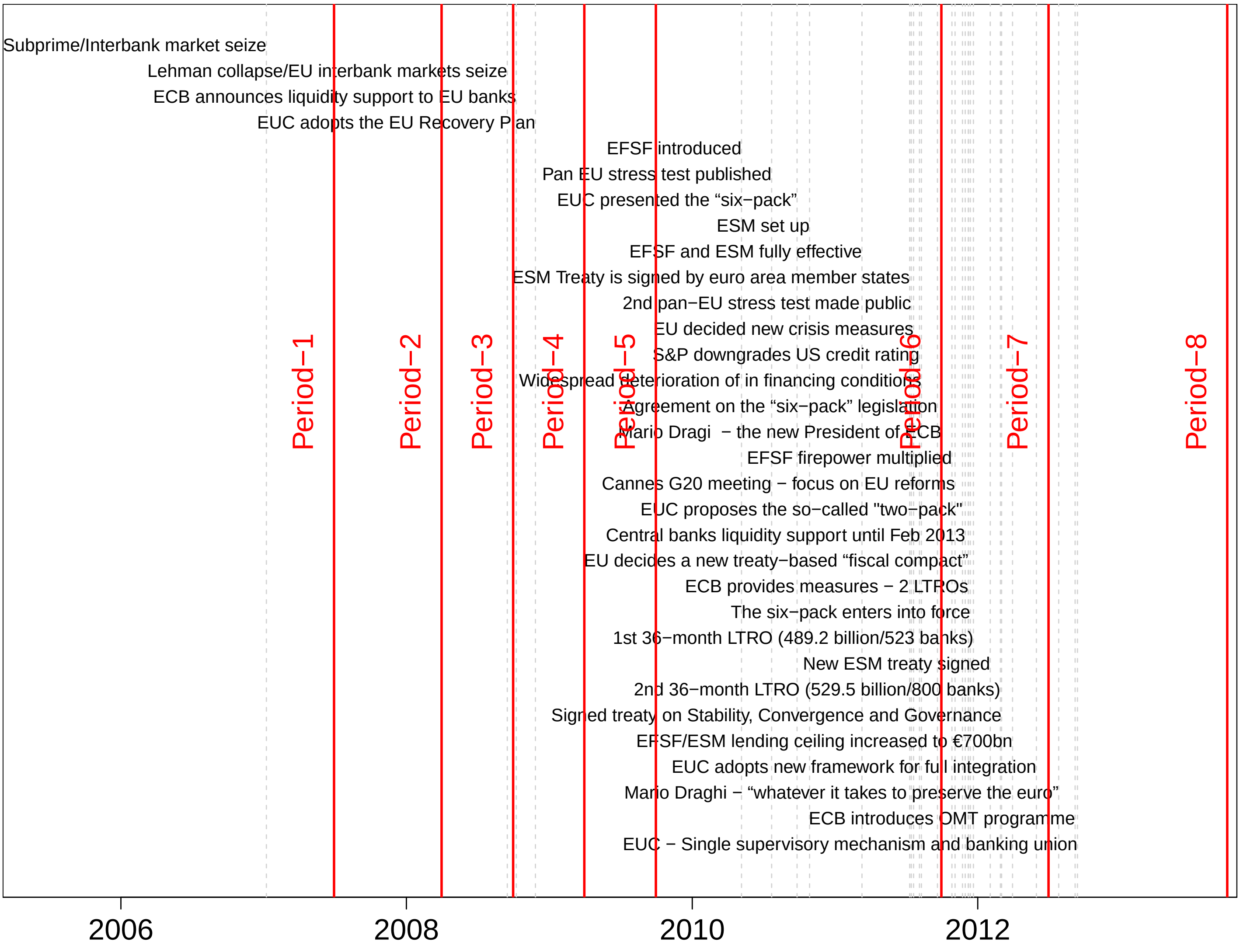
In stage 2 not a single contagion episode is detected while in stage 3, only two episodes of causality intensification, from banks to sovereigns though, are detected in Germany, confirming that the deterioration of Germany's banking system after the US subprime crisis resulted in a sovereign risk increase. When analyzing

Figure 3.7: Country wise major crisis events



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

Figure 3.8: Major policy actions at EU level



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

Table 3.4: Evolution of episodes of causality intensification between SIBs and sovereign risk.

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

causality intensification between SIBs and sovereigns risk before Lehman Collapse (Table 3.4), we do find episodes of contagion running from sovereigns to SIBs in two peripheral (Ireland and Spain) and two central countries (Germany and France).

3.6.2 Crisis stages

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

Following the collapse of Lehman Brothers, fears of losses in the European banks which were more exposed to US assets triggered episodes of causality intensification from banks to sovereigns, mostly in central EMU countries. Indeed, we detect episodes of causality intensification in this direction in Austria, Finland and the Netherlands (see Table 3.2) and as it is shown in Table 3.4, in the case of Austria and Finland, the causality intensification episodes might be triggered by their SIBs. These results might indicate that central EMU markets were hit more by the international financial crisis than peripheral markets. This finding is in accordance with the results presented in Table 3.5 indicating governments' commitments to supporting the banking system during the period October 2008-May 2010 and showing that in mid-2010 they were clearly higher in central than in peripheral countries (with the exception of Ireland). In particular, the government commitment to bail out banks in the three countries above mentioned was between 29% and 52% of their GDP at the end of 2008.

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

Table 3.5: Government support measures for financial institutions (October 2008-May 2010)

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

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

The group of countries which intervened at the earliest stages of the crisis by taking bulk of the losses associated with bailout (i.e. Austria, Germany and Ireland) or choose to nationalize banks (e.g., Belgium) saw a sharp reduction in the direction of risk transfer from banks to sovereign. However, Spain whose economy observed a serious slump (Spanish GDP fell 4.0% and 2.6%, in 2009:Q3 and 2009:Q4 respectively) jointly with Italy saw a sudden rise in risk transfers from sovereign on banks (Table 3.2). There may also have been some pressure from governments on banks within their jurisdiction to buy their domestic debt. Indeed, at the end of 2011, the home share of all Spanish and Italian banks' sovereign exposure was 81% and 50%, respectively. This may have broadened concerns about their exposure to bad assets and may have fed speculation about their solvency. As a further step, it might be interesting to fully analyze the econometric link between the timing and level of government guarantees and the occurrences of events impacting the financial needs of the economy. Besides, episodes of causality intensification from banks to sovereigns in this stage were detected in only three central countries. France and the Netherlands if we use the average banking risk indicator for the whole country (Table 3.2) and Finland when using the risk indicator corresponding to its SIBs (Table 3.4).

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

It is noticeable that during this period, in which concerns about European sovereign debt crisis transmission were at their peak and rescue packages were put in place, Table 3.2 shows that episodes of causality intensification from sovereigns to banks started rising gradually in most peripheral and central countries. Episodes of causality intensification from banks to sovereigns were identified in all peripheral and two central countries (Austria and France). These findings suggest the following ideas: (1) In Portugal and Italy, causality intensification from the sovereign to the banking sector can be easily understood, since the main source of vulnerability in those countries was concentrated in the public sector itself. Moreover, Portuguese and

Italian banks held the equivalent of 23% and 21% of their countries' GDP in the form of domestic bonds which, as we stated above, might have fed speculation regarding their solvency; (2) The sudden drop in investor confidence induced fears of contagion in all euro area countries and led to 'flight-to-safety' investments, which increased the demand for the German bund and also caused a sharp rise in yield spreads of EMU central countries. This increase in risk in the sovereign sector may have been transmitted to their banking sectors;[19] (3) Not only in Ireland (where banks' debt-to-GDP was close to 450% at the end of 2012), but also in Portugal, Spain, Italy and Greece the high leverage registered in the banking sector (194%, 150%, 110% and 100% of their GDP respectively, at the end of 2012) may have increased tensions in their already vulnerable and distressed public sector. Moreover, when looking at Table 3.4, we detect episodes of risk transfer from SIBs to sovereigns in Greece, Austria and France. It must be noticed that the episodes detected in 2011:Q3 in Greece and France are also detected when analyzing causality running from the average bank risk indicator for the whole country.

Stage 7: The seventh stage of the crisis, which began in 2011:Q4 when Mario Dragi replaced Jean-Claude Trichet as President of the European Central Bank and ended in 2012:Q2, was still a period of high turmoil in European markets. Italy was in the middle of a political crisis and the main rating agencies lowered the ratings not only of peripheral countries, but also of Austria and France. In this context of financial distress and huge liquidity problems, the European Central Bank responded forcefully by implementing (along with other central banks) nonstandard monetary policies, i.e., policies beyond setting the refinancing rate. In particular, the ECB's principal means of intervention were the so-called long term refinancing operations (LTRO). In November 2011 and March 2012, the ECB allotted to banks an amount close to 500 billion Euros for a three-year period. However, in March 2012 the second rescue package to Greece was approved and in June 2012 Spain requested financial assistance to recapitalizes its banking sector.

During the seventh stage, coinciding with the nonstandard monetary policies implemented by the ECB (two LTRO) to support the banking system, episodes of causality intensification from banks to sovereigns (see Table 3.2) were found mainly in peripheral countries (Greece, Ireland, Italy and Portugal). Recall that in spring 2011, the three program countries (Greece, Ireland and Portugal) made up more

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

than 50% of total liquidity provided through both the main refinancing operations (MRO) and the LTRO windows - although some episodes were also detected in this direction in Austria, France and the Netherlands. These results are reinforced in the analysis presented in Table 3.4.

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

Stage 8: Finally, the last stage of the crisis began in 2012:Q3 after Mario Draghi's statement on July 26 that '*within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough*,' which had a healing effect on markets, and finished at the end of the sample period in 2013:Q3. It is important to remark that after July's statement, on September 6 the ECB introduced the Outright Monetary Transactions (OMT) program. The program had two key elements. First, under the OMT, the ECB could purchase government bonds of a given country, focusing on maturities between 1 and 3 years, and with no ex-ante quantitative limits. Second, a country had to apply for the OMT in which case it would also have to undertake a set of fiscal adjustments. That is, the program involved conditionality. The ECB action implied an important reduction of redenomination risk. Therefore, as some authors have pointed out (see Angelini et al. (2014)), commitments by the ECB or the government to never redenominate, such as the OMT, have proved to be effective. Indeed, Angelini et al. (2014) present empirical evidence that suggest that OMT announcements decreased bond yields in peripheral countries. In this context, despite the healing effects of Mario Draghi's words and OMT announcements on financial markets, some episodes of causality intensification were still found from sovereigns to banks in Italy and Finland (in the latter country, their SIBs were the main recipients of the risk, see Table 3.4) and from banks to sovereigns (Portugal, Spain, France and the Netherlands). We should keep in mind that, although turbulence in financial markets fell sharply, the economic recession entered its second dip during this period. Thus, as Shambaugh (2012) mentioned, not only did the problems of weak banks and high sovereign debt reinforce each other, but were both exacerbated by weak economic growth.

3.6.3 Pre-crisis vs crisis period: In comparison

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

Germany represents an exception since we find two episodes of contagion from bank to sovereigns in the first sub-period, at the end of stage 3 (2008:Q2 and 2008:Q3), while not a single contagion episode is detected in any other stage or direction. In our opinion, the immunity of German bunds to the weakness of German banking sector might be explained by the specific form of its government interventions to bailout financial institutions or the stability of German government revenues (see Eschenbach and Schuknecht (2002)). In addition, it is important to keep in mind that the sudden drop in investor confidence that followed the crisis led to 'flight-to-safety' investments, increasing the demand for the German bund in times of distress. These results are corroborated when analyzing causality intensification between SIBs and sovereign risk in each of the eleven countries in the sample. In the pre-crisis period (stages 1 to 3) all the detected episodes run from sovereigns to SIBs; whilst in the crisis period (stages 4 to 8) 77% of the total detected episodes of causality intensification run from SIBs to sovereigns.

3.7 Concluding remarks

Based on our selection of bank and sovereign risk indicators at country level in eleven of the countries that have belonged to the EMU since its inception (only Luxembourg is excluded from the analysis), we applied a dynamic approach to testing for sudden and transitory increases in Granger-causality linkages to investigate the possible existence of causality intensification. Our direct analysis of the data allowed us to detect, trace and quantify the directional linkages. To contextualize the empirical results, we followed the Bank for International Settlements (2009) and divide the entire time span (2005:Q2 to 2013:Q3) into eight stages.

In the first three stages, from early 2005 until the collapse of Lehman Brothers, more than 77% of the total episodes of causality intensification detected were from sovereigns to banks, corresponding with a period of economic stagnation in EMU countries or with the beginning of a downturn in GDP growth in the euro area. After the last quarter of 2008, coinciding with the beginning of the financial crisis and the implementation of government measures to support financial institutions, the direction of the causality intensification underwent a change. In this second sub-period (stages four to eight), the majority of the episodes (around 63% of the total) ran from banks to sovereigns, notable cases being France, Greece, Ireland (only episodes of causality intensification in this direction were detected), Portugal and the Netherlands (where they account for more than 70% of the episodes). These results reinforces the idea that banks were the source of market turbulence, possibly reflecting the substantial government measures adopted at that time to support the domestic banking sectors that in turn adversely affected the fiscal position of sovereigns. Conversely, in Belgium and Finland causality intensification was mainly from sovereigns to banks, indicating that banks suffered from the deteriorating values of their sovereign bond holdings as well as higher funding costs. Finally, for Spain, Italy and Austria, we detected similar numbers of episodes of causality intensification in both directions, pointing to an adverse feedback loop between sovereigns and banks with shocks propagating from one to each other. These results are validated when analyzing causality intensification between SIBs and sovereign risk in each of the eleven countries in the sample, although only 16% of the detected episodes of contagion between banking and sovereign risk corresponds to SIBs. These findings might suggest that most of the risk transfer episodes are not related with SIBs and the strong emphasis placed on SIBs for detecting and monitoring systemic risk and financial system stability should be carefully reassessed.

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

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

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4 Incorporating creditors' seniority into contingent claim models: Application to peripheral euro area countries

SUMMARY

This paper highlights the role of multilateral creditors (i.e., the ECB, IMF, ESM etc.) and their preferred creditor status in explaining the sovereign default risk of peripheral euro area (EA) countries. Incorporating lessons from 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 EA countries in severe crisis episodes. This new priority structure of creditors, together with the contingent claims methodology, is then used to derive a set of sovereign credit risk indicators. In particular, the sovereign distance-to-default indicator, proposed in this paper (which includes both accounting metrics and market-based measures) aims to isolate sovereign credit risk by using information from the public sector balance sheets to build it up. Analysing and comparing it with traditional market-based measures of sovereign risk suggests that the measurement and predictive ability of credit risk measures can be vastly improved if we account for the changing composition of sovereigns' balance sheet risk based on creditors' seniority.

Keywords: Sovereign default risk, peripheral euro area countries, contingent claims, distance-to-default
JEL Code: E62, H3, C11

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4.1 Introduction

The global financial crisis, which began in the US in 2007, and the subsequent European sovereign debt crises of late 2009 have increased the need to understand and measure the sovereign credit risk of euro area (EA) countries. Understanding the nature of this risk is of paramount importance given the ever increasing size of the public debt in EA. However, empirical researchers find it difficult to reconcile the evolution of traditional market-based measures of sovereign risk in EA countries with their economic fundamentals (see De Grauwe (2012), De Grauwe and Ji (2013), Favero and Missale (2012), Aizenman et al. (2013), Beirne and Fratzscher (2013), among others). Also relevant is the feature unique to the EA according to which, unlike emerging countries or other developed economies, individual EA countries have no control over the currency in which their debt is denominated. This loss of control over their own currency and increased dependence on a common central bank (the European Central Bank (ECB)) makes countries fragile and vulnerable to changing market sentiments (see De Grauwe (2012)).

In this paper, we show that, if properly accounted for, an important element - the total debt held by multilateral creditors[1]- can reconcile some of the differences and improve the effectiveness of sovereign risk measures. Given the nature of the rescue and bail-out strategies, more and more debt is concentrating in the hands of multilateral institutions that are likely to have 'senior status'[2] in case of insolvency. To incorporate this, we propose a modified contingent claims model that takes into account the creditors' seniority, as observed in the sovereign debt restructuring of the past and integrates the lessons learned from the recent Greek debt restructuring, in order to derive a new set of sovereign credit risk indicators.

Why another sovereign credit risk indicator? Sovereign credit risk indicators are measures of governments' ability to repay their debt. In the context of EA, which has recently faced a fierce sovereign debt crisis, the choice of the optimal indicator is crucial. The amount of credit risk measured by these indicators may directly affect the behaviour of financial market participants when diversifying the risk of their global debt portfolios and may have major implications on financial stability. Moreover, they have a key role in determining the financing costs of the public sector since higher perceived risk implies higher long-term domestic interest rates, which in turn increase debt servicing costs and future government deficits.

Yet, according to the empirical literature, the traditional market-based sovereign

[1] The ECB, the European Financial Stability Facility (EFSF), the European Stability Mechanism (ESM), the International Monetary Fund (IMF), the European Investment Bank (EIB), etc.

[2] 'Senior status' means that the preferred lender is the first to recover its money in case of insolvency. The subordinated creditor, or junior creditor, on the other hand, receives only what is left after senior claim holders have been repaid

credit risk indicators (sovereign yield spreads, credit default swap (CDS) spreads and credit ratings) in times of crisis are mainly driven by factors other than the fiscal stance (see Fontana and Scheicher (2016)). The most commonly used measures of sovereign credit risk are CDS contracts. However, CDS contracts that reference sovereign bonds are only a small part of the sovereign debt market in EA ($3 trillion notional sovereign CDS outstanding at end-June 2012, compared with $50 trillion of government debt outstanding at end-2011: International Monetary Fund (2013)). Moreover, these contracts are thinly traded and for most countries their market price data has only been reliable since end 2007. The data on sovereign yield spreads and CDS are also prone to political interference; for example, in the recent European sovereign debt crisis, the authorities banned naked/uncovered purchases of sovereign CDS based on EA countries (International Monetary Fund (2013)). For some countries, the ECB provided price support to sovereign bonds in both primary and secondary markets. This aggravates the issue of liquidity and relevance. Thus, CDS and yield spreads are no longer indicative of what investors think about the credit risk but reflect more a mix of default risk expectations and forecasts of rescue measures. This is yet another instance of Goodhart's Law - 'a variable that becomes a policy target soon loses its reliability as an objective indicator' (Goodhart (1975a), Goodhart (1975b)). Studies examining the determinants of credit rating also suggest the pro-cyclical nature of credit ratings and their inadequate treatment of the domestic fiscal stance (see Soudis (2016)).

Moreover, since most sovereign debt contracts offer no explicit seniority to particular groups of creditors, the sovereign credit risk measures do not differentiate between the bond holdings of multilateral creditors (like the ECB, IMF, ESM, etc.) to those of a private investor. However, in a survey analysis, Steinkamp and Westermann (2014) showed that almost 90% of the market participants expect at least one of the multilateral' creditors holding to be senior to private investors. These authors also document the reactions of rating agencies, which justified their downgrades explicitly pointing to the seniority issue. The Greek debt restructuring in 2012 also validated this differentiation in which 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)). This trancheing of the sovereign default risk for creditors based on their seniority pushes the credit risk measures gradually towards the riskiness of junior claim holders.

Against this background, this chapter presents a new framework to measure and analyse sovereign credit risk in currency union countries using the structural model of Merton (1974), which was extended towards sovereign credit risk by Gapen et al. (2005). We exploit the observed market prices and market participants behaviour in sovereign debt restructuring, to build a credit risk indicator that incorporates this in credit risk measurement. Therefore, the main purpose of this paper, is to show how modern contingent claims analysis (CCA) can be modified and used to measure and analyse risk stemming from the public sector balance sheet, allowing the calculation of an indicator that measures sovereigns' distance-to-default (DtD). Estimating risk using an approach of this kind has a long tradition in modern financial theory but has only been applied to gauge sovereign risk in the case of emerging countries.

Why CCA? Taking stock of the rapid advances in the growing literature on measuring sovereign credit risk, our own assessment is that CCA offers the best possibility for incorporating the seniority structure of creditors in an already existing theoretical model. It is a theory grounded, market-based approach to analyse and measure the credit risk of a legal entity (firm or sovereign). The basic approach rests on the generalization of the option pricing theory pioneered by Black and Scholes (1973) and Merton (1974). The principle underlying the model is that if the liabilities of a legal entity have different priority (e.g., senior and junior), then the junior claims can be modelled as a call option on the asset value of the legal entity with senior claims as the strike price. The idea also gives legitimacy to current bankruptcy proceedings, in which the bankrupt entity formally surrenders its assets to its creditors and sale proceedings are divided among creditors based on the priority structure of liabilities.

CCA methodology is commonly called the "Merton Model." It was first adapted and utilized commercially by the KMV Corporation (Crosbie and Bohn (2003)) and is now firmly established as the theoretical basis for several applied models that are used to measure and evaluate credit risk for firms and emerging market sovereigns (see Bharath and Shumway (2008), European Central Bank (2012), Saldias (2013), Gray and Jobst (2010), Gray et al. (2010), Gray and Malone (2008), Gray et al. (2007), Gray and Walsh (2008), Harada and Ito (2008) and Harada et al. (2010)).

This paper is an extension of the existing CCA - based methodology for countries which are members of a monetary union (EA) and lack the ability to inflate away its debt in a distressed situation. To the best of our knowledge, this is the first paper to examine the application of CCA - based methodology for monetary union countries, and describes in detail a novel framework for measuring the sovereign credit risk. Based on creditors' seniority, we define a unique priority structure of debt holders and incorporate it into the theoretical model to calculate the credit risk for peripheral EA countries. Furthermore, this paper also contributes to the existing literature by comparing the proposed indicator with the traditional vulnerability indicators.

Our results suggest that the addition of this idiosyncratic component for individual sovereigns which is primarily linked to the sectoral distribution of their creditors, especially the debt held by multilateral creditors increases the information content of the sovereign credit risk measure. As most sovereign debt contracts offer no explicit seniority to a particular group of creditors, the existing sovereign risk measures increasingly reflect the risk for the junior claim holders and create a bias in all market-based credit risk measures. Once corrected, the new risk indicators are less correlated across countries, than the traditional market-based credit risk indicators (i.e., CDS spreads, sovereign yield spreads and credit ratings). Even though they share a highly correlated underlying factor linked to global risk and uncertainty, their weight diminishes in times of crisis. They also show better predictive ability and causal linkages with other sovereign risk measures.

The paper is organized as follows. Section 4.2 provides a review of the empirical literature on the main drivers of the traditional sovereign credit risk indicators. In Section 4.3, we give a conceptual overview of the Merton model, with an explanation of the basic features of the quantitative model. This is followed by a discussion of the challenges facing the direct application of this model to the EA setting. We then show how this model can be modified and used to quantify the credit risk for EA countries. Section 4.5 enumerates the databases used and the practical considerations in sovereign credit risk calculations. In section 4.6, we illustrate the application of our modified model to the actual data of EA countries, namely Greece, Ireland, Italy, Portugal, and Spain for the period 2000-2016. Section 4.7 explores in details the actual and potential implications of this framework for sovereign credit risk management. Finally, Section 4.8 offers some concluding remarks.

4.2 Literature review on traditional sovereign credit risk measures

The sovereign debt crisis in Europe, which began in late 2009, revived the literature on EA sovereign yield spread drivers and has attributed increasing importance to uncertainty and variables reflecting investment confidence and perceptions for the upcoming economic activity (see, among others, Georgoutsos and Migiakis (2013) or Beirne and Fratzscher (2013)). Many authors have also stressed the importance of other fundamental variables beyond the country's fiscal position to explain yield spread behaviour after the outbreak of the crisis (Allen et al. (2011) or Acharya et al. (2014), to name a few). In particular, Gomez-Puig et al. (2014) empirically investigate the determinants of EA sovereign bond yield spreads with respect to the German bund from January 1999 to December 2012, using panel data techniques and examining the role of a very exhaustive set of potential drivers. Their results stress that the rise in sovereign risk during the crisis can only partially be explained by the evolution of local macroeconomic variables. Specifically, they find that the relevance of the variables that measure global market sentiment increased during the crisis, especially in peripheral EA countries. These results have been corroborated by many other authors. Aristei and Martelli (2014), who also investigate sovereign spreads drivers in ten EA countries during the 2000-2012 period, show that proxies of consumer and market sentiment and expectations strongly affect spreads behaviour, especially during the crisis. Silvapulle et al. (2016), whose analysis focuses on peripheral EA countries during the 1999-2013 period, find that market sentiment variables (the stock returns or the VIX index, among them) had a significant impact on bond yield spreads in the crisis period. Boysen-Hogrefe (2017) argue that, since the announcement of the outright monetary transactions program (OMT), the debt-to-GDP ratio has become less relevant as a determinant for government bond spreads, while financial markets have become more concerned about the willingness and capability to cooperate with the institutions that conduct the adjustment programs. Finally, the analysis of Paniagua et al. (2017) also provides empirical evidence suggesting that not only fiscal indebtedness, but also a shift in global risk aversion and the worsening of other fundamentals, have played a significant role in explaining the evolution of long term spreads in peripheral EA countries.

The nature of sovereign credit risk using CDS data has been studied by Longstaff et al. (2011) for a sample of 26 developed and emerging countries during the 2000-2010 period by conducting a principal component analysis of the changes in sovereign CDS. Their results show that sovereign credit risk measured by CDS spreads tends present much higher correlations across countries than equity index returns for the same countries, due to the dependence of sovereign credit spreads on a common set of global market factors. Specifically, they find that a single principal component accounts for 64% of the variation in sovereign credit spreads. Badaoui et al. (2013) also try to isolate default risk from the sovereign risk premium in a sample of emerging market countries during the period 2005-2010; their decomposition exercise puts forward the idea that the increase in CDS spreads observed during the crisis period was mainly due to a surge in liquidity rather than to an increase in the default intensity. Broto and Perez-Quiros (2015), who analyse the sovereign CDS spreads of ten OECD countries with a dynamic factor model, conclude that although the CDS premium contains highly relevant information on sovereign risk, it must be previously corrected by the portion of the premium related to overall risk aversion and qualified by the contagion effects that may be present in it. Blommestein and Qia (2016) also find that contagion from the global financial market is an important factor affecting the pricing of CDS spreads in their sample of peripheral EA countries. Another interesting result is that, in contrast to previous studies which focused on pre-crisis periods, Blommestein and Qia (2016) find that domestic and economic financial developments have little impact on sovereign credit risk in Greece, Ireland, Portugal and Spain during the crisis. The causality is in fact the other way round:

sovereign credit risk significantly affects domestic economic and financial developments in crisis times. Fabozzi and Tsu (2016) introduce a novel technique of factor decomposition (independent component analysis) to investigate the behaviour of EA sovereign CDS spreads during the debt crisis. Their results identify three important factors: the risk associated with the peripheral countries, the global risk, and the EA common risk. They also show how the main source of risk changes over time: in 2009, it was the global factor, in 2010 the peripheral factor, and finally in 2012 the EA common factor. Finally, Aizenman et al. (2013) and Rubia et al. (2016) agree that if sovereign CDS spreads are wrongly assumed to solely reflect default risk, the severity of the underlying market conditions may be substantially overestimated, particularly during periods of distress. Specifically, according to Rubia et al. (2016) the case of peripheral EA countries in the midst of the debt crisis might illustrate this point accurately, since sovereign CDS contracts were traded at prices that were too high to reflect solely the credit default risk premium.

Finally, credit rating agencies (CRA) have played a prominent role in the recent financial crisis. They assign a credit rating to sovereign and private sector borrowers which indicates the probability of their failing to fulfil their obligations in their debt issues. Specifically, understanding the dynamics of sovereign credit ratings is highly relevant given their implications for capital flows and their strong link with private ratings. Despite their importance, the CRA do not provide enough detail about the ratings' determinants or their rating procedures (Mora (2006)), in spite of some recent regulatory initiatives to improve transparency. Some empirical literature has examined the main determinants of ratings and most papers state that CRA do not adjust adequately to domestic indicators. For instance, Soudis (2016), who applies the extreme bounds analysis technique to approximately 30 factors proposed by the literature as determinants of the ratings, finds that variables such as rule of law, openness to economic flows, central bank independence, and market-friendly policies are more robustly correlated with the ratings than foreign reserves, fiscal deficit, sovereign bond yields, and economic growth. Likewise, Boumparis and Panagiotidis (2017), who examine ratings determinants for EA countries during the 2002-2015 period, find that economic policy uncertainty impacts negatively on credit rating, especially in the lower rated countries. In other words, the creditworthiness of low rated countries takes a much bigger 'hit' than that of high rated countries when uncertainty rises. Other authors conclude that there is a certain amount of lag in the agencies' response to domestic variables and the debate revolves around the procyclical or sticky nature of ratings. Some authors (Ferri et al. (1999) and Monfort (2000), among them) point out that ratings are procyclical, meaning that in downgrade phases CRA are oversensitive to fundamentals and this, in turn, contributes to exacerbating the existing crisis. Other authors, such as Mora (2006) state that ratings are sticky rather than procyclical (they are adjusted only when there is a sufficiently large divergence between predicted and assigned ratings). More recently, Broto and Molina (2016) present mixed conclusions, as the reaction of the agency to macroeconomic developments differs during downgrade and upgrade periods: downgrade phases would have a procyclical nature, with a certain amount of lag, whereas upgrade periods would tend to be sticky.

All in all, the existing empirical literature on the determinants of traditional sovereign credit risk measures (bond yield spreads, CDS and ratings) suggests that those indicators are driven by factors other than the fiscal position, especially in times of crisis. In other words, since they are market based indicators and do not solely reflect default risk, they may substantially overestimate the difficulties of governments in repaying their debt, especially in periods of distress. In this context, the sovereign DtD indicator proposed in this paper - which includes both accounting metrics and market-based measures - aims to isolate sovereign credit risk by using information from the public sector balance sheets to build it up.

4.3 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.[3] 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

[3] 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.

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), Saldias (2013), Gray and Jobst (2010), Gray et al. (2010), Gray and Malone (2008), Gray and Walsh (2008)). For a detailed presentation, please refer to Gray et al. (2007).

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. 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 (see Chapter 2).

$$Distance-to-default\ (DtD(t)) = \frac{A(t)-S}{A(t)\sigma_A(t)} \tag{4.1}$$

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.

$$DtD^{RA}(t) = \frac{log(\frac{A(t)}{S}) + (r - 0.5\sigma_A^2)(T-t)}{\sigma_A\sqrt{T-t}} \tag{4.2}$$

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,

$$PD(t) = P[A(t) \leq D] = \Phi(-DtD^{RA}(t)) \tag{4.3}$$

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 4.1.

4.3.1 Application of CCA balance-sheet approach for firms

A firm is an economic organization in which a team of people coordinates their skills in order to produce goods and services. The typical liability structure of a firm has two basic components. The first is 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 firm 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 firm will be treated in a restructuring process and establishes the order of payment in the event of outright liquidation. These rules tell a firm'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. If the firm is publicly traded then CCA can use their debt and equity price data to derive a set of credit risk indicators.

However, in practice, the application of CCA for a firm is quite challenging. A firm's liability structure usually involves debt and equities of many different kinds with different priorities. 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 distress barrier (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 corporate credit risk measurement, the distress barrier is calculated as the sum of short-term debt, interest payments due within a year, and 50% of the long-term debt (see Singh et al. (2015)).

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.

4.3.2 Application of CCA balance-sheet approach for emerging market sovereigns

In order to apply the CCA for emerging countries, we must first understand the liability structure of the emerging market sovereigns. For the systematic presentation, Table 4.1 shows a simplified version of the sovereign accounting balance sheet.[4] On the asset side, *Foreign reserves* measure the net international reserves of the public sector. *Net fiscal asset* is the present value of the primary fiscal surplus over time (the present value of fiscal surplus minus interest payments) while *Other public assets* include the government's equity in public enterprises.

On the liability side, *Base money* is a liability of the monetary authorities and consists of the total currency in circulation and bank reserves (required bank reserves, excess reserves, vault cash). *Local-currency debt* of the government and monetary authorities are the total government-issued debt held outside the monetary authorities and the government. *Foreign-currency debt* is the part of the sovereign debt which is denominated in foreign currency. It is usually held by foreigners. *Guarantees* compose the implicit or explicit financial guarantees provided by the government to banks, financial institutions or contingent pension/social obligations.

Table 4.1: Accounting balance sheet for the sovereign (combined government and monetary authorities)

Assets	**Liabilities**
- Foreign reserves	- Base money
- Net fiscal assets	- Local currency debt
- Other public assets	- Foreign currency debt
	- Guarantee

CCA ignores the asset side of the balance sheet and works only with the liability side. It circumvents the problems of assessing the market value of all sovereign assets by estimating sovereign asset value and volatility indirectly with information on observable values of the liability side of the balance sheet.[5] Since liabilities

[4] This section borrows heavily from Gray et al. (2007).

[5] The problem can also be approached from the asset side of the sovereign balance sheet. *Foreign reserves* can be directly measured. For the *Net fiscal assets*, a reasonable value can be estimated by discounting all future expected cash flow (such as primary surplus) with an appropriate discount rate. *Other public assets* value can be determined from the observed market prices of all or part of the assets. This can be a market price quote, direct observation, bid-ask quote or other similar direct measures. In the case of illiquid securities for which no direct market price is available, a

are claims on current and future assets, this approach yields an 'implied' estimate for a sovereign's assets - value and volatility. The collective view of many market participants is incorporated in the observable market prices of liabilities, and the change in the market price of these liabilities determines the volatility.[6]

The sovereign balance sheet has two liabilities (foreign and local currency debt) whose value can be derived from sovereign assets and can be valued as contingent claims. However, seniority is not defined by legal status, as in the case of corporate liabilities, and must be inferred from observed government behaviour The emerging countries debt default and restructuring experiences of the last four decades suggest that governments often make strenuous efforts to remain current on their foreign-currency debt. These efforts effectively make foreign currency debt senior to domestic currency debt when governments show flexibility in issuing, repurchasing, and restructuring (see Eichengreen et al. (2002) and Sims (1999)).[7]

Thus, sovereign local currency debt can be modelled as an implicit call option on a sovereign's asset value. The market value of local currency debt and its price volatility is then used to derive the implied market value and volatility of sovereign assets. While the promised payments, or distress barrier, are known with a fair degree of certainty over a time horizon based on the maturity profile of foreign currency debt, the literature defines the "distress barrier" as the present value of the promised payments on foreign-currency debt (see Gray et al. (2007)). Sovereign distress occurs when the sovereign assets are insufficient to cover the promised payments on the foreign-currency debt.

Note that the probability of sovereign distress is higher when a bigger fraction of debt is denominated in a foreign currency, or when most of the foreign currency

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comparable or adjustable comparable security can be used as a proxy. Different expected future scenarios can then be generated to gauge the individual asset volatility (a procedure very similar to Debt Sustainability Analysis used by World Bank and IMF). The sovereign asset volatility can then be computed by aggregating the volatility of the individual assets using a weighting function.

The method looks straightforward but in fact is very difficult to apply. The tradable financial assets have direct or comparable observable market prices, but the implicit assets are extremely difficult to measure as this requires projecting the future cash flows, deciding the appropriate discount rate, and determining all the relevant components that underlie the cash flow projections for tangible and intangible items included in the asset value estimation. For example, determining the present value of the net fiscal asset requires estimates of future economic performance, a political commitment to a variety of programs including social security and other entitlement programs, and the use of an appropriate discount rate. Estimates for the value of other assets like the value of the public sector monopoly on money issuance run into similar problems. Furthermore, it is unclear how asset volatility should be best measured under this method.

[6]This approach implicitly assumes that market participants' views on prices incorporate forward-looking information about a sovereign's future economic prospects. This does not imply that the market is always right about its assessment of sovereign risk, but that it reflects the best available collective forecast of the expectations of market participants.

[7]Note that the underlying reason for this flexibility is the unlimited capacity of governments to print their own currency.

liabilities are short-term (rollover risk is high). Sovereigns can also sometimes trade below their contractual liabilities for a significant period of time if most of the liabilities are long-term, if most of the debt is denominated in the domestic currency or if the expected future fiscal position looks bright (higher implicit asset value).

4.4 The modified approach: Application to EA countries

4.4.1 Why is there a need for modification?

The most prominent feature of the EA is that, unlike emerging countries or other developed economies (e.g., US, UK, and Japan), individual EA countries are part of a monetary union. As part of the union, they do not have the possibility to inflate/dilute local currency debt in a distress situation before defaulting on foreign currency debt (for a detailed discussion, see De Grauwe (2012), Cochrane (2005) and Kopf (2012)). This effectively makes all EA sovereign debt 'foreign currency' debt, since their own central banks cannot print the currency in which their debt is denominated. Thus a case cannot be made that foreign currency debt holders are senior to local currency debt holders.

Also under the current institutional arrangement in the EA, the assets and liabilities of the monetary authority (the ECB) are independent of the sovereigns. In a practical sense, the monetary authority is just another lender to the sovereigns. The standard government view that credit from monetary authorities is the most junior obligation breaks down, and failing to honour this commitment can have serious consequences. This also exposes EA governments to the bouts of fear and distrust in the ECB's function as the lender of last resort. These fears can trigger a liquidity crisis, which can easily turn into a solvency crisis; higher interest rates and worsening debt dynamics can be self-fulfilling and sovereigns can effectively end up in default.

4.4.2 Discussion on the seniority of EA sovereigns' liabilities

The loss of control over domestic currency for EA countries, however, does not place all the creditors of an EA sovereign on a par with each other. To assess the seniority status of different actors and their precise place in the pecking order, we study the central episode of the European debt crisis - the restructuring and near-elimination of Greece's sovereign bonds held by private investors, comprising a face value of more than 100% of Greek GDP in March/April 2012 - together with the debt restructuring experience of multitude of emerging countries (see Roubini and Setser (2004)). Generally, government bonds come with a *pari passu* clause. However, the history of default and restructuring experiences in the context of sovereign lending makes it unclear what *pari passu* really means (see Weidemaier et al. (2013)).

There is surprisingly little *de jure* evidence that multilateral lenders are indeed senior to other creditors. It is primarily a convention and follows from the idea that, in future crises, this lender of last resort may be needed again in order to borrow further resources.[8] For instance, the IMF, which has proven its seniority in the financial crises of the past decades, is *de jure* not senior - it awards its credit lines without any corresponding clauses in its contracts or institutional by-laws. Nevertheless, its seniority is widely accepted and has never been challenged in the course of the financial crisis, by any of the creditors. Bilateral official creditors have also respected the IMF's' privilege position. Indeed, the historical willingness of bilateral creditors to restructure their claims in order to ensure payment to the IMF has been central to the idea of the fund's preferential status. Even during the Greek debt restructuring, the most favourable treatment achieved by other institutional lenders were on a par with the treatment of the IMF. This makes the IMF *de facto* the most clearly senior lender of all (see Martha (1990), Steinkamp and Westermann (2014) and Roubini and Setser (2004)).

Other multilateral lending facilities like the first Greek loan facility, the temporary rescue fund (EFSF), the permanent rescue fund (ESM) and the Target2 balances are *de jure* not senior, although they constitute multilateral claims of institutions - the Eurogroup or the Eurosystem of Central Banks - which are widely accepted as preferred creditors. A sovereign's desire to maintain its future access to emergency financing and a good working relationship with the other governments that provide this is a powerful incentive to follow the convention of paying multilateral creditors even if it defaults on its other debts. Sometimes the lending clauses explicitly give them preferred creditor status, junior only to the IMF loan. Target2 balances already enforced their senior status in the case of the Greek private sector involvement (PSI) in 2012, sanctioning this market belief (for details, refer to Sinn and Wollmershäuser (2012) and Whelan (2013)).

The most challenging task is to classify the holdings of the ECB. The ECB became an important creditor of countries in crisis via its Securities Markets Programme (SMP), collateralized lending to financial institutions and, later, the Outright Monetary Transactions (OMT) in order to stabilize sovereign bond yields in secondary markets. As all government bonds bought in the open (secondary) market

[8] Kletzer and Wright (2000) show in a formal analysis that this reason is actually sufficient and that no external enforcement is required.

contain the same legal clauses, it became unclear how these bonds would be treated in case of restructuring. In the case of OMT, the ECB explicitly acknowledged that it accepts the same priority as other private creditors in accordance with the terms of those bonds. However, accepting *pari passu* treatment did not mean that the ECB was open to participating in voluntary debt restructuring, such as the Greek PSI in February/March 2012. The Greek debt restructuring proposal excluded the bond holdings of the ECB (the single largest holder by far, with 42.7 billion euros (16.3%) of debt holding), other national central banks (5% of the total) and the European Investment Bank (EIB) (for further details, refer to Zettelmeyer et al. (2013) and Steinkamp and Westermann (2014)). So even if *de jure* the preferred creditor status of multilateral lenders is often ambiguous, their seniority is widely accepted by market participants.

Another interesting group of creditors is the domestic deposit-taking corporations (the banks). Markets believe that governments implicitly or explicitly undertake to honour the liabilities of *too-important-to-fail* banks.[9] In many cases, we can think of these guarantees to *too-important-to-fail* banks as senior claims. The reason for this is that a sovereign's creditworthiness depends heavily on the creditworthiness of its domestic banks. A deterioration in the creditworthiness of banks, as perceived by the market, can drastically increase the sovereign's contingent liabilities. This may cause a the government's own creditworthiness to deteriorate. Since the asset side of the bank's balance sheet typically consists of substantial holdings of domestic government debts, a deterioration in the government's creditworthiness can cause huge losses in its banks' portfolios. Sovereign fiscal strains can also impact banks' funding conditions since government securities are typically used as collateral to obtain short-term funding in debt markets.[10] Thus a self-fulfilling vicious loop develops in which deterioration in banks' health can increase the sovereign's contingent liability and fiscal strain which in turn has a negative impact on the banks' health.

Banks are also locked into a long-term relationship with the government. During times of crisis, domestic banks in fiscally stressed countries increase their holdings

[9] Grande et al. (2013) show that these guarantees help reduce risk premium on banks' liabilities and that their effect is proportional to the sovereign's creditworthiness. Implicit guarantees are harder to measure, but Angelini et al. (2011) and Schich and Lindh (2012) provide suggestive evidence that they may be among the reasons why on average large banks borrow at a discount.

[10] For example, in repo markets, a fall in the price of the sovereign bond can trigger margin calls or increase the haircut requirements, thus reducing the liquidity that can be obtained via a given nominal amount of sovereign paper. In an extreme scenario, a sovereign's rating downgrade below investment grade status disqualify it as collateral in funding operations, or as investments suitable for certain categories of investors such as pension and insurance funds.

Sovereign ratings also represent a ceiling for the ratings assigned to all other domestic borrowers. Increasing sovereign stress can lead to a ratings downgrade for a sovereign as well as its domestic banks, which in turn will increase the funding cost for banks.

of domestic sovereign debt considerably relative to foreign banks. This effect is stronger for state-owned banks and for banks with low initial holdings of domestic sovereign debt. This practice complies with the moral suasion argument[11] where banks choose to respond to pressure from their government on the understanding that current favours will be reciprocated in the future (for the presentation of the idea, refer to Horvitz and Ward (1987). Ongena et al. (2016) provide evidence of this behaviour during the European sovereign debt crisis.). This entails a natural collusion between two parties that have an equal interest, and so governments have an incentive to bail-out certain creditors more than others. Further uses of the bailout funds also indicate the priority banks receive over any other credit institution.

In summary, past experiences, survey responses and credit rating agencies' decisions have all suggested that a certain group of creditors are *de facto* senior to other market creditors (preferred creditor status), even if this is not formalized *de jure*. The large increase in the share of sovereign debt holding by these senior *de facto* creditors in the peripheral EA countries total debt outstanding and its observed co-movement with the interest rate spreads (refer to Figure 4 in Steinkamp and Westermann (2014)) makes the question addressed in this paper extremely timely and policy relevant. As a result, we focus here on the *de facto* rather than *de jure* classification.

4.4.3 Classification of creditors according to their place of residence and their institutional characteristics

We start our analysis here with the classification of different sovereign creditors and propose a hierarchy structure based on the institutional classification of creditors. We classify all creditors according to their place of residence and their institutional characteristics. We define the institutional unit as an economic entity that is capable, in its own right, of owning assets, incurring liabilities, and engaging in economic activities and in transactions with other entities. We follow the guidelines established by the World Bank (WB) and the International Monetary Fund (IMF) in bringing together detailed public sector debt data of high-income countries (Quarterly Public Sector Debt Statistics (QPSD)). Specifically, the guidelines classify creditors into two broad categories: domestic and external.

Domestic creditors are re-classified further into the following five categories: (a)

[11] The term *moral suasion* originally refers to an appeal to 'morality' or 'patriotic duty' to induce behaviour by the persuaded agency that is not necessary profit-maximizing for it. This appeal can be combined with a threat of a more repressive regime, as in the case of banking - intensified supervision, a revocation of banking license, or limited access to central bank funding (Horvitz and Ward (1987)).

Domestic central bank; (b) *Deposit-taking corporations except the central bank*, comprising all resident public deposit-taking corporations, except the central bank, that are controlled by general government units or other public corporations; (c) *Other financial corporations* consisting of all resident financial corporations, except public deposit-taking corporations, controlled by general government units or other public corporations; (d) *Non-financial corporations*, i.e., corporations whose principal activity is the production of market goods or nonfinancial services[12]; and (e) *Households and non-profit institutions serving households*. The external creditors are classified into: (a) Multilateral creditors - the ECB, EFSF/ESM, IMF, EIB, etc.; (2) Other national central banks within the EU; (c) Other non-resident financial corporations; and (d) Other non-residents.

4.4.4 Application to EA

Based on the discussion in the previous section, we define the priority structure of sovereign debt based on creditors' location and institutional classification, as shown in Table 4.2 (in decreasing order of priority).[13]

4.5 Data and methodology

4.5.1 Data description

In this subsection, we enumerate the datasets used in building our sovereign distance-to-default (DtD) - an alternative indicator of sovereign credit risk.

1. *Risk-free interest rate:* We consider the 10-year benchmark German bund yields as the risk-free rate (Source: Bloomberg).[14]

2. *Market value of sovereign debt:* We use the Quarterly Public Sector Debt Statistics (QPSD) database, developed jointly by the WB and the IMF, which brings together detailed public sector debt data from selected developing and high-income countries. It disseminates public sector debt data at the quarterly

[12] All resident non-financial corporations controlled by general government units or public corporations that are part of the public non-financial corporations subsector.

[13] Another way to classify the priority structure of sovereign liabilities could be based on the laws under which the contractual agreement is signed. Debt agreements signed under foreign jurisdiction would have a higher priority than debt agreements signed under domestic law, as governments during the time of crisis can change the terms of the agreement by a legislative fiat. But due to limited data accessibility, we prefer not to use this classification.

[14] Note that German bond yield is not always the lowest in EMU countries but during the time-frame of our study this was usually the case. We also used US government 10-year bond yields as risk-free rate and our results are robust to both these specifications.

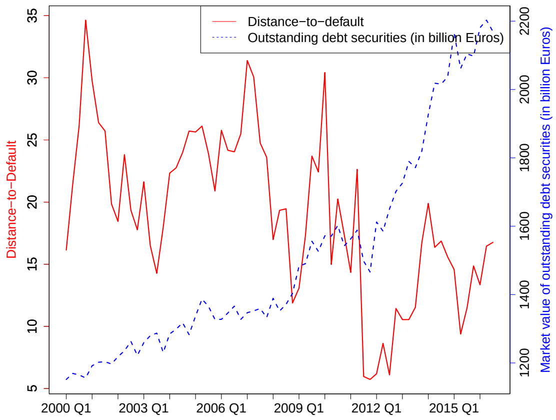
Table 4.2: Priority structure of sovereign liabilities

Senior claims
External creditor: Multilateral creditors outside the EU - the IMF, World Bank (EB), etc.
External creditor: Other multilateral creditors - the ECB, EFSF/ESM, EIB (the European Investment Bank), etc.
External creditor: Other national central banks within the EU
Domestic creditor: Deposit-taking corporation
Junior claims
Domestic creditor: Domestic central bank
Domestic creditor: Other financial corporations
Domestic creditor: Non-financial corporations
Domestic creditor: Households and non-profit institutions serving households
External creditor: Financial corporations not elsewhere classified
External creditor: Other non-residents

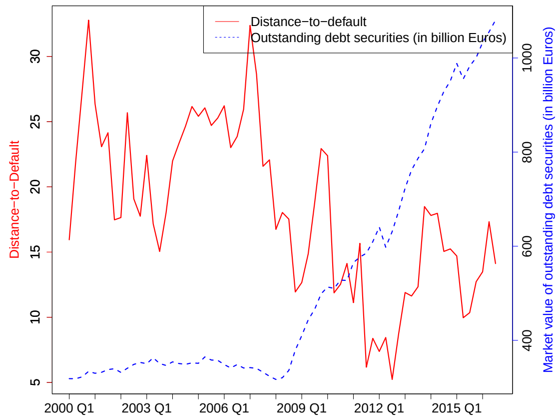
frequency. A detailed user guide is available at the Task Force on Financial Statistics website. We use this database to download the following items: (1) Gross PSD, General Gov., All maturities, Debt Securities, Market value, National Currency; (2) Gross PSD, General Gov., All maturities, Debt securities, Nominal Value, National Currency; (3) Gross PSD, General Gov., Long-term, With payment due in more than one year, Debt securities, Nominal Value, National Currency; (4) Gross PSD, General Gov., Long-term, With payment due in one year or less, Debt securities, Nominal Value, National Currency; and (5) Gross PSD, General Gov., Short-term, Debt securities, Nominal Value, National Currency. Except for Greece, we have the market value of all outstanding debt securities issued by the general government at the quarterly frequency. For the case of Greece, we use the nominal value. Figure 4.1 shows the evolution of gross general government debt as a percentage of GDP with sovereign DtD indices for individual countries.

3. *Volatility of sovereign debt:* 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

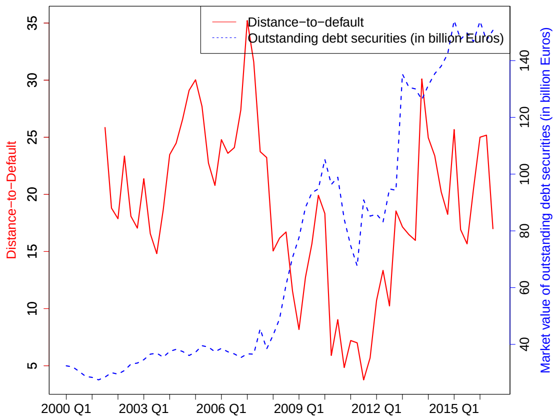
Figure 4.1: DtD vs Gross debt-to-GDP



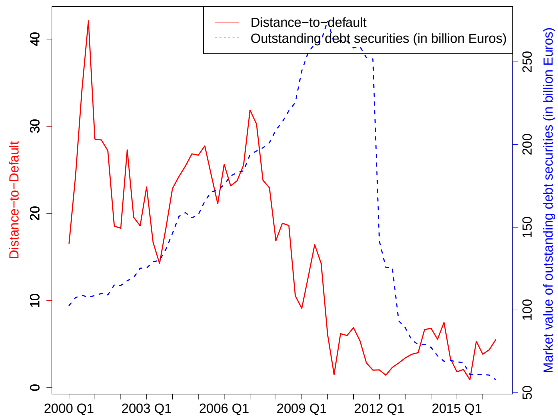
(a) Italy



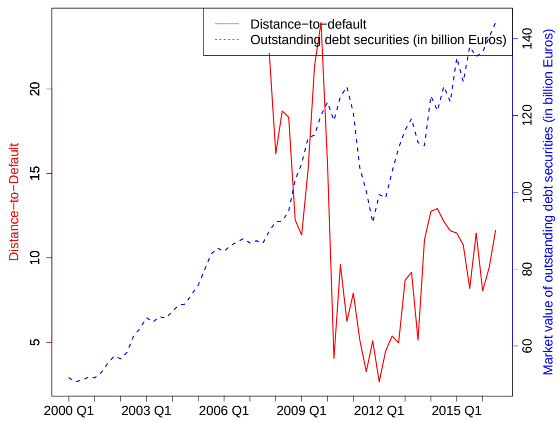
(b) Spain



(c) Ireland



(d) Greece



(e) Portugal

Notes: The figure shows the evolution of general government gross debt as a percentage of GDP with sovereign DtD indices for individual peripheral EA countries.

three months daily volatility.[15] Figure 4.2 shows the evolution of bond price volatility with sovereign DtD indices for individual countries.

4. *Sectoral sovereign bond holdings:* We use the cross-country sectoral sovereign bond holdings data developed in Merler and Pisani-Ferry (2012) (available at Bruegel website) which gathers publicly available data provided by national authorities on a country-by-country basis for 12 countries (Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, UK and US). It provides a sectoral breakdown of sovereign debt holders based on a systematic and standardized re-classification of all creditors into five categories - banks, central banks, public institutions, other resident sectors and non-resident holders. For most of the countries the data go back to the late 1990s and are mostly recorded at the quarterly frequency. Figure 4.3 plots the evolution of non-resident holding of general government debt with sovereign DtD indices for individual countries.

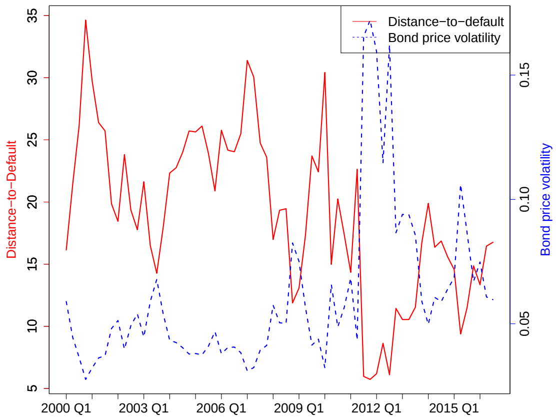
4.5.2 Methodology

Based on our discussion in Section 5.3, we consider the priority structure of creditors shown in Table 4.2. However, the best available public data on sectoral classification of all creditors (the Bruegel dataset) classifies them in the following categories: (1) Resident banks; (2) Central bank; (3) Other public institutions; (4) Other residents; and (5) Non-residents. Notice that under this classification all external creditors are classified under the common heading of Non-resident debt holders. This limitation implies that we cannot separate out the debt holding of multilateral creditors with the rest of the non-resident holders, which restricts our understanding of the dynamic implications of the redistribution of sovereign debt among the external debt holders. Since we do not have exactly the same classification of creditors, we consider the value of the senior claims as the sum of the market value of all non-resident debt holdings (external) and resident bank holdings.

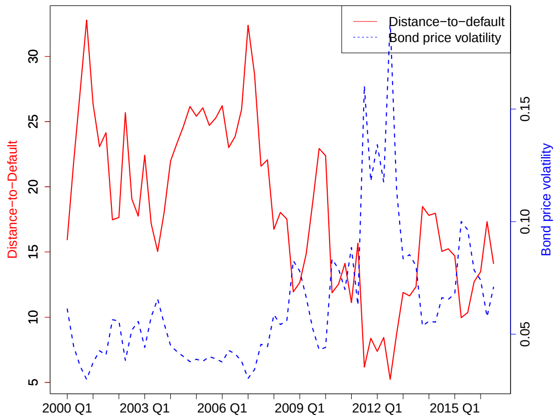
Our assumption here is that during the time of stress, the offloading/selling by other non-resident will be reflected in the market volatility. Also, the net buyers will be the multilateral creditors (like ECB, IMF, ESM etc.) or the domestic banks which will be reflected in the increased holding of the senior claimant (see Battistini et al.

[15] To check the robustness of our results, we also calculate the volatility of sovereign debt using the 10-year benchmark sovereign bond yield daily data (Source: Bloomberg) and calculate the daily bond prices and daily returns. We use different specifications for coupon payments (zero coupon, 1%, 2% and 4% coupon rate at the half-yearly/annual frequency). The quarterly volatility is then calculated as the standard deviation of daily returns (in that quarter) and is then annualized. These different specifications only scale the level of DtD and our main results are robust to all these specifications.

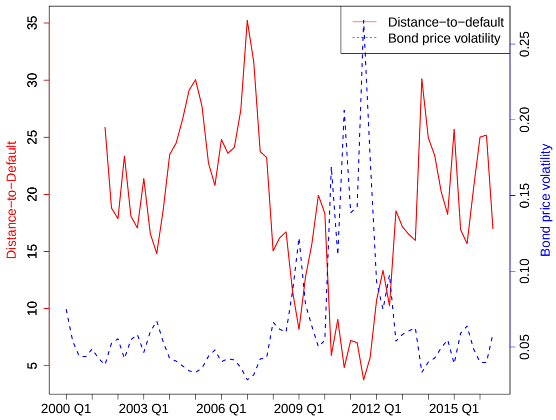
Figure 4.2: DtD vs Bond price volatility



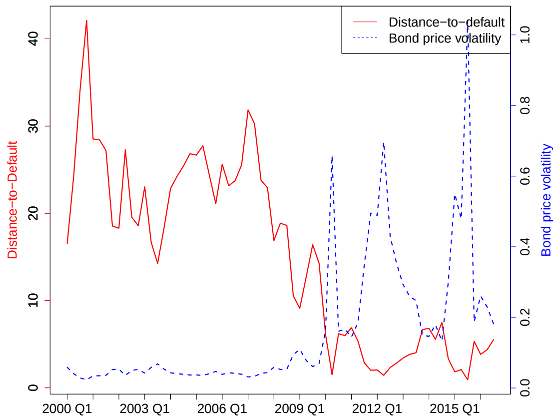
(a) Italy



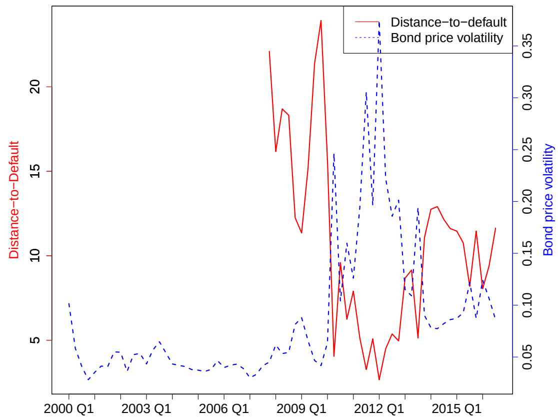
(b) Spain



(c) Ireland



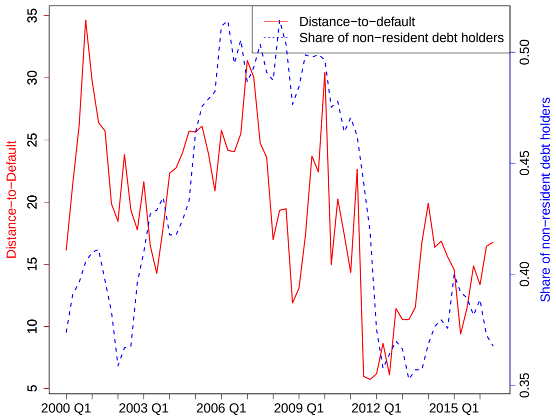
(d) Greece



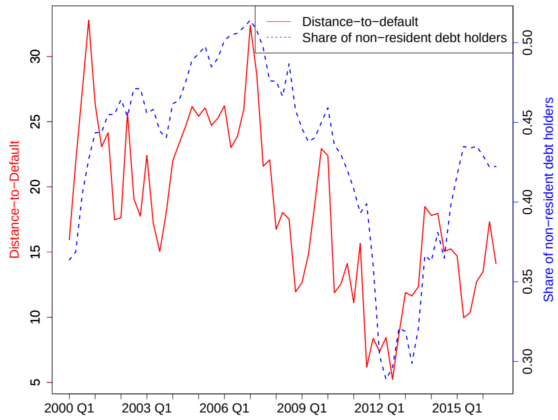
(e) Portugal

Note: The figure shows the evolution of sovereign's bond price volatility with sovereign DtD indices for individual peripheral EA countries.

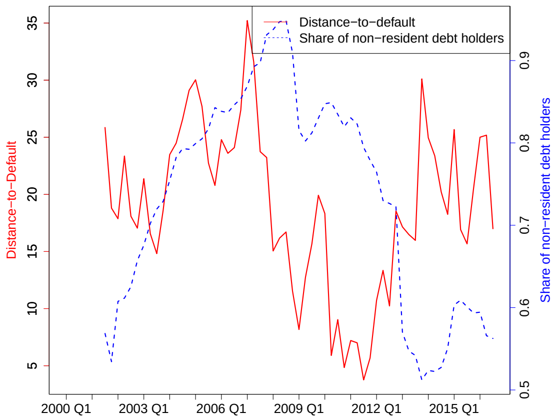
Figure 4.3: DtD vs Non-resident holding of government debt



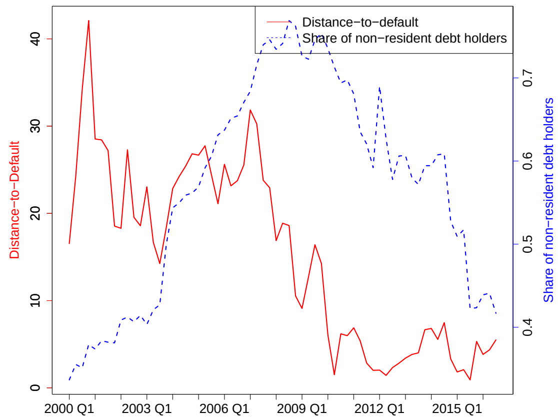
(a) Italy



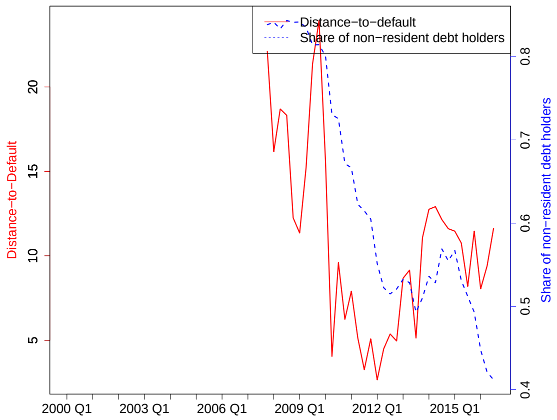
(b) Spain



(c) Ireland



(d) Greece



(e) Portugal

Note: The figure shows the evolution of the share of non-resident debt holding of general government gross debt with sovereign DtD indices for individual peripheral EA countries.

(2013), Acharya and Steffen (2015)). We also see that some of these debt buyers in the times of crisis are distressed debt hedge funds which were paid in full during the Greek debt restructuring (Zettelmeyer et al. (2013), Steinkamp and Westermann (2014)). So our assumption regarding the priority of non-resident debt holders is not far from reality.

We calculate a quarterly time series of the sovereign DtD for Greece, Ireland, Italy, Portugal and Spain. 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 as provided by the QPSD database together 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 is taken as the direct measure of the junior claim volatility. To calculate the default barrier, we use three other alternative specifications - (1) the sum of the general government's short-term debt and long-term debt where the payment is due in one year or less in nominal terms[16]; (2) the sum of part one and 50% of the long-term debt where payment is due in more than one year in nominal terms; and (3) the sum of debt holdings to all external debt holders in nominal terms - to check the robustness of our results.[17] Once the equity value, equity volatility and distress barriers are calculated, we use the procedure as documented in Gray et al. (2007) to calculate the quarterly time series of sovereign DtD for individual EA countries.

4.6 Stylized facts

Our focus is on five EA member states that have experienced a sovereign debt crisis: Greece, Italy, Ireland, Spain, and Portugal. Table 4.3 provides summary information for the sovereign DtD indicators. The measurement does not include units of account as it represents the number of standard deviation the sovereign's asset value is away from its distress barrier. The average value of the sovereign DtDs ranges widely across countries: the lowest average is 10.78 for Portugal, and the highest is 19.01 for Italy. Both the standard deviations and the minimum-maximum values indicate that there is a significant time-series variation in the sovereign DtD indices. For example, in the cases of Greece and Ireland, it ranges from 0.92 to 42.09 and 3.76 to 35.22 respectively. We also observe consistently low DtD numbers for Portugal.

[16] Note that we are using nominal value in place of market value. This is because the QPSD statistics do not provide the market value of short and long-term debt for individual countries.

[17] Our results are robust to all these alternative specifications. However, to save space, we document results only on the basis of the first one.

Table 4.3: Descriptive statistics for sovereign Distance-to-Default (DtD) indicators

	Mean	Standard Deviation	Minimum	Median	Maximum	Skewness	Kurtosis	Standard Error	N
Spain	18.23	6.42	5.23	17.75	32.78	0.08	-0.77	0.78	67
Greece	15.07	10.48	0.92	16.54	42.09	0.24	-1.11	1.28	67
Ireland	18.92	7.16	3.76	18.55	35.22	-0.19	-0.52	0.92	61
Italy	19.01	6.61	5.73	19.34	34.64	-0.05	-0.55	0.81	67
Portugal	10.78	5.45	2.66	10.92	23.93	0.62	-0.34	0.91	36

Notes: The table reports summary statistics for the quarterly sovereign DtD index for the period 2000Q1 to 2016Q3 (except for Portugal and Ireland). For Portugal, the series starts at 2007Q4, while for Ireland the series begins at 2001Q3.

4.6.1 Commonalities within sovereign DtD indices

To study the commonality in sovereign DtD indices, we first compute the correlations matrix of sovereign DtD levels. Since the time series of observations are not always of equal length, the correlation between each pair of countries is based on the periods for which the data overlap. The correlations matrix is shown in Table 4.4. All the correlations are positive and half of the pairwise correlations (Spain-Ireland, Spain-Italy, Spain-Portugal, Greece-Italy, and Greece-Portugal) are very large. In fact, half of all correlations are in excess of 80%. The highest correlation 0.94 is observed between Italy and Spain. The average pairwise correlation is slightly above 0.75 and Spain shows the highest average pairwise correlation just above 0.86.

Table 4.4: Correlations among sovereign DtD indicators

	Spain	Greece	Ireland	Italy	Portugal
Spain	1.00	0.90	0.78	0.94	0.82
Greece	0.90	1.00	0.62	0.84	0.84
Ireland	0.78	0.62	1.00	0.65	0.44
Italy	0.94	0.84	0.65	1.00	0.70
Portugal	0.82	0.84	0.44	0.70	1.00

Notes: This table reports Pearson correlations among the quarterly sovereign DtD indices for the 2000Q1 to 2016Q3 period. All correlations are statistically significant at 1% confidence level.

To check whether the correlations have increased during the crisis period,[18] we divide the sample period into two parts - (a) 2000 to 2007 as the pre-crisis period, and (b) 2008-2016 as the crisis period. We re-calculate the pairwise correlation for the 2000-2007 pre-crisis period as well as the 2008-2016 period encompassing the sovereign debt crisis (Table 4.5). We observe large differences in the average correlations. The average correlation is about 94% for the pre-crisis period, and it falls to 56% for the crisis period. We find the biggest drop in average correlation for Ireland - from 0.94 to 0.32 and a similar but less intense drop for Greece - from 0.94 to 0.50. The largest drop is between the Ireland-Greece pair, where it fell to 0.06 from 0.95 pre-crisis. This provides suggestive evidence of an increase in idiosyncratic components in the sovereign credit risk measure. All correlations are still positive but, the magnitude of the pair-wise correlation has been reduced drastically for individual pairs.

Table 4.5: Correlations among individual sovereign DtD indicators

	2000-2007					**2008-2016**				
	Spain	Greece	Ireland	Italy	Portugal	Spain	Greece	Ireland	Italy	Portugal
Spain	1.00	0.92	0.92	0.94	-	1.00	0.61	0.52	0.89	0.80
Greece	0.92	1.00	0.95	0.94	-	0.61	1.00	0.06	0.55	0.82
Ireland	0.92	0.95	1.00	0.96	-	0.52	0.06	1.00	0.27	0.41
Italy	0.94	0.94	0.96	1.00	-	0.89	0.55	0.27	1.00	0.68
Portugal	-	-	-	-	-	0.80	0.82	0.41	0.68	1.00

Notes: The table reports Pearson correlations between the quarterly sovereign DtD indices for the 2000Q1 to 2016Q3 period. All correlations are statistically significant at 1% confidence level. The pre-crisis period excludes Portugal because the sovereign DtD for this country is available only from 2007Q4 onwards.

4.6.2 Commonalities and differences with regard to other sovereign risk measures

In this section, we study the commonalities and differences among the various sovereign credit risk measures. In particular, we conduct the principal components analysis of the sovereign DtD and contrast the results with other credit risk measures. However, we need to be selective because a large number of credit risk indi-

[18] As discussed by Longstaff et al. (2011), Ang and Bekaert (2002), and others, there is a tendency for correlations in financial markets to increase during crisis episodes.

cators are available in the marketplace. We narrow our analysis to sovereign yield spreads, CDSs and the credit ratings.

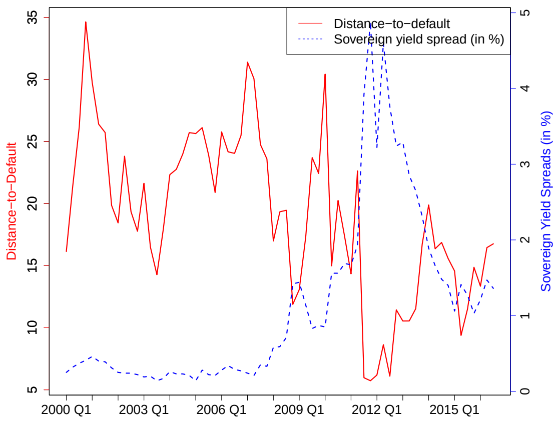
To calculate yield spreads for individual countries, we use the Maastricht criterion bond yields (the long-term interest rates). These are the rates used as a convergence criterion for the EMU, based on the Maastricht Treaty. The series relates to interest rates for long-term government bonds denominated 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, collected from Eurostat. Yield spreads are calculated as the difference between the ten-year benchmark sovereign bond yield of each individual country and that of Germany. Figure 4.4 shows the country-wise evolution of sovereign DtD and yield spreads. As can be seen, the sovereign DtD and yield spreads mirror each other for all countries in our sample. However, in the cases of Greece and Ireland, the level of DtD remains at dangerously low levels even when the level of yield spreads suggests otherwise.

We use five-year benchmark sovereign CDS daily mid-quotes from Datastream as the second measure of the sovereign credit risk. These data are available from 2007Q4 until 2016Q3. Following previous studies, we focus on the 5-year maturity, as these contracts are regarded as the most liquid in the market. Figure 4.5 show the country-wise evolution of the sovereign DtD index together with the 5-year benchmark sovereign CDS spreads for peripheral EA countries. Except for Greece, the CDS spreads have fallen drastically for all countries, though it remains higher than its pre-crisis level. The sovereign DtD reflects the same trend but shows far higher variation than the CDS spreads. Among the reasons for this variation are the fluctuations in bond market volatility, which are more pronounced in the case of smaller countries.

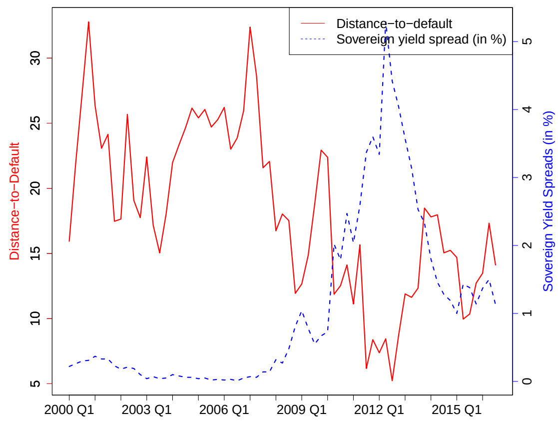
Finally, for credit ratings, we follow Blanco (2001) and build a credit rating variable (RAT) averaging the ratings assigned to sovereign debt by Standard & Poor's, Moody's and Fitch. Using data compiled from Bloomberg, 21 different categories are considered. The first category is made up of the highest-rated debts, while the twenty-first category includes the lowest-rated debts. Therefore, by construction, the higher the value of RAT, the worse the rating categories. Figure 4.6 shows the country-wise evolution of the sovereign DtD index together with the credit rating for each peripheral EA country. The plot suggests that credit ratings show less frequent and extreme movements compared with other sovereign risk measures. Sovereign DtD matches the trend of credit ratings, but shows far higher volatility.

Table 4.6 provides summary information for CDS, yield spreads and credit ratings which are selected here for comparison.

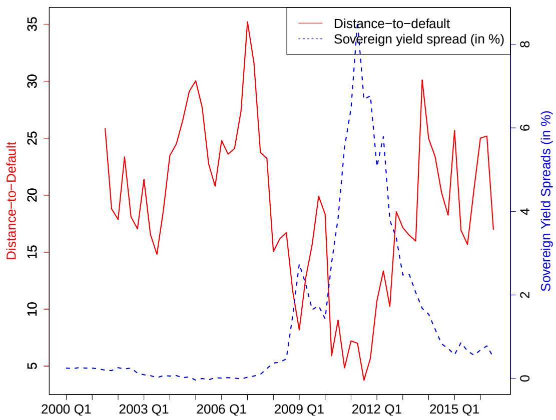
Figure 4.4: Sovereign DtD vs sovereign yield spreads



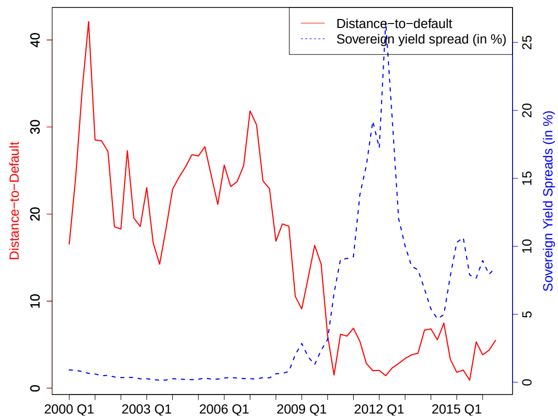
(a) Italy



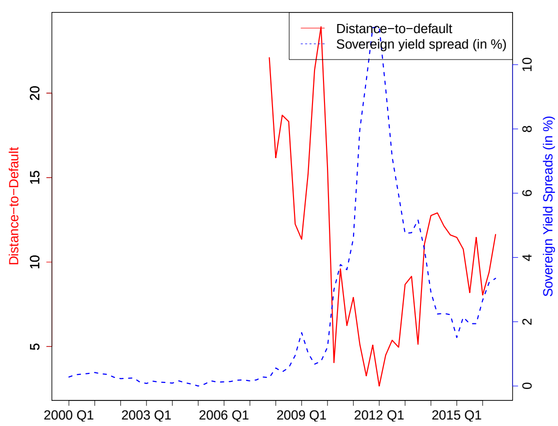
(b) Spain



(c) Ireland



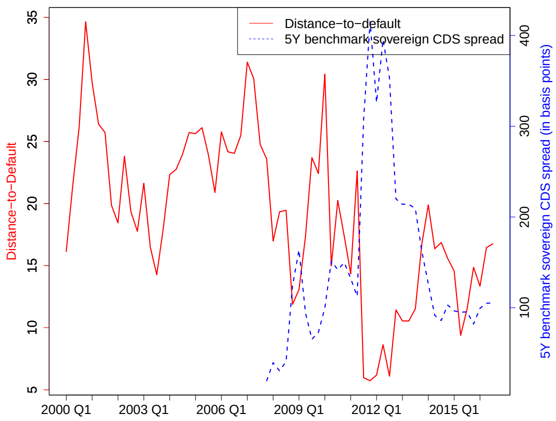
(d) Greece



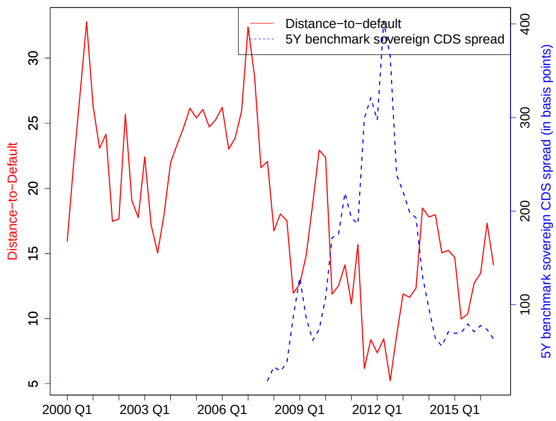
(e) Portugal

Note: Yield spreads are based on the Maastricht criterion bond yields (long-term interest rates) data provided by Eurostat. These are the rates used as a convergence criterion for the EMU, based on the Maastricht Treaty. The series relates to interest rates for 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 ten-year benchmark sovereign bond yield of each individual country and that of Germany.

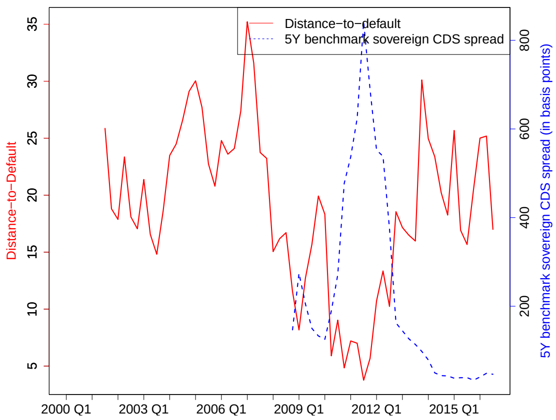
Figure 4.5: Sovereign DtD vs 5-year benchmark sovereign CDS spreads



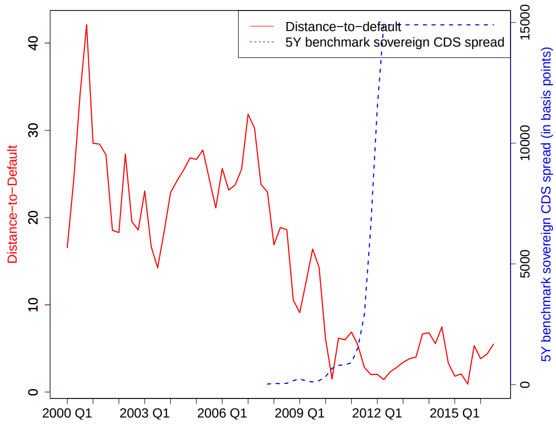
(a) Italy



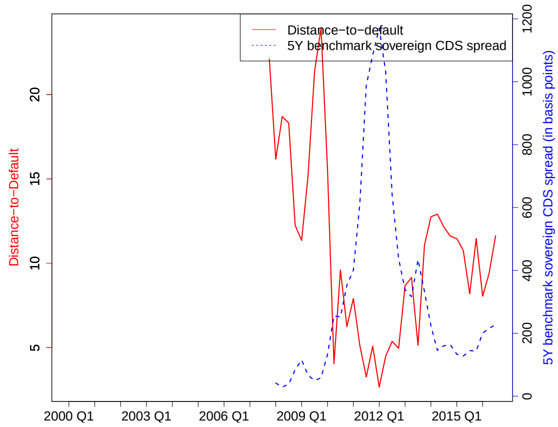
(b) Spain



(c) Ireland



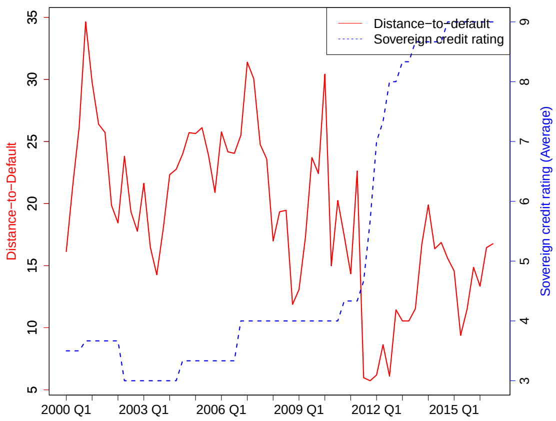
(d) Greece



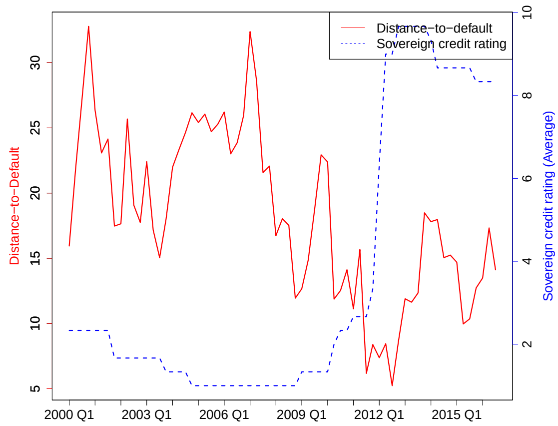
(e) Portugal

Note: The five-year benchmark sovereign CDS spreads data are available starting from 2007Q4. The Greek CDS spreads post the 2012 Greek debt restructuring experience are not reliable. Source: Datastream.

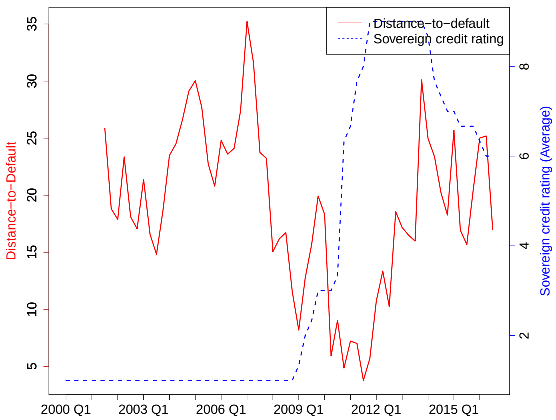
Figure 4.6: Sovereign DtD vs sovereign credit rating



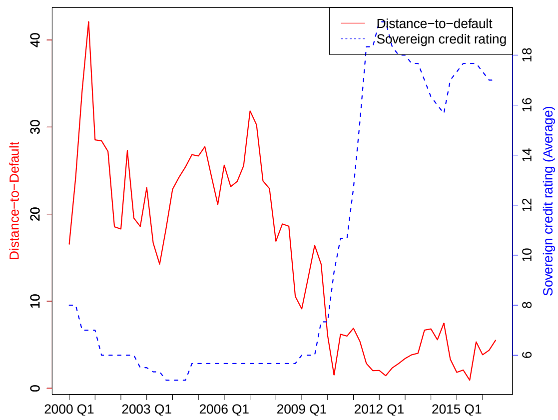
(a) Italy



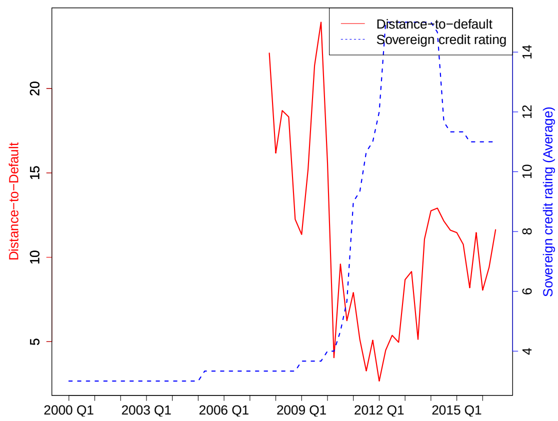
(b) Spain



(c) Ireland



(d) Greece



(e) Portugal

Note: Credit ratings data are built by averaging the ratings assigned to sovereign debt by Standard & Poor's, Moody's and Fitch. Using data compiled from Bloomberg, 21 different categories are considered. The first category is made up of highest-rated debts whereas the twenty first includes the lowest-rated debts.

Table 4.6: Descriptive statistics for other comparable sovereign risk indicators

	Mean	Standard Deviation	Minimum	Median	Maximum	Skewness	Kurtosis	Standard Error	N
				Part I: Five-year sovereign Credit Default Swap (CDS) spreads					
Spain	140.77	100.98	18.79	91.3	402.16	0.95	-0.14	16.83	36
Greece	8200.64	7102.17	20.32	13180.66	14904.36	-0.15	-1.98	1183.7	36
Ireland	227.23	226.1	33.09	138.7	841.86	1.16	0.11	39.97	32
Italy	148.36	100.2	19.58	108.91	415.01	1.22	0.63	16.7	36
Portugal	318.58	313.06	28.99	215.7	1170.3	1.49	1.16	52.92	35
				Part II: Sovereign yield spreads					
Spain	1.06	1.28	0.01	0.37	5.29	1.37	1.08	0.16	67
Greece	4.53	5.87	0.15	0.87	26.52	1.52	2.03	0.72	67
Ireland	1.38	2.01	-0.04	0.39	8.54	1.81	2.44	0.25	67
Italy	1.13	1.16	0.14	0.59	4.88	1.48	1.52	0.14	67
Portugal	2.04	2.81	0	0.56	11.18	1.76	2.41	0.34	67
				Part III: Credit ratings					
Spain	3.64	3.34	1	1.67	9.67	0.91	-1.04	0.41	67
Greece	10.01	5.44	5	6.00	19.33	0.61	-1.50	0.66	67
Ireland	3.58	3.25	1	1.00	9.00	0.64	-1.38	0.40	67
Italy	5.06	2.27	3	4.00	9.00	0.88	-1.05	0.28	67
Portugal	6.47	4.57	3	3.33	15.00	0.84	-1.02	0.56	67

Notes: Part I of the table reports summary statistics for the quarterly average five-year sovereign CDS spreads for the period 2007Q4 to 2016Q3. CDS spreads are measured in basis points (Source: Bloomberg). Part II reports summary statistics for the quarterly sovereign yield spreads for the period 2001Q1 to 2016Q3. The yield spreads are measured in percentage terms (Source: Eurostat). Part III of the table reports summary statistics for the quarterly average sovereign credit rating indicators for the 2000Q1 to 2016Q3 period. The rating is the average of sovereign credit rating available from S&P's, Moody's and Fitch rating agencies (Source: Bloomberg).

Correlations among sovereign risk measures

In this section, we compute the correlations between sovereign DtD and traditional measures of credit risk for individual peripheral EA countries. Since the time series of observations are not always of equal length for all indicators, we select the longest continuous period for which the data overlap. This period turns out to be 2008Q4 to 2016Q3. Table 4.7 shows the correlation results for individual countries. As can be seen, most of the pairwise correlations are large and all of them are negative. In fact, they are all between -0.5 and -0.8. The average correlation for Ireland is the highest at -0.76, while the lowest is for Greece at -0.62. The magnitude of the correlations is quite similar for CDS and yield spreads in almost all countries. These results suggest a strong pattern of commonality in sovereign risk measures, except for the credit rating excluding Greece. The low correlation between the DtD and the rating may be explained by the fact that our index probably captures information over and above the market-perceived credit worthiness of government bonds.

Table 4.7: Country-wise correlations among comparable sovereign risk indicators

	Sovereign DtD				
	Spain	Greece	Ireland	Italy	Portugal
CDS spreads	-0.69	-0.56	-0.77	-0.71	-0.71
Yield spreads	-0.68	-0.68	-0.75	-0.71	-0.75
Credit rating	-0.19	-0.78	0.18	-0.33	-0.44

Notes: This table reports the Pearson correlations among the quarterly sovereign DtD with sovereign CDS and yield spreads for individual peripheral EA countries under study. The sample period is 2008Q4 to 2016Q3, the period for which we have the CDS, yields, ratings and sovereign DtD data for all peripheral EA countries. All correlations are statistically significant at 1% confidence level. The results are robust to other correlation measures.

Principal component analysis

In search of a common underlying factor, we now turn to principal component analysis. Table 4.8 reports summary results for the 2008Q4-2016Q3 period.[19] For comparison, we also report the principal components for sovereign CDS, yield spreads and credit ratings. The results show that there is a strong commonality in the behaviour of all four indices, since the first two principal components explain roughly 90% of the variation for all risk measures. However, the explanatory power of the first principal component registers its lowest values in the case of the sovereign DtD (67.17%), while the highest values correspond to the credit ratings at 87.91% followed by sovereign yield spreads at 83.30%.

To explore this further, Figure 4.7 plots the weighting vectors for the first three principal components for sovereign DtD together with the other three risk mea-

[19] This is the period for which sovereign DtD is available for the peripheral EA countries under study.

Table 4.8: Principal component analysis result (2008Q4-2016Q3)

Principal Component	Percentage Explained	Total	Percentage Explained	Total	Percentage Explained	Total	Percentage Explained	Total
	Sovereign DtD		**CDS spreads**		**Yield spreads**		**Credit rating**	
First	67.17	67.17	70.19	70.19	83.30	83.30	87.91	87.91
Second	19.51	86.68	24.24	94.43	9.88	93.18	9.32	97.23
Third	9.92	96.59	3.80	98.23	3.79	96.97	2.07	99.30
Fourth	2.21	98.81	1.24	99.47	2.25	99.22	0.45	99.76

Notes: This table reports summary statistics for the principal components analysis of the sovereign DtD, CDS, yield spreads and credit ratings for all peripheral EA countries. The sample period is 2008Q4 to 2016Q3, the period for which we have the CDS, yields, ratings and sovereign DtD data for all peripheral EA countries.

sures. As shown, the first principal component consists of a roughly uniform weighting of 0.5 (-0.5 in case of sovereign DtD) for all risk measures. We can think of it as a parallel shift factor driven by global risk and uncertainty as suggested by Longstaff et al. (2011). Also, the correlations between the first principal component based on all four measures are roughly 74% which suggests that the principal source of variation across all sovereign credit risk measures is the same. The second principal component places substantial positive weights on Greece and a negative weight on Ireland. This can be seen as a divergence between Ireland, Greece and the rest of the peripheral countries.

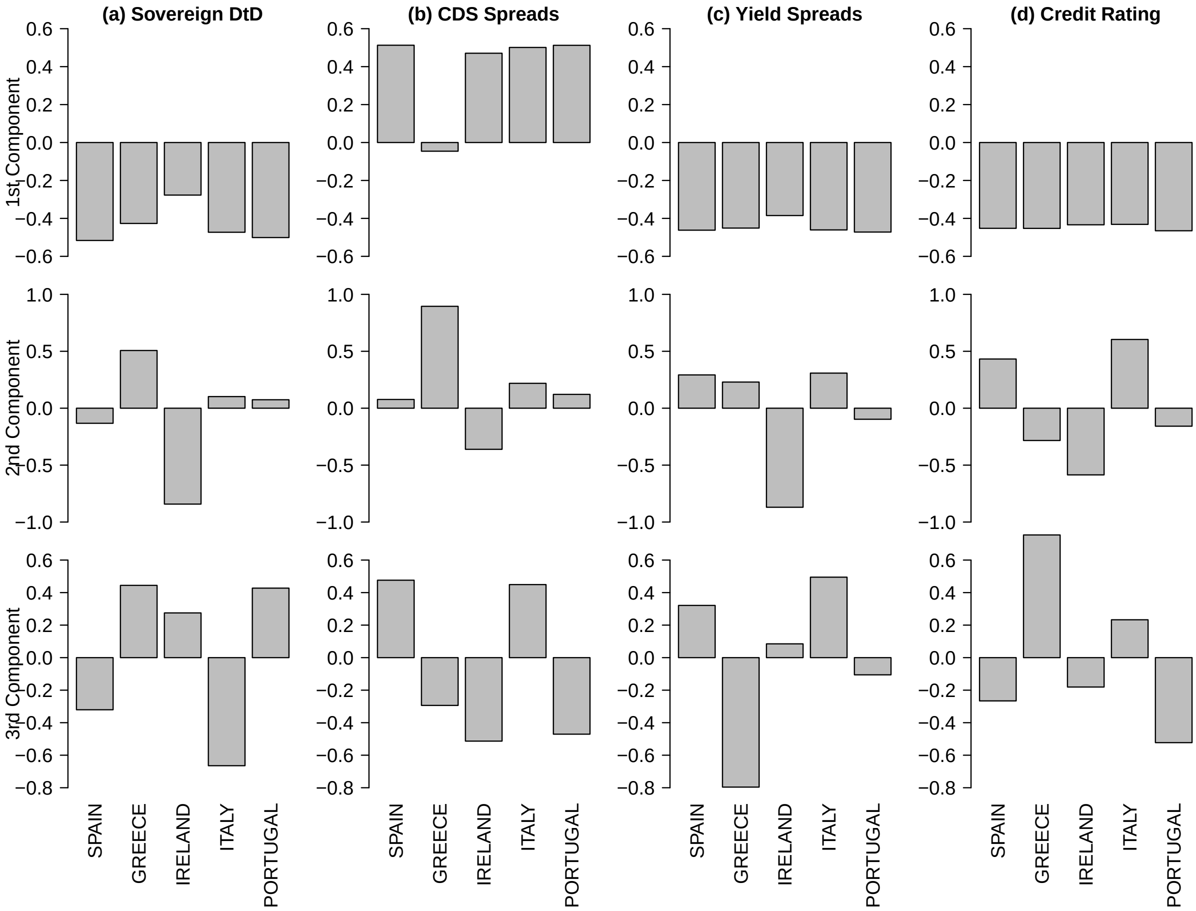
4.7 Analysis

Taking stock of the commonality and differences with other credit risk measures, here we try to understand the information content of the sovereign DtD indicators. In this section, we also test the forward looking nature of sovereign DtD and its predictive ability compared with other credit risk measures.

4.7.1 Correlations

In this subsection, we focus on the correlation among the proposed DtD indicator and the three traditional measures of sovereign risk (yield spread, CDS and rating). Following common practice, the examined co-movements are classified as follows. If $\rho(j), j \in (0, \pm 1, \pm 2, \pm 3, \pm 4)$ denotes the cross correlation between DtD_{t-j} and

Figure 4.7: Principal components of sovereign DtD, CDS, yield spreads and credit ratings



Notes: The figure shows the weighting vectors for the first three principal components for the sovereign DtD, CDS, yield spreads and credit ratings respectively for peripheral EA countries. The sample period is 2008Q4 to 2016Q3. This is the period for which we have the CDS, yields, ratings and sovereign DtD data for all countries.

X_t, we say that DtD co-moves in the same (opposite) direction of X if the maximum value of ρ is positive (negative) and not very close to zero. We also say that the DtD indicator is leading, synchronous or lagging X as $\rho(j)$ reaches a maximum for $j < 0, j = 0, j > 0$. In particular, for $0.5 \leq |\rho(j)| < 1$, we use the adjective 'strong', for $0.25 \leq |\rho(j)| < 0.5$ we use the adjective 'weak' and, when $0 \leq |\rho(j)| < 0.25$ we say that the series are 'not correlated'. The cut-off point of 0.25 was chosen because it roughly corresponds to the null hypothesis that the correlation coefficient is zero at 5% level of significance, given our sample size.[20]

In Table 4.9, each row displays the correlation coefficient between sovereign DtD at different time lags (from -4 to +4) and the given sovereign risk indicator. As can be seen in Part I, in three out of the five cases there is evidence of a strong negative leading relationship between sovereign DtD and sovereign yield spread (Greece, Ireland and Spain), while in the two remaining cases (Italy and Portugal) we find strong negative synchronous association. Regarding the relationship between sovereign DtD and sovereign CDS, in Part II, we detect a strong negative leading association in all the countries under study, indicating that a deterioration of the sovereign solvency (a reduction in DtD) increases the future perceived risk of sovereign bonds. Finally, the evidence presented in Part III suggests a strong negative leading relationship between sovereign DtD and sovereign rating for all countries (i.e., a reduction in DtD generates a future increase in the interest rate paid on government bonds as the market anticipates an increased risk). These results are very insightful since they suggest that although the correlation between the four indices is very high, the DtD indicator seems to lead the evolution of the other three, suggesting that our index may contain useful information for forecasting the traditional indicators.

4.7.2 Granger-causality

The concept of Granger-causality, introduced by Granger (1969) and Sims (1972), is widely used to ascertain the importance of the interaction between two series. One variable is said to Granger-cause some other variable if past information about the latter provides statistically significant information about the former that is not present in its own past information. In this subsection we use vector autoregression (VAR) models for establishing causal links between the proposed DtD indicator and the traditional measures of sovereign risk. In particular, for each equation in the VAR, we make use of the Wald test for the joint significance of each of the other lagged endogenous variables in that equation. The resulting Wald statistics are reported in Table 4.10 and reinforce the results obtained in the correlations analysis.

As can be seen, in the case of Ireland we find evidence of a bi-directional Granger-causality relationship between DtD and yield spreads, while for the remaining countries under study the results suggest a unidirectional Granger-causality running from DtD to yield spread. Regarding the relationship between sovereign DtD and sovereign CDS, our results suggest weak evidence (at 10%) of a unidirectional Granger-causality relationship running from CDS to DtD in the case of Italy. Fi-

[20] The standard error is approximately $T^{-1/2}$, T being the sample size (68 in our case). Thus two standard errors would be 0.24.

Table 4.9: Correlation between sovereign DtD and sovereign yield spreads

Lag	-4	-3	-2	-1	0	1	2	3	4
					Part I: Correlation with sovereign yield spreads				
Greece	-0.7289	-0.7409	-0.7599	**-0.7724**	-0.7716	-0.7512	-0.7201	-0.6981	-0.6927
Ireland	-0.6679	-0.7251	-0.7623	**-0.7657**	-0.7393	-0.6280	-0.5422	-0.4602	-0.3786
Italy	-0.5164	-0.6118	-0.6232	-0.6822	**-0.7498**	-0.6902	-0.6353	-0.5909	-0.5417
Portugal	-0.5203	-0.5787	-0.6675	-0.7550	**-0.7840**	-0.6832	-0.5967	-0.5275	-0.4514
Spain	-0.6722	-0.7198	-0.7345	**-0.7614**	-0.7555	-0.7082	-0.6515	-0.6044	-0.5536
					Part II: Correlation with sovereign CDS spreads				
Greece	**-0.7275**	-0.6885	-0.6764	-0.6653	-0.5832	-0.5863	-0.5096	-0.4327	-0.3557
Ireland	-0.5723	-0.7095	**-0.7801**	-0.7777	-0.6488	-0.5579	-0.4330	-0.3167	-0.3167
Italy	-0.2719	-0.3954	-0.4427	**-0.5709**	-0.5650	-0.5081	-0.3628	-0.2880	-0.1742
Portugal	-0.4369	-0.5100	-0.5902	**-0.6792**	-0.642	-0.6125	-0.5281	-0.4148	-0.3163
Spain	-0.3942	-0.4718	-0.5591	**-0.6339**	-0.5436	-0.5184	-0.3842	-0.2734	-0.1771
					Part III: Correlation with sovereign credit rating				
Greece	**-0.8697**	-0.8597	-0.8492	-0.8341	-0.8191	-0.7924	-0.7593	-0.7399	-0.7384
Ireland	**-0.5833**	-0.5378	-0.4896	-0.4188	-0.3550	-0.2896	-0.2359	-0.1893	-0.1342
Italy	**-0.6615**	-0.6482	-0.6382	-0.6108	-0.6052	-0.5782	-0.5557	-0.5328	-0.5090
Portugal	-0.8061	**-0.8141**	-0.7400	-0.6696	-0.5703	-0.4972	-0.4230	-0.3478	-0.2938
Spain	**-0.7160**	-0.7032	-0.6650	-0.6247	-0.5905	-0.5491	-0.4961	-0.4425	-0.4097

Notes: Values in bold letters indicate the highest correlation coefficient for any given row.

nally, we find evidence of a bi-directional relationship between DtD to rating for Greece, while for the remaining four countries we find statistically significant uni-directional Granger-causality relationships running from DtD to rating. Summing up, the results suggest causality from DtD to two traditional sovereign risk measures: yield spreads and credit rating, but not the other way around.

4.7.3 Generalized Impulse-Response Functions (GIRF)

In this subsection, we analyse the GIRF to further evaluate the relationship between the proposed DtD indicator and the traditional measures of credit risk. Since the Cholesky-factor identification may be sensitive to ordering, we make use of a generalized VAR decomposition (GVD), invariant to ordering, proposed by Koop et al. (1996) and Pesaran and Shin (1998). GIFR traces out the responsiveness of the

Table 4.10: Granger causality test (Wald test probabilities)

	Greece	Ireland	Italy	Portugal	Spain
Sovereign DtD ⟶ Yield spread	**0.0593***	**0.0234****	**0.0021*****	**0.0900***	**0.0074*****
Sovereign DtD ⟶ CDS spread	0.1438	0.1370	0.3036	0.7807	0.3318
Sovereign DtD ⟶ Credit Rating	**0.0431****	**0.0000*****	**0.0156****	**0.0000*****	**0.0005*****
Yield spread ⟶ Sovereign DtD	0.1638	**0.0643***	0.6911	0.9803	0.2437
CDS spread ⟶ Sovereign DtD	0.5095	0.2589	**0.0990***	0.3539	0.2720
Credit Rating ⟶ Sovereign DtD	**0.0573***	0.8098	0.2499	0.5189	0.1370

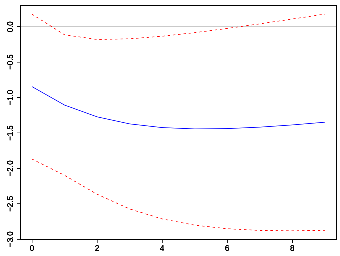
Notes: The bold letters shows the statistically significant Granger causality linkages. The ***, **, and * stand for significant coefficient at the 1%, 5%, and 10% levels, respectively.

dependent variable in the VAR to shocks to each of the variables.

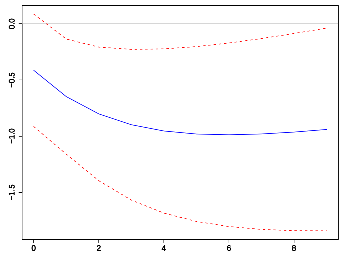
Figures 4.8 to 4.10 show the estimated GIRF to a one standard deviation shock, which once again suggests the forward-looking nature of the DtD indicator. As can be seen in Figure 4.8, in all five cases yield spreads respond negatively to shocks in DtD, and in Italy and Portugal the negative response is progressively reduced to zero. Turning to Figure 4.9, except for Spain and Italy, we observe a negative response of CDS to DtD shocks that dies out and over time reaches zero. Interestingly, for Greece this initial response is positive.

Finally, in relation to the GIRF for sovereign DtD and sovereign rating, for all countries under study (Figure 4.10), we find a negative and increasing response of rating to DtD shocks suggesting that an increase in DtD would result in a better credit classification by the rating agencies. Nevertheless, in the case of Portugal there is evidence of a minor reversion in the negative response after quarter four.

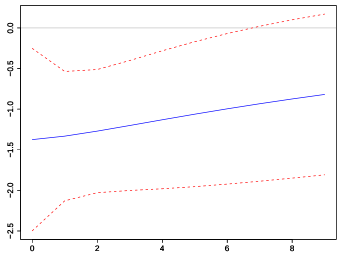
Figure 4.8: Generalized IRFs: Sovereign DtD and sovereign yield spread



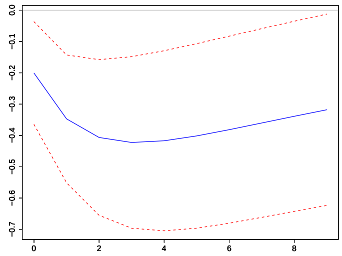
1a. Greece (Response of DtD to yield spread)



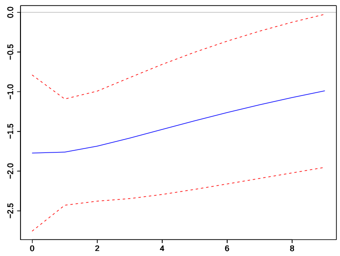
1b. Greece (Response of yield spread to DtD)



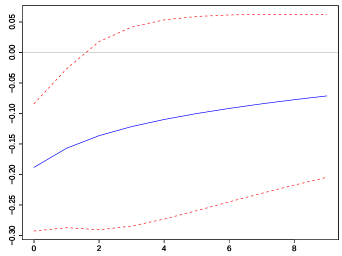
2a. Ireland (Response of DtD to yield spread)



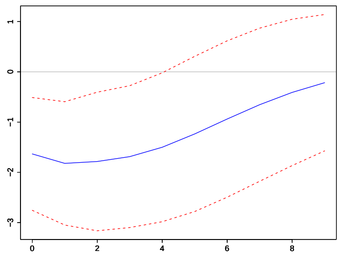
2b. Ireland (Response of yield spread to DtD)



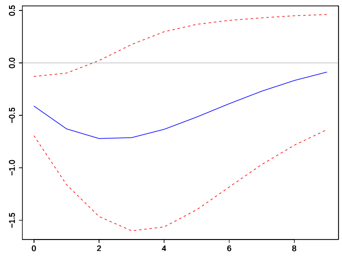
3a. Italy (Response of DtD to yield spread)



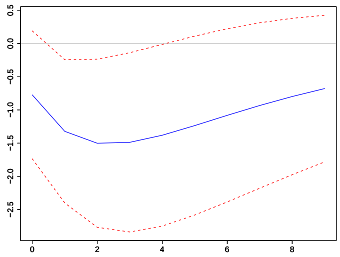
3b. Italy (Response of yield spread to DtD)



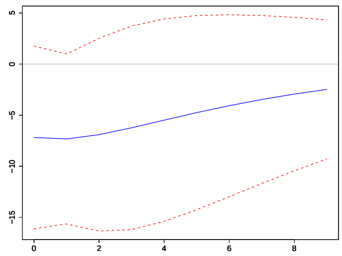
4a. Portugal (Response of DtD to yield spread)



4b. Portugal (Response of yield spread to DtD)



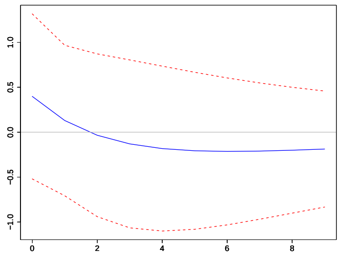
5a. Spain (Response of DtD to yield spread)



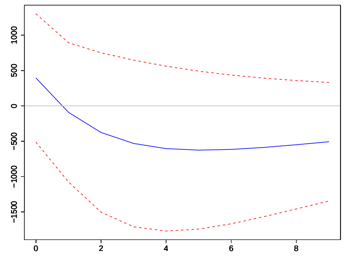
5b. Spain (Response of yield spread to DtD)

Notes: Standard error bands are computed using analytic respond standard errors.

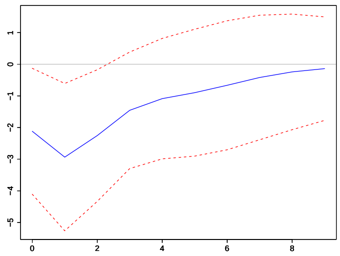
Figure 4.9: Generalized IRFs: Sovereign DtD and sovereign CDS spread



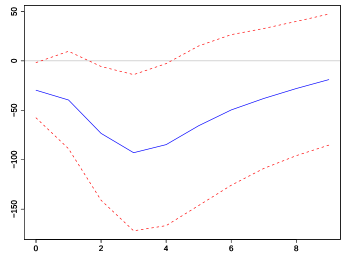
1a. Greece (Response of DtD to CDS spread)



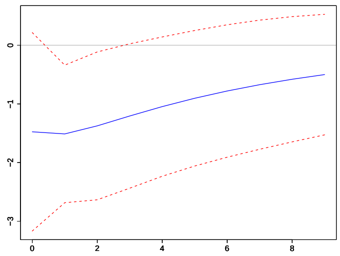
1b. Greece (Response of CDS spread to DtD)



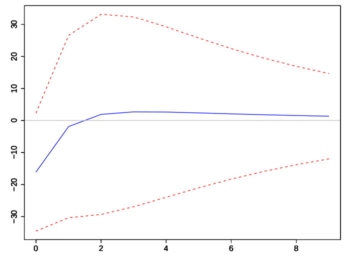
2a. Ireland (Response of DtD to CDS spread)



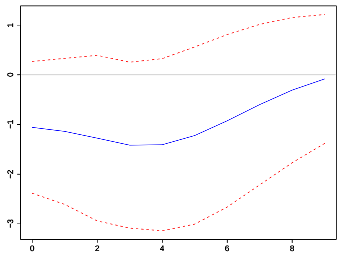
2b. Ireland (Response of CDS spread to DtD)



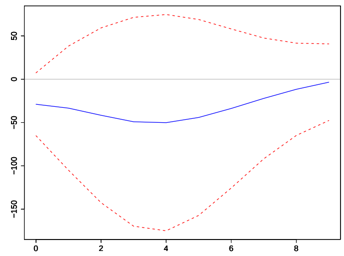
3a. Italy (Response of DtD to CDS spread)



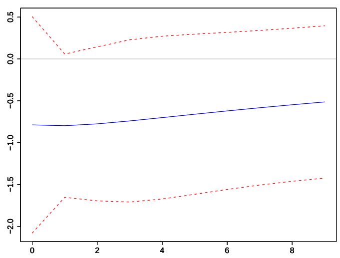
3b. Italy (Response of CDS spread to DtD)



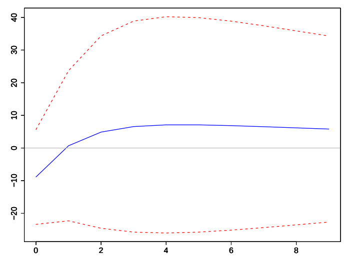
4a. Portugal (Response of DtD to CDS spread)



4b. Portugal (Response of CDS spread to DtD)



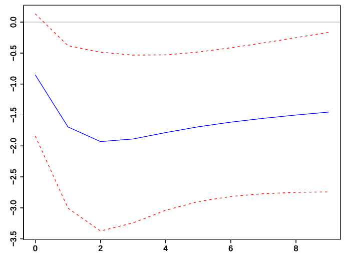
5a. Spain (Response of DtD to CDS spread)



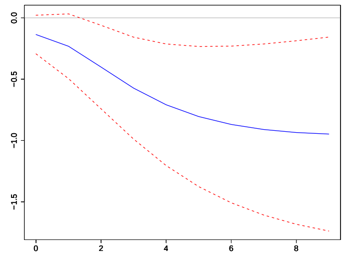
5b. Spain (Response of CDS spread to DtD)

Notes: Standard error bands are computed using analytic respond standard errors.

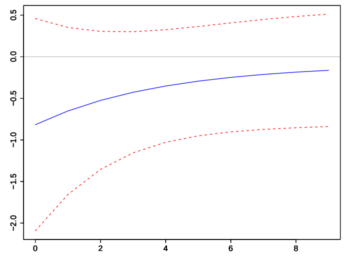
Figure 4.10: Generalized IRFs: Sovereign DtD and sovereign credit rating



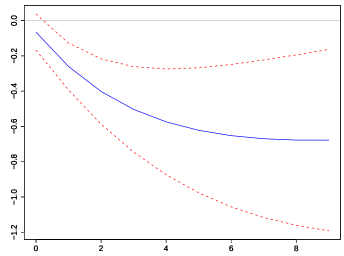
1a. Greece (Response of DtD to Credit Rating)



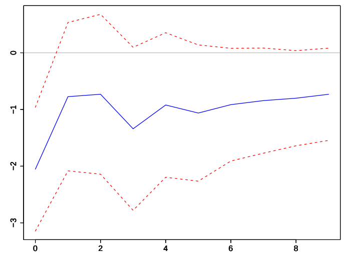
1b. Greece (Response of Credit Rating to DtD)



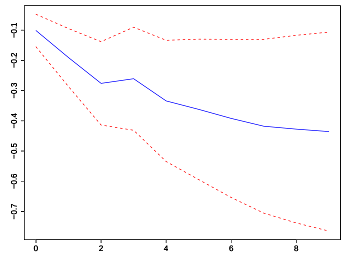
2a. Ireland (Response of DtD to Credit Rating)



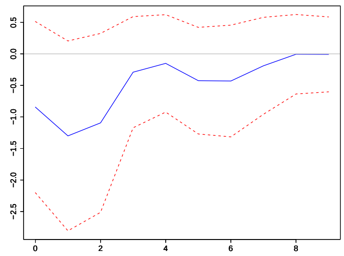
2b. Ireland (Response of Credit Rating to DtD)



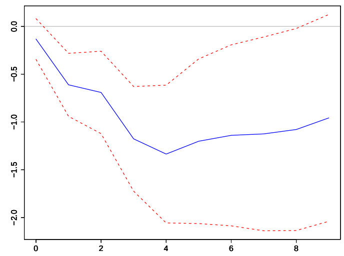
3a. Italy (Response of DtD to Credit Rating)



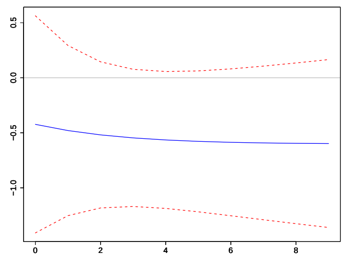
3b. Italy (Response of Credit Rating to DtD)



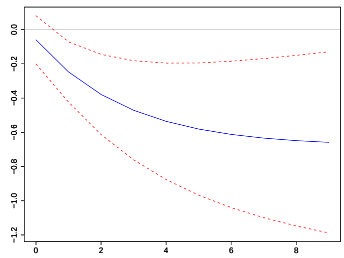
4a. Portugal (Response of DtD to Credit Rating)



4b. Portugal (Response of Credit Rating to DtD)



5a. Spain (Response of DtD to Credit Rating)



5b. Spain (Response of Credit Rating to DtD)

Notes: Standard error bands are computed using analytic respond standard errors.

4.7.4 Diebold-Yilmaz connectedness measure

In this subsection, we apply the Diebold-Yilmaz connectedness index methodology (Diebold and Yilmaz (2009, 2012, 2014)) to the four sovereign risk indicators under study. This connectedness measures is based on forecast error variance decompositions from vector auto-regressions (see Section 2.5.3). The variance decomposition matrix gives us an intuitively appealing connectedness measure, that is the percentage of the future uncertainty in variable i resulting from the shocks in variable j.

The full-sample connectedness is presented in Table 5.12. The ij^{th} entry of the upper-left 4×4 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-most 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.

As can be seen, the diagonal elements (own connectedness) are among the largest individual elements in the table, ranging from 31.37% (Yield spread) to 59.64% (CDS) in the case of Greece, from 20.22% (Credit rating) to 63.32% (Yield spread) in the case of Ireland, from 24.02% (Credit rating) to 44.30% (Yield spread) in the case of Italy, from 38.21% (CDS) to 56.20% (Credit rating) in the case of Portugal, and from 30.84% (Yield spread) to 59.47% (Credit rating) in the case of Spain. Interestingly, the own connectedness measures are 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 affecting a particular indicator spread on the other indicators. The total connectedness of the sovereign risk indicators varies between 53.82% in the case of Greece (indicating that 46.18% of the variation is due to idiosyncratic shocks) to 63.59% in Italy (indicating that 36.41% of the variation is due to idiosyncratic shocks). This result contrasts sharply with the value of 78.3% obtained by Diebold and Yilmaz (2014) for the total connectedness between US financial institutions and with the value of 97.2% found by Diebold and Yilmaz (2012) for international financial markets. Our result is closer to the value of 54.23% found by Fernández-Rodríguez et al. (2016) for the EMU sovereign market volatility.

Regarding the net (TO minus FROM) contribution, our results suggest that, in the case of Greece, DtD and CDS are net receivers of shocks from the other two sovereign risk indicators. For Ireland, we find that DtD and yield spreads are net triggers of shocks, and in Italy, we observe that DtD and credit ratings are net

Table 4.11: Country-wise net pairwise directional connectedness among sovereign risk indicators

		DtD	CDS	Yield Spread	Credit Rating	**Contribution from others**
	DtD	45.71	5.40	20.76	28.12	54.29
	CDS	1.62	59.64	20.07	18.67	40.36
Greece	Yield Spread	11.90	11.64	31.37	45.08	68.63
	Credit Rating	11.07	13.02	27.93	47.98	52.02
	Contribution to others	34.97	33.51	68.67	65.69	**Total Connectedness = 53.82**
	Net contribution	-19.32	-6.85	0.04	13.68	
		DtD	CDS	Yield Spread	Credit Rating	**Contribution from others**
	DtD	47.67	13.08	34.75	4.50	52.33
	CDS	17.21	24.31	57.74	0.75	75.69
Ireland	Yield Spread	23.69	12.57	63.32	0.42	36.68
	Credit Rating	54.15	4.26	21.37	20.22	79.78
	Contribution to others	66.60	55.17	64.26	21.90	**Total Connectedness = 61.12**
	Net contribution	14.27	-20.53	27.58	-57.88	
		DtD	CDS	Yield Spread	Credit Rating	**Contribution from others**
	DtD	39.84	25.93	30.25	3.98	60.16
	CDS	16.87	37.47	41.06	4.60	62.53
Italy	Yield Spread	18.67	35.43	44.30	1.61	55.70
	Credit Rating	15.26	27.99	32.73	24.02	75.98
	Contribution to others	56.04	70.45	70.14	29.79	**Total Connectedness = 63.59**
	Net contribution	-4.12	7.92	14.44	-46.19	
		DtD	CDS	Yield Spread	Credit Rating	**Contribution from others**
	DtD	40.87	25.25	24.80	9.08	59.12
	CDS	7.76	38.21	52.41	1.62	61.79
Portugal	Yield Spread	10.89	36.32	50.05	2.74	49.95
	Credit Rating	21.61	17.11	17.49	43.80	56.20
	Contribution to others	49.61	67.31	65.42	23.47	**Total Connectedness = 56.77**
	Net contribution	-9.51	5.52	15.47	32.73	
		DtD	CDS	Yield Spread	Credit Rating	**Contribution from others**
	DtD	38.42	24.08	27.56	9.94	61.58
	CDS	17.32	34.22	31.26	17.21	65.78
Spain	Yield Spread	17.49	31.56	30.84	20.11	69.16
	Credit Rating	16.41	14.96	9.16	59.47	40.53
	Contribution to others	57.14	67.35	68.79	44.28	**Total Connectedness = 59.26**
	Net contribution	-4.44	1.57	-0.37	3.74	

receptors of shocks. In the case of Portugal, CDS and yield spread are found to be net transmitters of shocks. Finally, in the case of Spain, our results indicate that DtD and yield spread are net receivers of shocks.

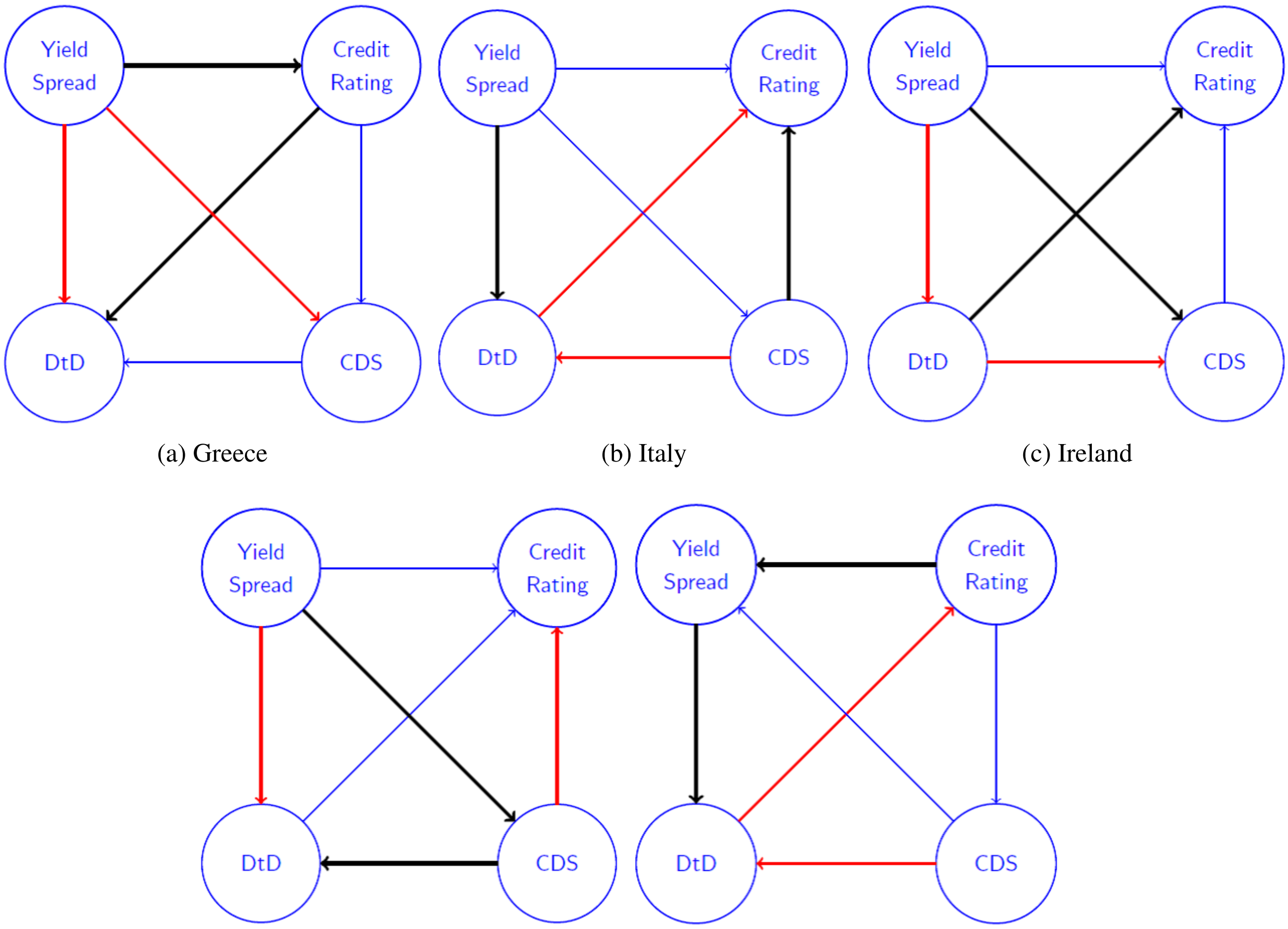
So far, we have discussed the behaviour of the total connectedness and total net directional connectedness measures for four sovereign credit indicators. However, in order to gain further insights, we have also examined their net pairwise directional connectedness. Figure 5.10 displays the net pairwise directional connectedness among the sovereign risk indicators for each country under study. As can be seen, yield spreads are the triggers in the connectedness relationships in all countries except Spain, where CDS is the main transmitter of shocks. DtD is a net receiver of shocks from all other indicators in the case of Greece, a receiver of shocks from yield spreads and CDS in the case of Italy, Portugal and Spain, and a net propagator of shocks to credit rating in all countries except Greece. Finally, credit rating is a net receiver of shocks from the other three sovereign risk indicators in the cases of Ireland, Italy and Portugal, and a net trigger of shocks to CDS in the cases of Greece and Spain.

4.7.5 Regression analysis

Finally, in this last subsection, we empirically evaluate the relevance of the variables that have been proposed in the recent theoretical and empirical literature as potential drivers of sovereign risk. To this end, we use a data-based method for obtaining a parsimonious representation of the data-generating process: the general-to-specific approach (for detail, see Hendry (1995)). In this approach, the modeller specifies an initial general model that adequately characterizes the empirical evidence within his or her theoretical framework. Starting from a general unrestricted model that captures the essential characteristics of the underlying dataset and contains all relevant variables and sufficient lags, this general model is reduced in complexity by eliminating statistically insignificant variables, checking the validity of the reductions at each stage to ensure the congruence of the finally selected model (see Faust and Whiteman (1997)). This method has proved useful in practice for selecting empirical economic models (see Hendry (2000)).

The dependent variables in our empirical analysis are the proposed DtD indicator and the three traditional measures of sovereign risk (yield spread, CDS, and rating). With regard to the independent variables (Table 4.12), we consider both fundamental variables and market sentiment variables (see, e.g., Gomez-Puig et al. (2014) and references within). Three of the fundamental variables are used to measure the country's fiscal position; the government debt-to-GDP ratio (DEBT), the government deficit-to-GDP (DEF) and the index of the fiscal stance (FSI) suggested

Figure 4.11: Country-wise net pairwise directional connectedness among sovereign 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. For each country, we first order the computed net directional connectedness values from the highest to the smallest and find the two points that divide the ordered distribution into three parts, each containing a third of the population.

by Polito and Wickens (2011, 2012). An increase in DEF and DEBT would signal an intensification in the sovereign risk, while a rise in the FSI would indicate a need for higher fiscal consolidation to achieve a pre-specified debt target at any future time horizon, and therefore would have a positive relationship with sovereign risk. Moreover, the inflation rate (INF) is used as a proxy of the appreciation of the real exchange rate and, thus, the country's loss of competitiveness. A rise in inflation represents a deterioration of competitiveness; therefore, it should increase sovereign risk. The same sign is expected for the unemployment rate (U) which proxies the country's growth potential, while a negative effect might be expected between an increase in the current account balance-to-GDP (CAC) and the sovereign risk.

Turning to the market sentiment variables, we used the implied volatility in the Standard and Poor's 500 index options (VIX) and a synthetic measure of financial market uncertainty in the EA (FMU) as indicators of uncertainty in the global financial and EA financial markets. We also consider the index of economic policy uncertainty (EPU), built by Baker et al. (2013), to assess whether policy uncertainty has influenced sovereign risk, and a country-level index of financial stress (CLIFS) to evaluate the degree of financial stress in national financial markets. A positive sign is expected for their respective coefficients. Finally, the consumer confidence indicator is used to gauge economic agents' perceptions of future economic activity. It seems reasonable to expect a negative relationship between this and sovereign risk, since an increase in consumer confidence may lead to a rise in investor confidence in the economy's potential for growth.

Tables 4.13-4.16 reports the empirical results. As can be seen, all explanatory variables turn out to be significant and their signs are in accordance with the literature.[21] An important result of these regression analyses is that, while market sentiment variables seem to play a dominant role in determining traditional measures of sovereign risk, macroeconomic fundamentals are identified as the main drivers of sovereign risk, as measured by the proposed DtD indicator. These results suggest that the DtD indicator isolates the fundamental and fiscal situation of the country better than the other three risk indicators, which are influenced much more by market sentiment and uncertainty.

In order to gauge the predictive power of our basic model and to assess how each explanatory variable contributes to the explanation of the dependent variable, we perform stochastic dynamic simulations. Table 4.17 reports the results for each sovereign risk indicator under study. Column 2 represents the actual values of the dependent variables averaged over the period of the analysis, while column 3 shows the averaged predicted values. The remaining columns present the contribution of

[21] Recall that, by construction, a reduction in DtD indicates an increase in sovereign risk.

Table 4.12: Variables that measure macroeconomic fundamentals and market sentiments

Variable	Description	Source
Variables that measure macroeconomic fundamentals		
Net position towards the rest of the world (CAC)	Current-account-balance-to-GDP	OECD
Growth potential (U)	Unemployment rate	Eurostat
Competitiveness (INF)	Inflation rate. Quarterly average of HICP monthly interannual rate of growth	Eurostat
Fiscal position (DEF)	Government deficit-to-GDP	Eurostat
Public debt (DEBT)	Government debt-to-GDP	Eurostat
Index of the Fiscal stance (IFS)	This indicator compares a target level of the debt-GDP ratio at a given point in the future with a forecast based on the government budget constraint. It was created by Polito and Wickens (2011, 2012)	Provided by Polito and Wickens for the 1999-2011 period and updated by the authors
Variables that measure market sentiment		
Variable	Description	Source
Index of economic policy uncertainty (EPU)	This index reflects the frequency of newspaper references to policy uncertainty and was built by Baker et al. (2013)	http://www.policyuncertainty.com
Consumer confidence indicator (CCI)	This index is built by the European Commission which conducts regular harmonised surveys of consumers in each country	European Commission (DG ECFIN)
Global risk (VIX)	A measure of implied volatility of the Standard & Poor's 500 Index	www.cboe.com
Country-Level Index of Financial Stress (CLIFS)	A composite indicator proposed by Duprey et al. (2017)	European Central Bank
Financial market uncertainty (FMU)	A synthetic measure of financial market uncertainty in the EA, calculated from bond markets, equity markets and the exchange rate (ECB (2016))	European Central Bank

the explanatory variables across countries. As can be seen, our results suggest that while macroeconomic fundamentals are the main drivers of sovereign risk measured by the proposed DtD indicator (explaining an average of 88.42%), market sentiment variables are identified as the key determinants of the traditional measures of credit risk (contributing to explain, on average, 75.05% of the CDS risk indicator in the sample, 61.80% of the yield spreads and 62.89% of the credit ratings).

Table 4.13: Regression results - Sovereign DtDs as dependent variable

	Greece	Ireland	Italy	Portugal	Spain
Constant	-39.845	33.5087	-198.6146	-92.7164	-15.3592
	(-2.1545)	(15.9688)	(-2.6483)	(-2.7918)	(-2.2581)
CCI			0.0992		
			(1.8844)		
CLIFS	-18.4588	-21.9271		-41.824	
	(-3.2603)	(-5.6606)		(-6.0840)	
FSI	-86.2261		-184.583	-101.4647	-29.8149
	(-3.4593)		(-2.3736)	(-2.5296)	(-7.5091)
EPU			-0.0564		-0.0325
			(-2.9011)		(-3.1594)
DEF		-0.1614			
		(-2.7778)			
DEBT	-0.1267	-0.1136	-0.1883	-0.1661	0.2216
	(-3.4674)	(-5.3969)	(-2.7243)	(-2.8143)	(3.7751)
INF		-0.9317	-2.1948	-16963	-0.8108
		(-2.2956)	(-3.0293)	(-5.3509)	(-1.9978)
Adjusted R^2	0.8177	0.6974	0.6522	0.7728	0.7115
DW Test	2.2196	2.1451	2.2685	2.2091	2.2731

Table 4.14: Regression results - Sovereign CDS as dependent variable

	Greece	Ireland	Italy	Portugal	Spain
Constant	1056.2241	3329.7553	789.7618	4636.6751	1116.8771
	(2.8330)	(2.7541)	(4.7277)	(3.7058)	(2.3506)
CCI	288.8605	33.1086		43.5238	9.6179
	(4.8956)	(2.6371)		(2.9516)	(2.4939)
VIX	146.7042	7.7496			6.2819
	(2.8256)	(2.7088)			(2.8521)
CLIFS	4476.9251		763.4245	1089.3973	984.0513
	(2.6372)		(2.7691)	(2.7163)	(4.3163)
FMU		76.9658			
		(2.7486)			
FSI		1633.6370			106.5221
		(3.6631)			(4.3729)
EPU			2.9454		
			(3.4151)		
DEBT		13.1096	2.2288	1.5962	4.4881
		(3.5413)	(3.7286)	(2.7650)	(4.1051)
INF	1596.7260		50.2957	97.4861	
	(4.2451)		(3.5624)	(3.6849)	
Adjusted R^2	0.8595	0.7721	0.7836	0.7551	0.7551
DW Test	2.2237	2.2178	2.2422	2.232	2.2271

Table 4.15: Regression results - Sovereign yield spreads as dependent variable

	Greece	Ireland	Italy	Portugal	Spain
Constant		3.4359	5.6094	89.217	4.0921
		(3.4312)	(5.1998)	(4.5158)	(3.124)
CCI			-0.0308	0.8185	
			(-3.9038)	(-2.7399)	
VIX	0.2513		0.026	0.2304	0.0963
	(3.1691)		(2.7820)	(2.7747)	(4.2712)
CLIFS	20.3810	2.2155	2.1031	12.4637	7.2661
	(3.6375)	(2.7941)	(2.7661)	(3.4600)	(3.2550)
FMU		0.6990	0.2438		
		(2.8123)	(2.7362)		
FSI	9.9387	0.1389	2.1032	37.7502	1.0803
	(3.4181)	(3.9837)	(2.8121)	(4.3383)	(3.5735)
EPU	0.0934		0.0156		
	(3.4131)		(3.7134)		
DEF		0.0262			
		(-2.9370)			
DEBT	0.0579		0.025	0.2549	0.0068
	(2.7892)		(3.1542)	(3.1112)	(2.7653)
INF	0.6181				0.2608
	(2.3593)				(2.8981)
Adjusted R^2	0.7963	0.6715	0.7589	0.7154	0.847
DW Test	2.2712	2.2246	2.2137	2.2142	2.205

Table 4.16: Regression results - Sovereign credit ratings as dependent variable

	Greece	Ireland	Italy	Portugal	Spain
Constant	8.0092	1.9588	87.9446	83.0416	
	(3.5636)	(3.3996)	(5.5008)	(5.6072)	
CCI	-0.0232	-0.0258		-0.0708	-0.0751
	(-1.9934)	(-3.8802)		(-2.1954)	(-3.2737)
VIX	0.0856	0.0161	0.0221	0.0202	0.0532
	(2.7640)	(2.7541)	(2.8178)	(2.8086)	(2.9683)
CLIFS	7.1819	3.3777	1.4153	8.9597	8.5063
	(3.5540)	(3.2121)	(2.7448)	(3.4548)	(3.8129)
FSI			67.995	58.0251	
			(3.4965)	(3.5573)	
EPU	0.0177				0.0057
	(3.0587)				(2.0121)
DEBT	0.1369	0.067	0.0286	0.3945	0.1627
	(3.0109)	(2.9817)	(2.8517)	(3.0699)	(3.7364)
INF					0.1944
					(2.7352)
Adjusted R^2	0.8081	0.8432	0.8314	0.8458	0.8374
DW Test	2.2239	2.2716	2.2766	2.1798	2.7612

Table 4.17: Predictive power and relative contributions of the explanatory variables

Panel I: Sovereign DtD model

Country	Actual DtD	Predicted DtD	CCI	CLIFS	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
			Individual Contributions (%)							Aggregate contribution (%)	
Greece	15.07	15.04	0	3.47	79.12	0	0	17.42	0	96.53	3.47
Ireland	13.39	13.36	0	35.30	0	0	6.04	49.05	9.60	64.70	35.30
Italy	18.75	18.69	3.13	0	84.35	2.45	0	8.42	1.66	94.43	5.57
Portugal	10.78	10.73	0	5.26	78.00	0	0	14.96	1.77	94.74	5.26
Spain	17.57	17.51	0	0	55.86	8.30	0	31.88	3.97	91.70	8.30

Panel II: Sovereign CDS model

Country	Actual CDS	Predicted CDS	CCI	VIX	CLIFS	FMU	FSI	EPU	DEBT	INF	Macroeconomic fundamentals	Market sentiment
			Individual Contributions (%)								Aggregate contribution (%)	
Greece	8200.64	8185.88	79.42	10.11	3.65	0	0	0	0	6.81	6.81	93.19
Ireland	261.63	258.97	51.02	3.73	0	1.12	16.46	0	27.67	0	44.13	54.75
Italy	148.36	146.88	0	0	15.48	0	0	44.61	33.86	6.06	39.91	60.09
Portugal	318.58	315.77	88.79	0	4.07	0	0	0	4.25	2.89	7.14	92.86
Spain	140.77	139.22	54.32	8.73	11.32	0	4.09	0	21.53	0	25.63	74.37

Panel III: Sovereign yield spread model

Country	Actual yield spread	Predicted yield spread	CCI	VIX	CLIFS	FMU	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
			Individual Contributions (%)									Aggregate contribution (%)	
Greece	4.53	4.53	0	13.12	9.22	0	21.96	32.97	0	19.18	3.55	44.70	55.30
Ireland	1.53	1.52	0	0	59.61	10.61	13.37	0	16.40	0	0	29.78	70.22
Italy	1.13	1.11	31.64	6.81	2.96	0.49	0	21.86	0	36.24	0	36.24	63.76
Portugal	2.04	2.02	41.53	16.72	0.87	0	26.18	0	0	14.71	0	40.89	59.11
Spain	1.06	1.04	0	40.73	19.86	0	18.68	0	0	8.66	12.06	39.41	60.59

Panel IV: Sovereign credit ratings model

Country	Actual credit rating	Predicted credit rating	CCI	VIX	CLIFS	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
			Individual Contributions (%)								Aggregate contribution (%)	
Greece	10.01	9.91	42.27	4.35	3.16	0	6.09	0	44.12	0	44.12	55.88
Ireland	3.35	3.29	67.01	1.73	4.26	0	6.42	0	20.57	0	20.57	79.43
Italy	5.06	5.01	0	26.27	9.01	45.91	18.81	0	0	0	45.91	54.09
Portugal	6.46	6.40	38.51	2.65	0.67	36.43	21.74	0	0	0	36.43	63.57
Spain	3.77	3.77	25.75	3.95	4.25	0	27.54	0	36.97	1.53	38.50	61.50

Notes: The results are obtained based on the models presented in Table 4.13 to 4.16.

4.8 Concluding remarks

Based on the theory and practice of modern contingent claims methodology, this paper proposes a modified contingent claims model that incorporates the priority structure of creditors in measuring sovereign credit risk for euro area peripheral countries. These new risk indicators model an important element - the total debt held by multilateral creditors (i.e., the ECB, IMF, ESM etc.), which provides additional information and helps to reconcile the country's credit risk with its underlying economic fundamentals.

By analysing the behaviour and fluctuations of sovereign DtD, our results show that the new credit risk indicator is less correlated across countries than the existing market based credit risk indicators (i.e., CDS spreads, sovereign yield spreads and credit ratings). Even though they share a highly correlated underlying factor linked with global risk and uncertainty, its weight diminishes in times of crisis. Sovereign DtD shows better predictive ability (1-4 quarters) and very high correlations for most of the peripheral EA countries. The Granger causality test reveals the direction of causality running from sovereign DtDs to yield spreads and credit ratings (and not the other way round), suggesting better information content.

Generalized VAR also provides evidence of the additional information content of the proposed sovereign risk indicator in explaining the traditional ones when accounting for dynamic interrelationships between them. When analysing the connectedness between the sovereign risk indicators using the framework proposed by Diebold and Yilmaz (2012, 2014), we found system-wide values ranging from 53.82% in the case of Greece to 63.59% in Italy. Finally, the regression analysis suggests that macroeconomic fundamentals are the main drivers of sovereign risk measured by the proposed sovereign DtD indicator, while market sentiment variables are the key determinants of the traditional measures of credit risk.

Our results show that the alternative sovereign credit risk measure proposed has a meaningful signalling power in assessing sovereign vulnerabilities, suggesting a potential role in the policy makers' tool box for monitoring risks and vulnerabilities. This is relevant given the recent trend among policy makers to give a greater focus to financial stability analysis, financial system resilience, crisis prevention, and management.

There are several natural extensions to our analysis. Policies aimed at reducing sovereign risk should be explored in detail in future work. Going forward, the DtD framework could be extended beyond the sovereign context. In addition, given the flexibility of this framework, the financial sector and sovereign risk analysis could be integrated with macro-financial feedbacks in order to design monetary and fiscal policies.

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5 Revisiting the sovereign-bank linkages: Evidence from contingent claims analysis

SUMMARY

We analyse the interconnection between the sovereign and banking sector credit risk in the peripheral euro area countries over the 2004Q4-2013Q2 period. Applying the contingent claims methodology, 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 interconnection based on principal components analysis, Granger causality network and Diebold-Yilmaz's connectedness index. The empirical results show strong connectedness and co-movement between country-level banking and sovereign risk indicators. However, we 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 find weak interconnection and more divergence across the various risk indicators. Our findings also suggest that secondary and derivatives market indices are more driven by common underlying factors than are contingent claim based risk measures.

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

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"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)

5.1 Introduction

The European sovereign debt crisis, which started in late 2009, raised serious concerns about the negative feedback loop between sovereign and bank credit 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 vicious cycle 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).

However, there exist some irreconcilable differences between empirical researchers regarding the underlying nature of the sovereign-banking nexus observed. Comparing the sovereign risk of the UK and Spain, De Grauwe (2012) notes the higher default risk premium on government bonds in Spain than in the UK, even though the UK faces less favorable sovereign debt and deficit dynamics and a comparable banking sector risk. De Grauwe argues that this difference in the evaluation of the sovereign default risks is related to the fact that Spain belongs to a monetary union, while the UK does not and therefore has control over the currency in which it issues its debt. This loss of control over the currency makes euro area countries and banks equally dependent on the European Central Bank in times of crisis, thus increasing the linkages between banks and sovereign risk.

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.

In this paper we try to broaden our understanding of the sovereign-bank linkages by statistically assessing the contagion and amplification mechanisms, without taking a clear stand on the causes of the increasing/decreasing interconnection; we are more concerned with the identification of bi-directional linkages between the sovereign and the banking sector and with quantifying the magnitude of that spillover from one part of the system to another and its resulting impact. Our aim is to review the results presented in Chapter 3 since our primary credit risk indicator is the contingent claim model-based distance-to-default (DtD) measure for banks and sovereigns (this measure was only used for banks in Chapter 3). However, to check the robustness of our results, we use two other banking and sovereign risk indicators based on the secondary market (sovereign yield spreads and banking sector equity returns) and the derivatives market (banking sector average CDS spreads and sovereign CDS spreads).

In addition, we also use three different econometric techniques to uncover the underlying interconnection structure in the data and apply them to the quarterly bank and sovereign risk indicators. The econometric techniques we use are: principal component analysis, pairwise Granger causality, and Diebold and Yilmaz's connectedness index. Principal component analysis is used to analyze the interrelationships between the sovereign and the banking sector and to explain these variables 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.[1]

While acknowledging the achievements of various studies that identify the sources of systemic risk, we have nonetheless detected a gap in the literature. First, by incorporating the role of multilateral creditors to measure sovereign risk using publicly available data, we try to fill this gap within the framework of the existing theoretical models. Secondly, we quantify the magnitude and direction of interconnection between banking and sovereign risk measures using three alternative risk indicators to provide robust evidence to support or refute previous findings. The idea of interconnection here is not directly related to any grand unifying theory. We assess the interconnection using a variety of statistical measures without imposing any restric-

[1] 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.

tion on the dynamics. An exhaustive summary of all plausible reasons for direct and indirect interconnection are presented in Section 5.3.

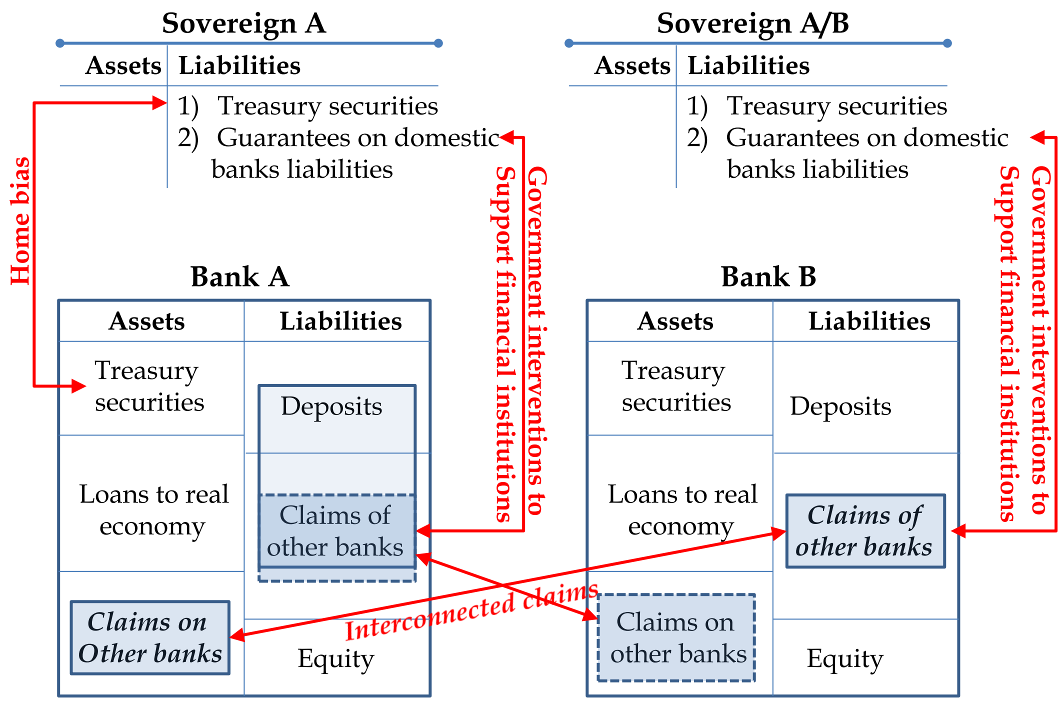
Our results suggest that the banking and sovereign credit risk are highly interconnected during the time period we study. Also, there is clear evidence of an increasing role of idiosyncratic risk factors driving the evolution of all the risk indices in the post-crisis period, thus supporting the claims 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. 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.

The rest of the paper is organized as follows. In Section 5.2 we provide a simple framework for an overview of the idea of interconnection. Section 5.3 explains the channels via which interconnections arise between sovereign and bank risk with a brief review of the related literature. Section 5.4 describes the credit risk indicators used in our empirical analysis of the interconnections. Section 5.5 explains the econometric methodology used to assess the interconnections between the bank and sovereign risk indicators. Section 5.6 presents the empirical findings, whilst Section 5.7 offers some concluding remarks.

5.2 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 5.1 shows the stylized balance sheet of a financial institution and its direct inter-linkages with the sovereign balance sheet. The figure is purely schematic and is not intended to indicate the relative magnitudes of the various parts of the balance sheet. Bank 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 5.1: Direct linkages between sovereign and financial institutions



The bank's liabilities include obligations to depositors, other financial entities and bank's equity holders. Bank deposits in most countries 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. 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. Bank equity is the owner's capital and is of great interest to regulators. It is kind of skin-in-the-game of promoters and shareholders of the bank. The sovereign liabilities consist of - Treasury securities issued by the sovereign and explicit/implicit guarantees provided by the government on domestic banks' liabilities.

5.2.1 Why does financial interconnection arise? Channels of interconnection

Consider N financial institutions indexed by i which are distributed across M countries indexed by j ($M < N$). Consider a financial institution i, having a risk exposure x_i, based in country j. Assume that fractions α_{ij} $(j \in 1, 2, .., M)$ of this exposure are directly concerned with 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 $(\sum_{j=1}^{M} \alpha_{ij}) x_i$.[2] 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. These are risk exposure which is 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,

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

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:

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

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 $\hat{\pi}_i$ in case of crisis. In the following section, we review the literature of models explaining the reasons for this variation.

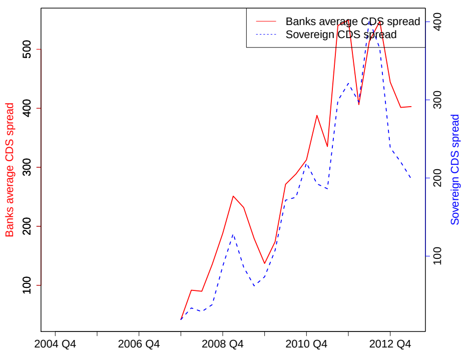
5.3 Literature: Direct and indirect linkages between sovereigns and banks

5.3.1 Sovereign-bank linkage

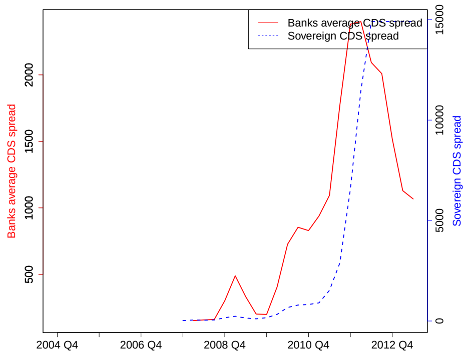
A review of the channels through which sovereign risk can affect bank risk (and vice versa) was widely presented in Section 3.1. Based on those linkages, some authors have described the development of a "diabolic loop" as the major cause of the crisis in euro area countries. European banks, encouraged by the absence of any regulatory discrimination between bonds, held an excessive part of their own national debt (see Figure 2.2b), which fed speculation on the banks' solvency. In turn, sovereigns were in constant danger of having to rescue their own banks, which, combined with the uncertainty regarding the fiscal support they would receive from their European partners, increased the riskiness of their bonds (see Brunnermeier et al. (2011) and Reichlin (2013)). Hence, in times of crisis, banks and sovereign default risk start moving in locksteps (see Figure 5.2). In addition, although Section 3.2 summarizes the literature focused on the joint dynamics between sovereign and bank risk, some recent contributions should be added to that literature review: De Marco and Macchiavelli (2016), Ongena et al. (2016), Altavilla et al. (2016), Kallestrup et al. (2016) and Horváth et al. (2015).

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.

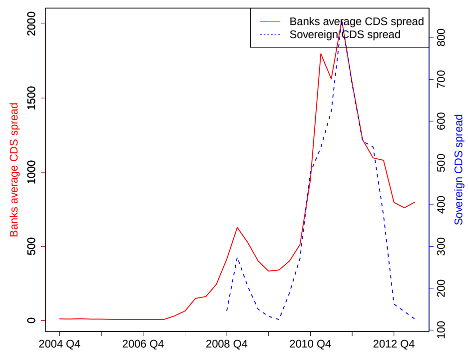
Figure 5.2: Banking sector average CDS spreads vs Sovereign CDS spreads



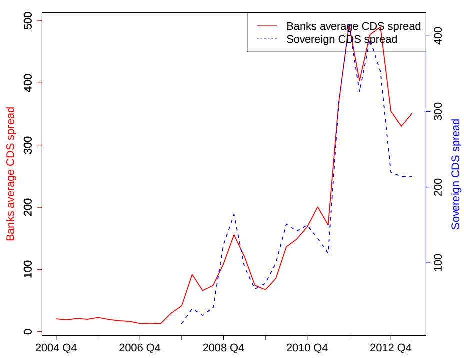
(a) Spain



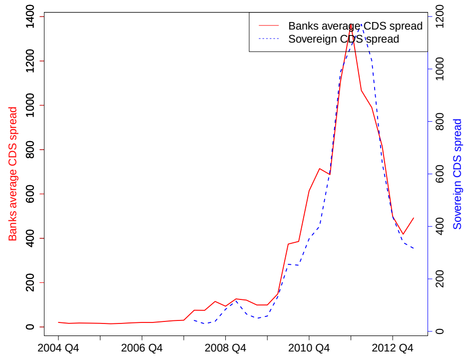
(b) Greece



(c) Ireland



(d) Italy



(e) Portugal

Using propriety data on banks' monthly securities holdings, Ongena et al. (2016) also show that in times of crisis, European banks in fiscally 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. (2016) 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.

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.

5.3.2 Bank-bank linkage

Direct bank linkages arise from the network of bi-directional claims that banks hold against each other (as shown in Figure 5.1). These network connections usually have positive effects as they diversify the risk exposure of individual banks. However, they also open channels through which negative shocks can spread throughout the system. The rest of this subsection explains the channels via which negative shocks propagate in our current financial system.

i. DIRECT LOSS SPILLOVERS THROUGH DEFAULT: Imagine an entity that has sold guarantees in the form of Credit Default Swaps and reneges on its contractual obligation at the payment date. In this case, the default of this entity can bring down all its counterparties, causing cascading losses and collapses throughout the financial system (e.g., the case of AIG in the summer of 2008). Eisenberg and Noe (2001) provided the basic network model that became the backdrop for much subsequent work on contagion in financial networks.

ii. MARK-TO-MARKET LOSS: Losses in the financial network can spread from one node to another through changes in the market value of underlying assets. When market prices drop, financial intermediaries need to liquidate their assets in order to meet funding and collateral constraints. These new sales amplify the downturn, leading to further sales, and so on, leading to a self-reinforcing liquidity crisis. Allen and Gale (2004), Brunnermeier and Pedersen (2009) and Diamond and Rajan (2005) present different mechanisms via which this can affect market conditions.

iii. FUNDING RUN: When short-term funding becomes scarce, the financial institutions which have high dependence on short-term funding find it extremely difficult to rapidly adjust to the new situation. This creates fear among market participants who start to hoard excess liquidity as a precautionary measure, leading to further liquidity shortage - as happened during the days following the Lehman bankruptcy. Heider et al. (2015) provide evidence of interbank market freeze during the 2008 financial crisis while Acharya et al. (2011) does so for the case of repo markets.

iv. INFORMATION CONTAGION: A disclosure by one bank regarding its assets may lead creditors to make inferences about the assets held by other banks, producing "information contagion." If one bank is forced to sell illiquid assets and in so doing drives down the price of these assets, then other banks holding similar assets incur fire-sale externalities through the price drop (see Chen (1999), Acharya and Yorulmazer (2008b), Aghion et al. (2000) and Acharya and Thakor (2016)).

v. CONTAGION THROUGH CORRELATION: Shock outside a particular asset class can force banks to sell their most liquid securities in order to raise cash quickly. This transfers the negative shock from a less liquid asset class to highly liquid market securities. Other market participants observing this sale can join in the sell-off, and this pattern can continue for a few days. Khandani and Lo (2011) document this rapid deleveraging for quant hedge funds in August 2008. Note that these are not conventional fire sale, as the assets sold are highly liquid.

vi. COMMON EXPOSURE: Banks expose themselves to the same risk by investing in similar assets. This may be due to the negative externalities arising from the failure of another bank (see Acharya and Yorulmazer (2008b); Acharya (2009)) or the herding behaviour generated by the financial regulations as shown in Farhi and Tirole (2012) and Acharya and Yorulmazer (2008a).

5.3.3 Sovereign-sovereign linkage

Sovereigns are not directly linked to each other. However, in times of crisis, they do coordinate and support each other by providing foreign currency credit lines to central banks in order to mitigate tensions arising in the foreign currency markets. Sovereigns implicitly guarantee these foreign currency loans. An indirect way in which sovereigns might be connected is the 'wake-up call' hypothesis suggested by Goldstein (1998). Since financial markets become more sensitive to market fundamentals in times of crisis, the system moves to a new equilibrium where the same risk is priced differently (see Beirne and Fratzscher (2013)).

5.4 Bank and sovereign risk indicators: Data and preliminary analysis

To measure the vulnerability of banks and sovereigns, we use the contingent claims literature and derive a set of credit risk indicators. To validate our results, we compare them with other market-based indicators of bank and sovereign risks. The variables and data sources are summarized in Table 5.1.

Table 5.1: Description of variables

Variable	Description	Frequency	Source
$BankDtD$	Banks average DtD based on the DtD of a sample of banks headquartered in each country. For the list of banks used in the calculation and for the detailed methodology, please refer to Chapter 2.	Quarterly	Author's calculation
$SovDtD$	Sovereign DtD. For detailed methodology, please refer to Chapter 4.	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 5.2.	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. For detailed calculation, please refer to Chapter 2.	Quarterly	Datastream
$SovSPR$	Difference between the 10 year benchmark yield of a country over Germany.	Quarterly	Eurostat

5.4.1 Banking sector risk measures

To assess the banking sector risk in each individual country, we use three different bank risk measures. Two of them are standard market-based measures, while the third one is based on both market and balance sheet based information. The rest of the subsection enumerates them in greater detail.

1. Banking sector average DtD ($BankDtD$)

To assess the banking sector risk in each EMU country, we use the country-wise banking sector $aDtD$ indicator developed in Chapter 2. $aDtD$ can be interpreted as the number of standard deviations the asset value of the banking sector in each country is away from its default barrier. The closer it is to zero, the closer the banking sector is to distress.

2. Banks average CDS spreads (*$BankCDS$*)

Based on the derivatives market, we use bank CDS daily mid-quotes from Datastream for the five peripheral euro area economies, namely Greece, Ireland, Italy, Portugal, and Spain. The data are available from 2007Q4 until 2013Q2. 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 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 5.2).

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' headquarters in a particular country. The detailed calculation methodology is explained in Chapter 2. All indices are normalized to 100 (at the beginning of the last quarter in 2004) for all countries.[3]

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). Table 5.3 provides summary statistics of all banking sector credit 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.

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

[3]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.

Table 5.2: 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).

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.

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 5.4. To evaluate these results, we use the

Table 5.3: Summary statistics of banking sector risk measures

Country	Mean	Standard Deviation	Minimum	Median	Maximum	Skewness	Kurtosis	SE	N
Average banking sector Distance-to-default 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 (CDS) 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.

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.[4]

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

[4] 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.

Table 5.4: Correlations between banking sector risk measures

	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT
			$BankDtD$					$BankCDS$					$BankEQU$		
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

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 $BankEQU$.

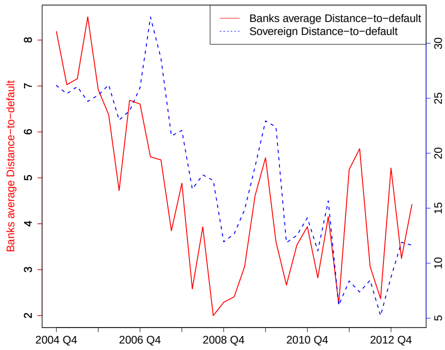
5.4.2 Sovereign risk measures

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

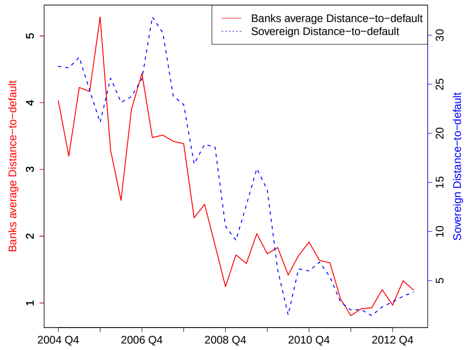
1. Sovereign distance-to-default ($SovDtD$)

As has been said, the country-wise sovereign DtD ($SovDtD$) indicator developed in Chapter 4 is our fundamental measure to assess sovereign risk in each country. $SovDtD$ can be interpreted as the number of standard deviation the sovereign's assets value are away from its debt obligations. The closer it is to zero, the closer the sovereign is to distress. Figure 5.3 shows the evolution of $SovDtD$ and $BankDtD$ for each country considered in our analysis.

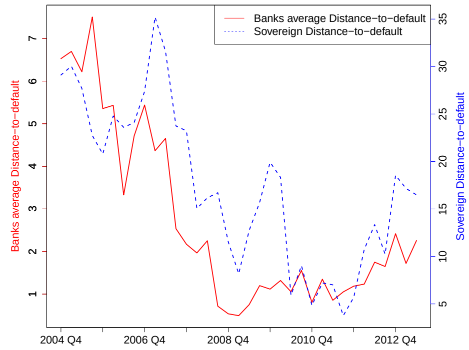
Figure 5.3: Banking sector average DtD ($BankDtD$) vs Sovereign DtD ($SovDtD$)



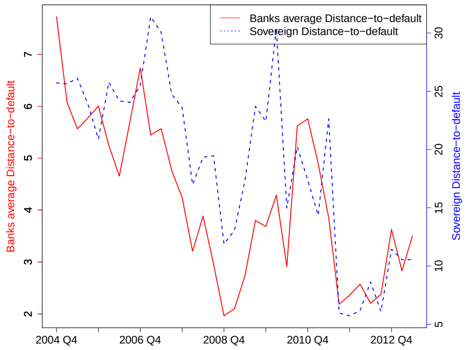
(a) Spain



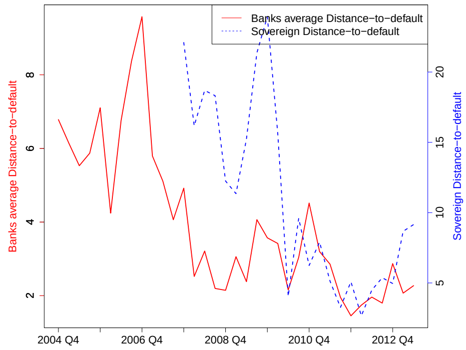
(b) Greece



(c) Ireland



(d) Italy



(e) Portugal

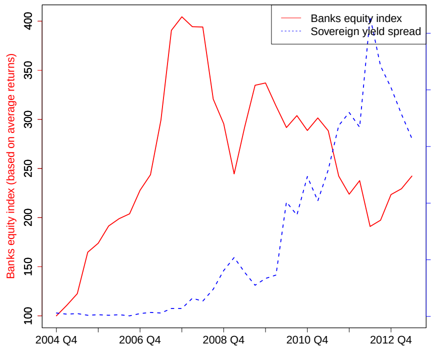
2. Sovereign CDS spreads ($SovCDS$)

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 5.2 shows the evolution of $SovCDS$ and $BankCDS$ for each country considered in our analysis.

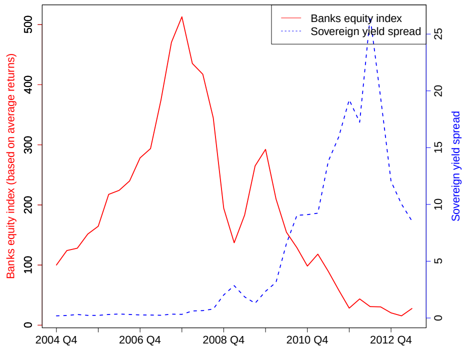
3. Sovereign yield spreads ($SovSPR$)

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 5.4 shows the evolution of $SovSPR$ and $BankEQU$ for each country considered in our analysis.

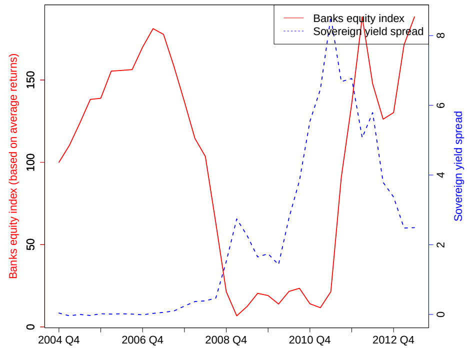
Figure 5.4: Banking sector equity index ($BankEQU$) vs Sovereign yield spreads ($SovSPR$)



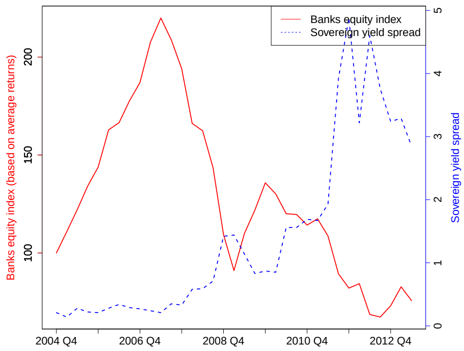
(a) Spain



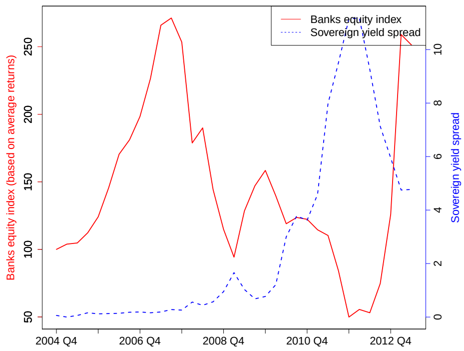
(b) Greece



(c) Ireland



(d) Italy



(e) Portugal

Commonality and differences among sovereign credit risk measures

Our sample contains Greece, Ireland, Italy, Portugal and Spain and we use quarterly data from 2004-Q4 to 2013-Q2. Table 5.5 provides summary statistics of all sovereign credit 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.

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

Table 5.5: Summary statistics of sovereign risk measures

Country	Mean	Standard Deviation	Minimum	Median	Maximum	Skewness	Kurtosis	SE	N
Sovereign Distance-to-default measure									
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
Five year benchmark Sovereign credit default swap (CDS) spreads									
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 over Germany									
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

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 5.6. 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.[5] 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 5.6: Correlations between different sovereign risk measures

	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT	ES	GR	IR	IT	PT
	$SovDtD$					$SovCDS$					$SovSPR$				
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

5.4.3 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

[5] 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.

correlation between each sovereign risk indicator is based on the common sample. The correlations matrices are shown in Table 5.7.[6] 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 $SovCDS$.

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

5.5 Methodology: Assessing interconnection

We use several econometric techniques to assess the interconnection between the banking sector and sovereign credit risk indicators without modelling the details of the entire network structure. We show that just by including the banks and sovereign credit 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 ac-

[6] 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.

Table 5.7: 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	-0.8	0.72	-0.81	0.95
$BankEQU$	0.84	-0.8	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	-0.8
$SovSPR$	-0.77	0.95	-0.78	0.69	-0.8	1
Ireland	$BankDtD$	$BankCDS$	$BankEQU$	$SovCDS$	$SovDtD$	$SovSPR$
$BankDtD$	1	0.03	0.67	-0.19	0.5	-0.05
$BankCDS$	0.03	1	0.3	0.91	-0.59	0.9
$BankEQU$	0.67	0.3	1	0.18	0.21	0.15
$SovCDS$	-0.19	0.91	0.18	1	-0.72	0.92
$SovDtD$	0.5	-0.59	0.21	-0.72	1	-0.67
$SovSPR$	-0.05	0.9	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	-0.8	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	-0.8	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	0.2	0.09
$BankCDS$	0.01	1	-0.9	0.96	-0.88	0.94
$BankEQU$	0.06	-0.9	1	-0.88	0.82	-0.88
$SovCDS$	0.04	0.96	-0.88	1	-0.84	0.96
$SovDtD$	0.2	-0.88	0.82	-0.84	1	-0.82
$SovSPR$	0.09	0.94	-0.88	0.96	-0.82	1

count 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.

5.5.1 Principal component analysis

To measure the commonality among the sovereign and banking sector credit risk indices, we use Principal Component Analysis (PCA), a technique in which the credit risk of all institutions (individual sovereigns and their banking sector) is decomposed into orthogonal factors of decreasing explanatory power (refer to Muirhead (1982) for detailed exposition). We follow Billio et al. (2012). More formally, let C_i be the credit risk of institution i, $i = 1,2,3,..,N$. Let $E[C_i] = \mu_i$ and $Var[C_i] = \sigma_i$, then the variance of the system σ_S will be,

$$\sigma_S^2 = \sum_{i=1}^{N}\sum_{j=1}^{N} \sigma_i \sigma_j E[R_i R_j]$$

where, R_k is the standardized credit risk of institution k given by $R_k \equiv (C_k - \mu_k)/\sigma_k$ for $k = i,j$. We now introduce N zero-mean uncorrelated variables ζ_k for which,

$$E[\zeta_k \zeta_l] = \begin{cases} \lambda_k, & \text{if } k = l \\ 0, & \text{if } k \neq l \end{cases}$$

and all the higher order co-movements are equal to those of R_i's, where λ_k is the k-th eigenvalue. We express the R_i's as a linear combination of the ζ_k's

$$R_i = \sum_{k=1}^{N} L_{ik} \zeta_k$$

where L_{ik} represents the factor loadings for ζ_k for an institution i. Thus, we have

$$E[R_i R_j] = \sum_{k=1}^{N}\sum_{l=1}^{N} L_{ik} L_{jl} E[\zeta_k, \zeta_l] = \sum_{k=1}^{N} L_{ik} L_{jk} \lambda_k$$

$$\sigma_S^2 = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N} \sigma_i \sigma_j L_{ik} L_{jk} \lambda_k$$

PCA yields the decomposition of the variance-covariance matrix of the credit risk measures into the orthogonal matrix of loadings L (eigenvectors of the correlation matrix) and the diagonal matrix of eigenvalues Λ. Usually, the first few eigenvalues (denoted by n) explain most of the variation of the system. This subset captures a larger proportion of variations when a majority of credit risk indices move together, as is often associated with stress episodes. Therefore, periods in which few principal components (PCs) explains more than a fraction H of the total variation are indicative of the increase in interconnection.

To classify periods of increasing interdependence, we define $\Omega = \sum_{k=1}^{N} \lambda_k$ and $\omega = \sum_{k=1}^{n} \lambda_k$ as the total risk of the system and the risk associated with the first n PC respectively. The ratio of the two above values can be defined as "Cumulative Risk Fraction (CRF)" to capture the periods of increased interconnection:

$$CRF = \frac{\omega}{\Omega}$$

When the system is highly interconnected, a small number n of N principal components can explain most of the variation in the system. By examining the time variation in the magnitudes of CRF, we will be able to detect increasing correlations between institutions, i.e., increased linkages and integration as well as similarities in risk exposures, which can contribute to systemic risk. We also compute a matrix which calculates the proportion of the variance in each original variable C_i accounted for by the first n factor, which is given by the sum of the squared factor loadings.

5.5.2 Granger causality

In this subsection, we apply two measures of interconnection based on linear Granger causality tests to quantify the magnitude and directionality of linkages between banking and sovereign risk indicators: a static and a dynamic measure. The detailed methodology used in both cases is widely explained in Section 3.5.

Following the methodology, we first establish the directionality of Granger causal linkage. Then following Billio et al. (2012), we define the following measure of causality:

$$Y \rightarrow X = \begin{cases} 1, & \text{if Y Granger causes X} \\ 0, & \text{otherwise} \end{cases}$$

and define $Y \rightarrow Y \equiv 0$. This measure is then used to define the network-based measure of interconnection between the N banking and sovereign risk indicators. We define the *Degree of Granger Causality (DGC)* for a risk indicator as the fraction of statistically significant Granger-causality linkages with the rest $(N-1)$ of the risk indicators. For example, if the banking sector risk indicator of Italy Granger causes m other risk indicators in our sample, then DGC $= (m/(N-1))$.

5.5.3 Diebold-Yilmaz's connectedness measure

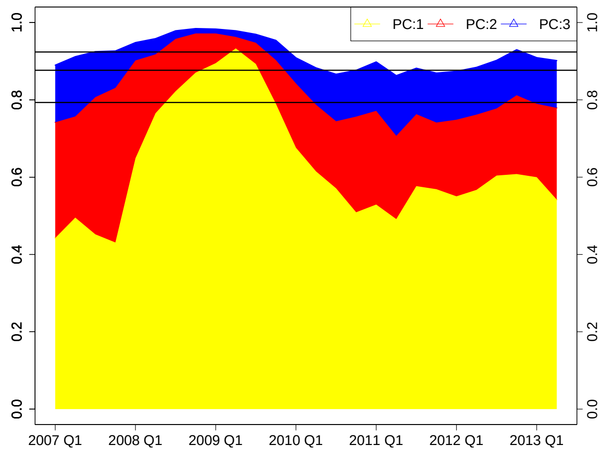
To explore further the systemic underlying component among various credit risk indices, we use the VAR (vector auto regression) methodology based measure of connectedness proposed in Diebold and Yilmaz (2009, 2012, 2014). For the detailed calculation methodology, please refer to Section 2.5.3.

5.6 Empirical results

5.6.1 Principal components analysis (PCA)

To measure the commonality between sovereign and banking sector credit risk indices, we apply the PCA methodology as discussed in Section 5.5. However, 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 5.5. 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 5.5: PCA of the normalized indices of sovereign and banking sector credit risk 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.

The first principal component is very dynamic and captures between 43% to 93%

of the variation in credit risk. Starting from a low level of roughly 45%, it starts to increase rapidly in 2008. We see 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. 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 5.8 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 5.8: Principal component analysis results

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 5.9 documents the proportion of the variance in each original variable credit 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.

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 credit 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 5.9),[7] 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.

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 5.9), 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.

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

Table 5.9: Connectedness 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 $BankCDS$

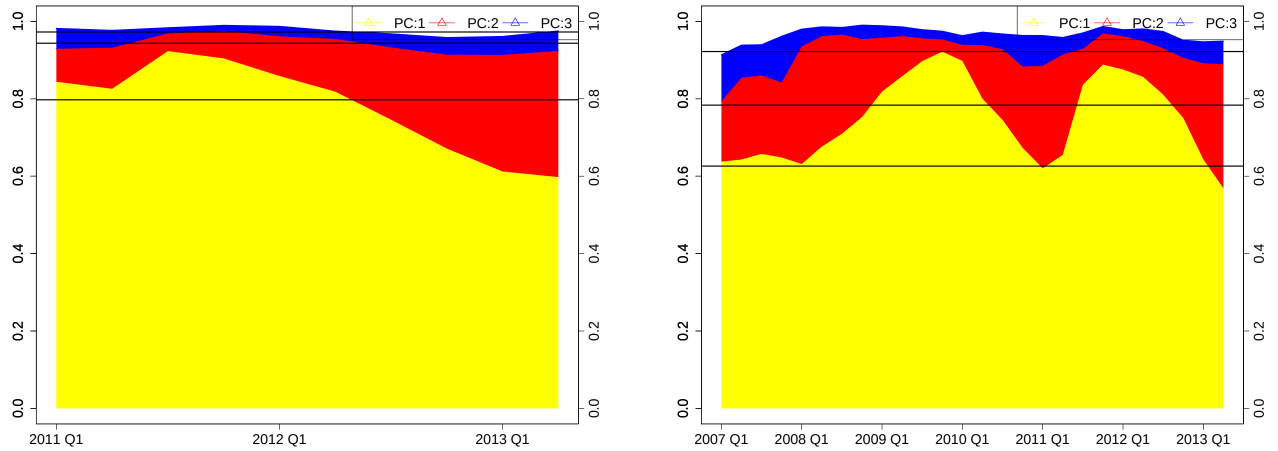
	Full-sample			Pre-crisis (2004Q4-2008Q3)			Crisis period (2008Q4-2013Q2)		
	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3	PC-1	PC-1:2	PC-1:3
$BankCDS$ - Spain	-	-	-	-	-	-	0.12	0.12	0.26
$SovCDS$ - Spain	-	-	-	-	-	-	0.12	0.13	0.14
$BankCDS$ - Greece	-	-	-	-	-	-	0.12	0.13	0.17
$SovCDS$ - Greece	-	-	-	-	-	-	0.05	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.

Figure 5.6: PCA based on alternative sovereign and banking sector risk indices for peripheral euro area countries



(a) Based on $SovCDS$ and $BankCDS$ (2011Q1-2013Q2)

(b) Based on $SovSPR$ and $BankEQU$ (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.

5.6.2 Interconnection based on Granger causality

Static Granger-causal relationships

Regarding the cross-country Granger causality linkages between the sovereign and bank risk indicators, Table 5.10 presents the computed degrees of Granger causality (DGC). Referring to the DtD indicators, our results for the whole sample suggest that the percentage of statistically significant Granger-causality relationships with the rest of risk indicators ranges from 0 in the cases of $BankDtD$ in Italy and Spain to 44% and 33% for $BankDtD$ in Portugal and Greece respectively. As for the $SovDtD$, the cases of Greece and Portugal stand out (both with a DGC of 22%). When evaluating the DGC before and during the crisis, in all cases there is a reduction except for the $SovDtD$ in Greece, Italy, and Portugal.

Turning to the CDS risk indicator, our results for the whole sample indicate a greater degree of Granger causality than with the DtD indicator (except for the cases of $SovCDS$ in Greece and Spain), with values ranging from 11% for $BankCDS$ in Spain and $SovCDS$ in Portugal to 44% for both $BankCDS$ and $SovCDS$ in

Table 5.10: Degree of Granger causality (DGC) based on static Granger causality linkages

Between $BankDtD$ and $SovDtD$ indices

	Full sample (2004Q4-2013Q2)	Pre-crisis (2004Q4-2008Q3)	Crisis (2008Q4-2013Q2)
$BankDtD$ - Spain	0.00	0.13	0.11
$SovDtD$ - Spain	0.11	0.00	0.00
$BankDtD$ - Greece	0.33	0.13	0.11
$SovDtD$ - Greece	0.22	0.00	0.11
$BankDtD$ - Ireland	0.11	0.13	0.00
$SovDtD$ - Ireland	0.11	0.00	0.00
$BankDtD$ - Italy	0.00	0.25	0.00
$SovDtD$ - Italy	0.11	0.00	0.11
$BankDtD$ - Portugal	0.44	0.50	0.00
$SovDtD$ - Portugal	0.22	0.00	0.22

Between $BankCDS$ and $SovCDS$ indices

	Full sample (2004Q4-2013Q2)	Pre-crisis (2004Q4-2008Q3)	Crisis (2008Q4-2013Q2)
$BankCDS$ - Italy	0.22	-	0.11
$SovCDS$ - Italy	0.33	-	0.33
$BankCDS$ - Spain	0.11	-	0.11
$SovCDS$ - Spain	0.00	-	0.00
$BankCDS$ - Greece	0.33	-	0.33
$SovCDS$ - Greece	0.00	-	0.00
$BankCDS$ - Ireland	0.44	-	0.22
$SovCDS$ - Ireland	0.44	-	0.44
$BankCDS$ - Portugal	0.44	-	0.22
$SovCDS$ - Portugal	0.11	-	0.11

Between $SovSPR$ and $BankEQU$ indices

	Full sample (2004Q4-2013Q2)	Pre-crisis (2004Q4-2008Q3)	Crisis (2008Q4-2013Q2)
$BankEQU$ - Spain	0.11	0.67	0.00
$SovSPR$ - Spain	0.00	0.44	0.33
$BankEQU$ - Greece	0.00	0.67	0.00
$SovSPR$ - Greece	0.11	0.00	0.11
$BankEQU$ - Ireland	0.11	0.56	0.22
$SovSPR$ - Ireland	0.44	0.44	0.33
$BankEQU$ - Italy	0.11	0.44	0.00
$SovSPR$ - Italy	0.00	0.00	0.22
$BankEQU$ - Portugal	0.00	0.56	0.00
$SovSPR$ - Portugal	0.33	0.00	0.56

Notes: The numbers represent the Degree of Granger causality (DGC) as discussed in Section 5.2

Ireland and for $BankCDS$ in Portugal. Due to limited data availability, we cannot assess the DGC before the crisis, but the results for the crisis period are similar to those in the whole sample, except in the cases of the $BankCDS$ in Italy, Ireland, and Portugal, where reductions are recorded.

Finally, with reference to $SovSPR$ and $BankEQU$, for the whole sample we find a decrease in the DGC with respect to the DtD indicators in the cases of $SovSPR$ in Greece, Italy and Portugal, and for $BankEQU$ in Spain and $SovSPR$ in Italy, Portugal and Spain. When considering the possible variation of the DGC before and during the crisis, we detect a decline in the cases of $SovSPR$ in Ireland and Spain and $BankEQU$ in Greece, Ireland, and Portugal.

Dynamic Granger causality linkages

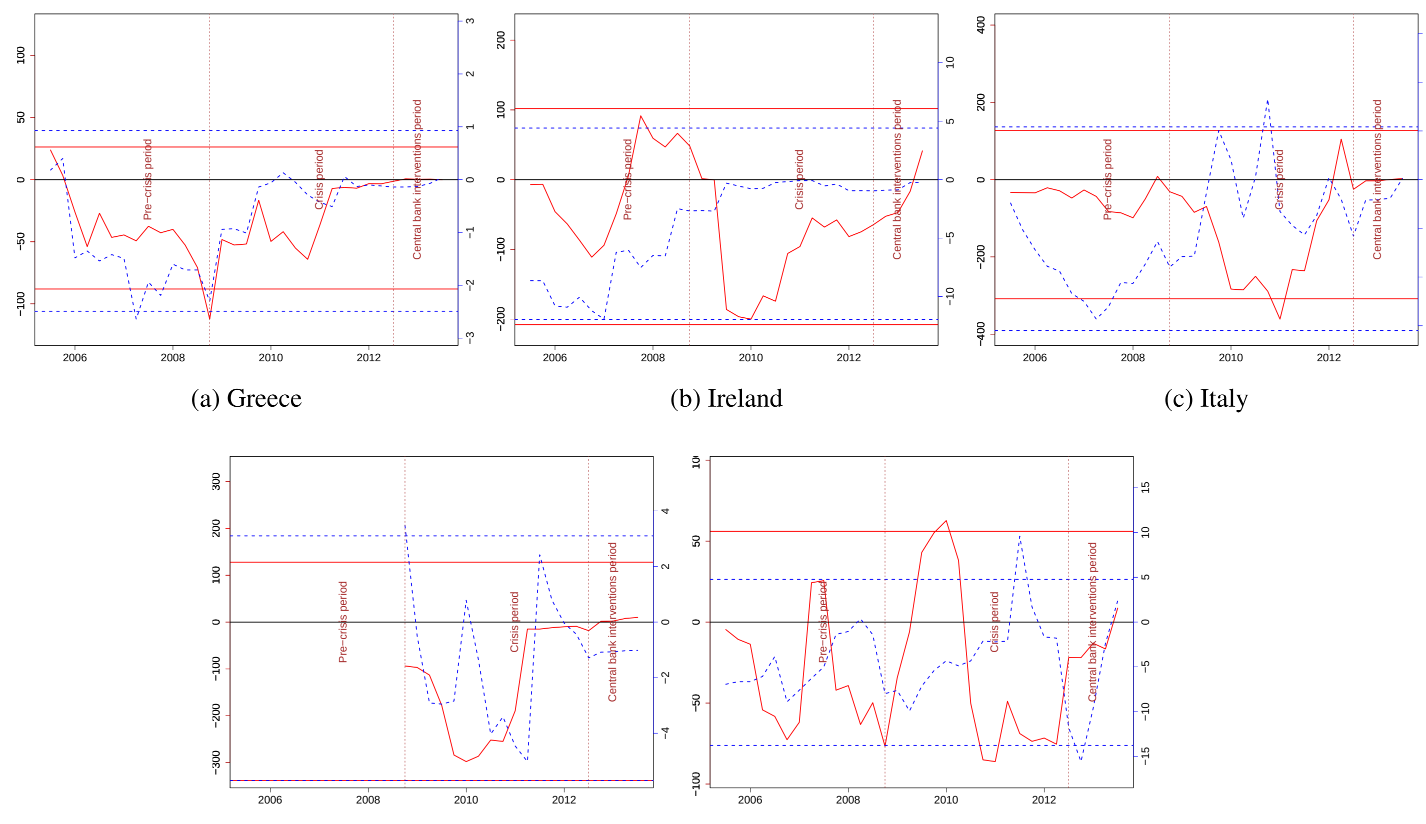
As explained in Section 3.5.1, since the presence and intensity of Granger-causality may vary over time, we also adopt a dynamic analysis to detect episodes of significant short-run abrupt increase in the causal linkages and associated episodes of Granger-causality intensification with episodes of contagion.[8]

To summarize, in Figures 5.7, 5.8 and 5.9 we plot the evolution over time of the difference between $FPE(m,0)$ and $FPE(m,n)$ statistics for each individual country based on different risk measures. These graphs provide us with a view of the dynamic bi-directional influence between sovereign and banking risks for each peripheral euro country and constitute our indicator of causality intensification based on time-varying Granger-causality analysis, since it illustrates the changes in the directions and magnitudes over time. In Table 5.11 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 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.

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

[8] Using the framework for grading the strength of the Granger-causality relationship proposed by Atukeren (2005), we obtain the same classification of episodes of intensification. Atukeren (2005)'s framework uses Poskitt and Tremayne (2013)'s posterior odds ratio test and Jeffreys (1961)'s Bayesian concept of grades of evidence.

Figure 5.7: Bi-directional bank-sovereign linkages using dynamic Granger causality (based on $BankDtD$ and $SovDtD$ indices)



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

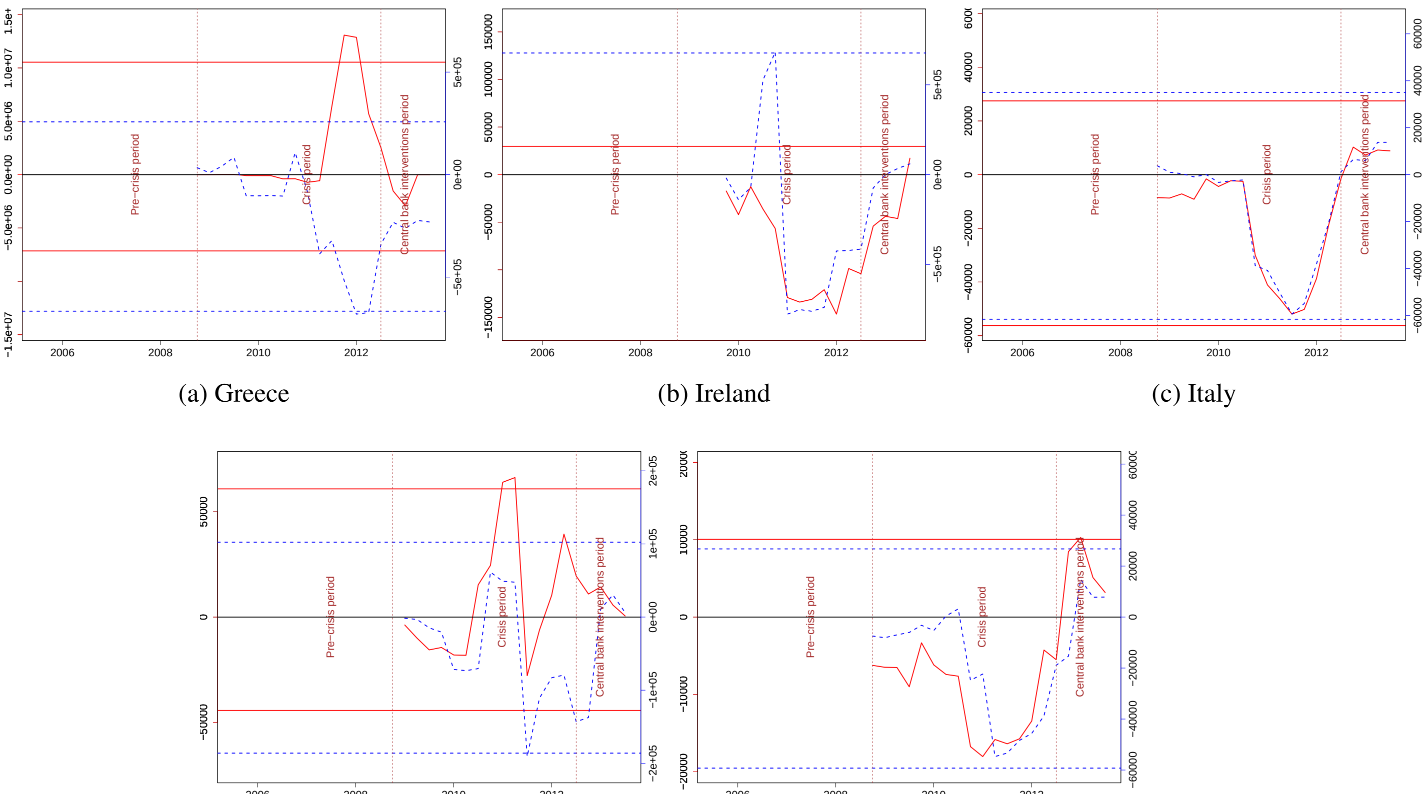
(d) Portugal (e) Spain

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.

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

Figure 5.8: Bi-directional bank-sovereign linkages using dynamic Granger causality (based on $SovCDS$ and $BankCDS$ indices)



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

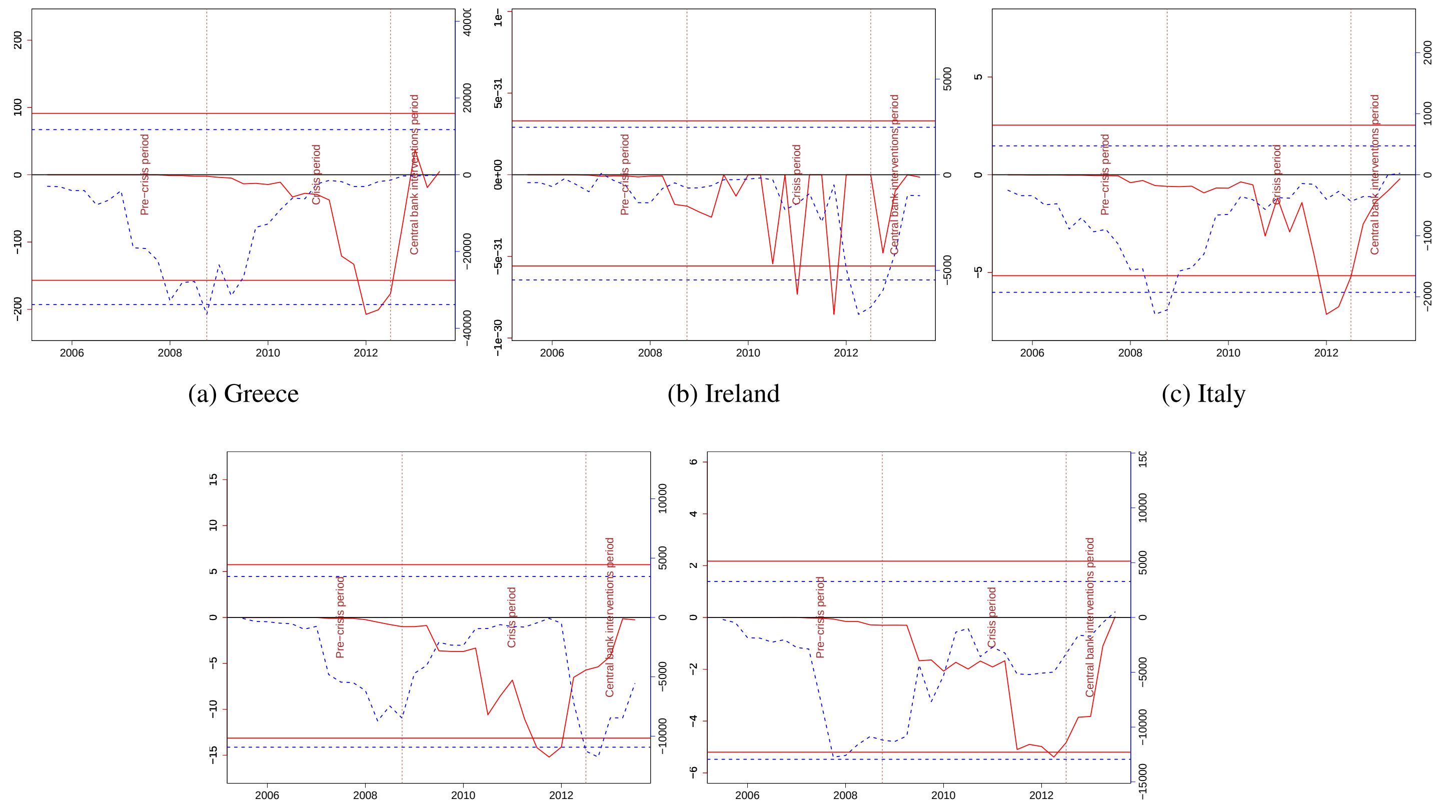
(d) Portugal (e) Spain

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.

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, the DtD analysis shows episodes of risk transfer from banks to the sovereign in late 2009 and early 2010 periods; while, from early 2011, we see evidence of risk trasfer from sovereign to banks. So, for the period 2010Q2-2012Q1, they support the existence of doom loop between sovereign and banks. Analysis based on CDS spreads also provide evidence (although weaker) regarding the development of bi-directional sovereign-bank linkages in 2012Q3. Finally, the yield spread and bank equity index based

Figure 5.9: Bi-directional bank-sovereign linkages using dynamic Granger causality (based on $SovSPR$ and $BankEQU$ 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.

analysis suggests no linkages between banks and sovereign risks.

Table 5.11 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 for Spain pointing to an adverse feedback loop between sovereigns and banks and corroborating, for this country, the findings of Singh et al. (2016), where a two-way negative feedback between sovereign and banks was also detected using $SovSPR$ and $BankDtD$ data. However, 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

Table 5.11: 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	
	Based on $BankEQU$ and $SovSPR$	
Period	Banks to Sovereign	Sovereign to Banks

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 and banking sector equity indices.

of linkages between banks and sovereigns.

5.6.3 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 5.12. 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.

As can be seen, the diagonal elements (own connectedness) are among the largest individual elements in the table, ranging from 18.83% ($SovCDS$) to 59.64% ($SovSPR$) 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 20.71% ($BankEQU$) 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 sovereign 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.

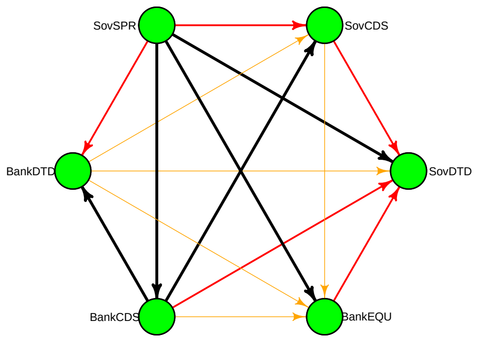
Figure 5.10 plots the country-wise net directional connectedness between various risk indices. The plots suggest that, in the case of Greece, $SovSPR$ and $BankCDS$ are net triggers of shocks while $SovDtD$ and $BankEQU$ are net diffusers of shocks. For Ireland, we find that $SovDtD$ and $BankDtD$ are 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. SovSPD 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 uncer-

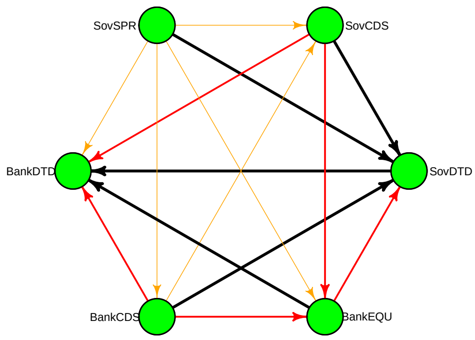
Table 5.12: Total connectedness between banking and sovereign risk indicators

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**

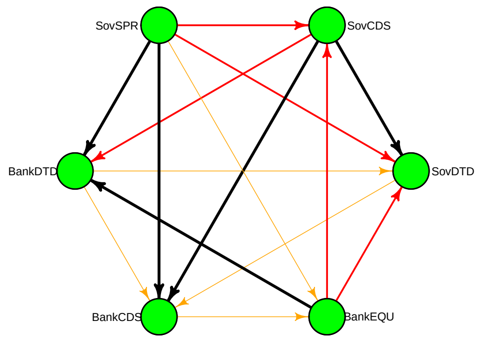
Figure 5.10: Country-wise net pairwise directional connectedness between sovereign and banking sector risk indicators



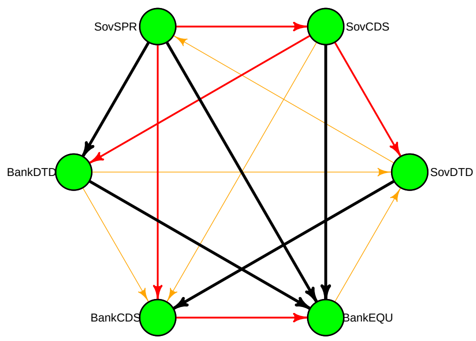
(a) Greece



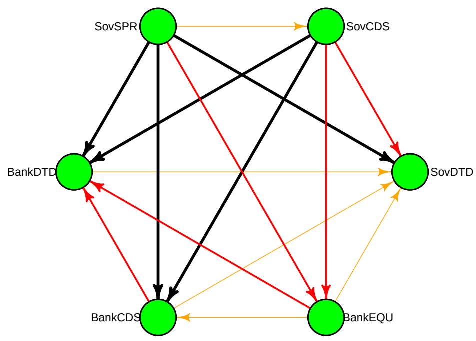
(b) Italy



(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.

tainty to the idiosyncratic risk factors based on the sovereign and banking sectors balance sheet vulnerabilities.

5.7 Concluding remarks

To understand the nature of the sovereign-bank nexus, in this paper we assess the interconnections and their time-varying nature for peripheral euro-area countries. Firstly, we discuss the nature of these interconnections and the reasons for increasing/decreasing linkages. We then propose three different econometric techniques based on principal component analysis, Granger-causality tests and Diebold-Yilmaz's connectedness indices in order to quantify the directional intensity of the interdependence between banking and sovereign risk measures. Our primary credit risk indicator is a contingent claim model-based distance-to-default measure for banks and sovereigns. However, for comparison, we use two other 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).

Our results suggest strong connectedness and co-movement between country-level banking and sovereign risk indicators. 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 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.

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 5.3. As membership of the monetary union can have a considerable influence on the banks' and sovereign credit risk in euro-area countries (see De Grauwe (2012); De Grauwe and Ji (2013), we will explore the role of fiscal support, central bank interventions and banking union in the sovereign-bank nexus.

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6 Concluding remarks

This dissertation comprising four essays specifically focuses on the banking and sovereign credit risk measurement and their linkages across time. I strongly feel that the key issue for research-based policymaking is measurement. Regulators around the world look for tools to monitor the build-up of risks, to analyse and quantify the negative externalities imposed by different market participants or various transmission channels on the entire system. Beginning at Chapter 2, I used balance sheet information together with market data to derive a set of bank credit risk measures, to assess banks' riskiness and interconnectedness across countries. However, where I fail is how to link the measures produced by these tools to regulatory interventions: observing the important role that smaller banks have in the build-up of country-level risk does not translate directly into a clear policy response. Linking risk estimates to well-defined policy objectives would be my focus in future research.

Chapter 4 shifts the attention from banks to sovereigns' risk measure in euro area countries. For the first time, developed countries' "no default" assumption was challenged during the Greek debt restructuring of 2012. In this chapter, I argued that the historical development and the evolving institutional setting in the euro area makes sovereigns increasingly similar to firms. The EU policy initiatives in the last couple of years, like the upcoming banking union, the single bank resolution mechanism, and the common unemployment benefit schemes, are all leading towards rule based sovereign debt restructuring mechanism in future, where sovereigns' will be allowed to default and restructure their debt independently without impairing their domestic banks. In this scenario, we highlight the role of multilateral creditors (i.e., the ECB, IMF, ESM etc.) and their preferred creditor status in explaining the sovereign credit risk of peripheral euro area countries. Incorporating lessons from sovereign debt crises in general, and from the Greek debt restructuring in particular, I define the priority structure of sovereigns' creditors that will be relevant for peripheral euro area countries in severe crisis episodes. This new priority structure of creditors, together with the contingent claims methodology, is then used to derive a set of sovereign credit risk indicators.

Chapter 3 and 5 of this thesis are focussed on statistical measures of interconnection, where I connect my findings with the historical narration of bank-sovereign nexus observed during the European sovereign debt crisis. Since the channels via which these shocks propagate within a network is quite complex and not fully understood at the theoretical level, we shy away from identifying the vulnerable/central institutions or the prominent channels, which were responsible for the propagation of shocks within the financial network. However, going forward, I would like to understand and quantify from a practical standpoint, the contagiousness of particular institution or a specific channel.

I believe that this work makes several important contributions to the literature of banking and sovereign credit risk measurement and raises a number of interesting questions that can hopefully be addressed in future research. Euro area is at a cross-road where building further institutions towards a more integrated monetary union will challenge its federal structure. Greater understanding is required about the build-up of bank and sovereign risk and their interconnection, especially for countries which are part of a currency union. Default, delisting, recapitalization, or nationalization of weak and failing financial institutions does not automatically make the whole financial system more stable or resilient. A lack of credible risk measures must not be considered as a sign of financial stability.

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