Measuring sovereign risk in peripheral euro area countries with contingent claim models: A comparison with traditional indicators

Manish K.Singh, Department of Economics and Riskcenter, Universitat de Barcelona, Spain
Marta Gómez-Puig*, Department of Economics and Riskcenter, Universitat de Barcelona, Spain
Simón Sosvilla-Rivero, Complutense Institute for Interational Studies, Universidad Complutense de Madrid, Spain.

Abstract

This paper proposes a modified contingent claims model that incorporates the priority structure of creditors to measure and monitor sovereign credit risk in five peripheral euro area countries during the period 2000Q1-2016Q3. Unlike traditional indicators of sovereign risk, the sovereign distance-to-default (DtD) indicator that we propose, not only uses market-based measures, but also information from the public sector balance sheets to better isolate sovereign credit risk. By analyzing and comparing the behavior of sovereign DtD with three of the most relevant traditional market-based indicators (CDS spreads, sovereign yield spreads and credit rating), our results indicate that the proposed sovereign risk indicator shows better predictive ability than traditional ones and, in contrast with the latter, it is mainly driven by macroeconomic fundamentals rather than market sentiment variables. Therefore, it presents a meaningful signaling power in assessing sovereign vulnerabilities.

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

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 indicators 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)) make 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

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[1]The ECB, the European Financial Stability Facility (EFSF), the European Stability Mechanism (ESM),

*Corresponding author: Departament of Economics and Riskcenter, Universitat de Barcelona. Av. Diagonal 696, Barcelona 08034, Spsin. Tel. +34 934020113.
E-mail addresses: manish.singh (Manish K. Singh), marta.gomezpuig@ub.edu (Marta Gómez-Puig), sosvilla@ccee.ucm.es (Simón Sosvilla-Rivero),

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 (Schiavone (2018)). 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 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)). Besides, credit rating agencies systematically under- or over-estimate risk assessments (see, e.g., Amstad and Packer (2015)), raising concerns about the information content of credit ratings and

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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.

their association with sovereign spreads and default risk (see Binici et al. (2018)).

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 since asymmetrical losses were observed 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 paper 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 price and market behaviour in sovereign debt restructuring and build a credit risk indicator that incorporates this in our 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 approach, that includes both accounting metrics and market-based measures, to analyse and assess 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) which 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 lenders, 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.

In particular, our findings indicate that although the correlation between the DtD indicator and the traditional market-based credit risk indicators is high, the DtD indicators seems to lead the evolution of the other three, meaning that it contains useful information for forecasting traditional risk measures. In addition, they also suggest that causality linkages run from the DtD indicator to the traditional ones and the regression analysis indicates 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.

The paper is organized as follows. Section 2 provides a review of the empirical literature on the main drivers of the traditional sovereign credit risk indicators. In Section 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 in Section 4 how this model can be modified and used to quantify the credit risk for EA countries. Section 5 enumerates the databases used and the practical considerations in sovereign credit risk calculations. We also 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 6 explores in details the actual and potential implications of this framework for sovereign credit risk management. Finally, Section 7 offers some concluding remarks.

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 and Schnabl (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 (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 yield 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 to 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.

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 $A(T)$, then the pay-off for the senior claim holder 'P_S' will be, $P_S = min\{S, A(T)\}$, while the pay-off for the junior claim holder 'P_J' will be $P_J = max\{A(T) - S, 0\}$.

This pay-off for the junior creditors is analogically similar to the pay-off for the buyer of a typical call option. For a given strike price K, the pay-off for the buyer of the call option depends on the firm's equity price E, and is given by $P_C = max\{E - K, 0\}$, where E is the firm's equity value at the maturity of the option. CCA exploits this analogy and the fundamental relationships between the value of an entity's assets and the dependent contingent claim (the call option). The junior claims are modelled as an implicit call option on the value of the entity's assets while considering the senior claims as the strike price. So if the entity's future senior claims are known and its junior claims are tradable in the marketplace, then CCA uses this information to derive the value of the entity's asset (A) and asset volatility (σ_A). The methodology is well established in the literature (see Black and Scholes (1973), Merton (1974, 1977), Gray et al. (2007), European Central Bank (2012), Saldias (2013), Gray and Jobst (2010), Gray et al. (2010), Gray and Malone (2008), Gray and Walsh (2008)). For a detailed presentation, please see Appendix A.

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

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

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[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.

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

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

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

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

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

3.1. 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.

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 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 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 are claims on current and future assets, this approach yields an 'implied' estimate for a sovereign's assets - value and volatility. The

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[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*

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.

We are assuming that the junior lenders' pay-off is $P_J = \max\{A - S_S, 0\}$, where, S_S represents the senior creditors claim on government assets. However, being the junior creditor is not exactly the same as being a equity holder here. As a junior creditor, the maximum claim on the government assets is limited by the amount of the junior loans (S_J). Analytically, in

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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 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.

these circumstances, the pay-off should be

$$P_J = \max\{A - S_S, 0\} - \max\{A - (S_S + S_J), 0\}$$

The cap on the maximum pay-off renders the junior creditors a writer of another call option with strike price $S_S + S_J$. This second component clearly doesn't matter much in times of elevated default risk, but it will change the dynamics of the DtD measure in calmer periods.

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 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. The modified approach: Application to EA countries

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 (2011)). 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.

4.2. 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 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 Private Sector Involvement (PSI) in February/March 2012. The Greek debt restructuring proposal excluded the bond holdings of the ECB (the single largest holder by

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

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 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 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

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[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.

[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)).

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.

4.3. 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) *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. 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 2 (in decreasing order of priority).[13]

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[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

Table 2: Priority structure of sovereign liabilities

Senior claims

External creditor: Multilateral creditors outside the EU - the IMF, the World Bank (WB), 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

5. Data and methodology

5.1. DtD 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 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

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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.

Figure 1: *DtD* vs Gross debt-to-GDP

(a) Italy

(b) Spain

(c) Ireland

(d) Greece

(e) Portugal
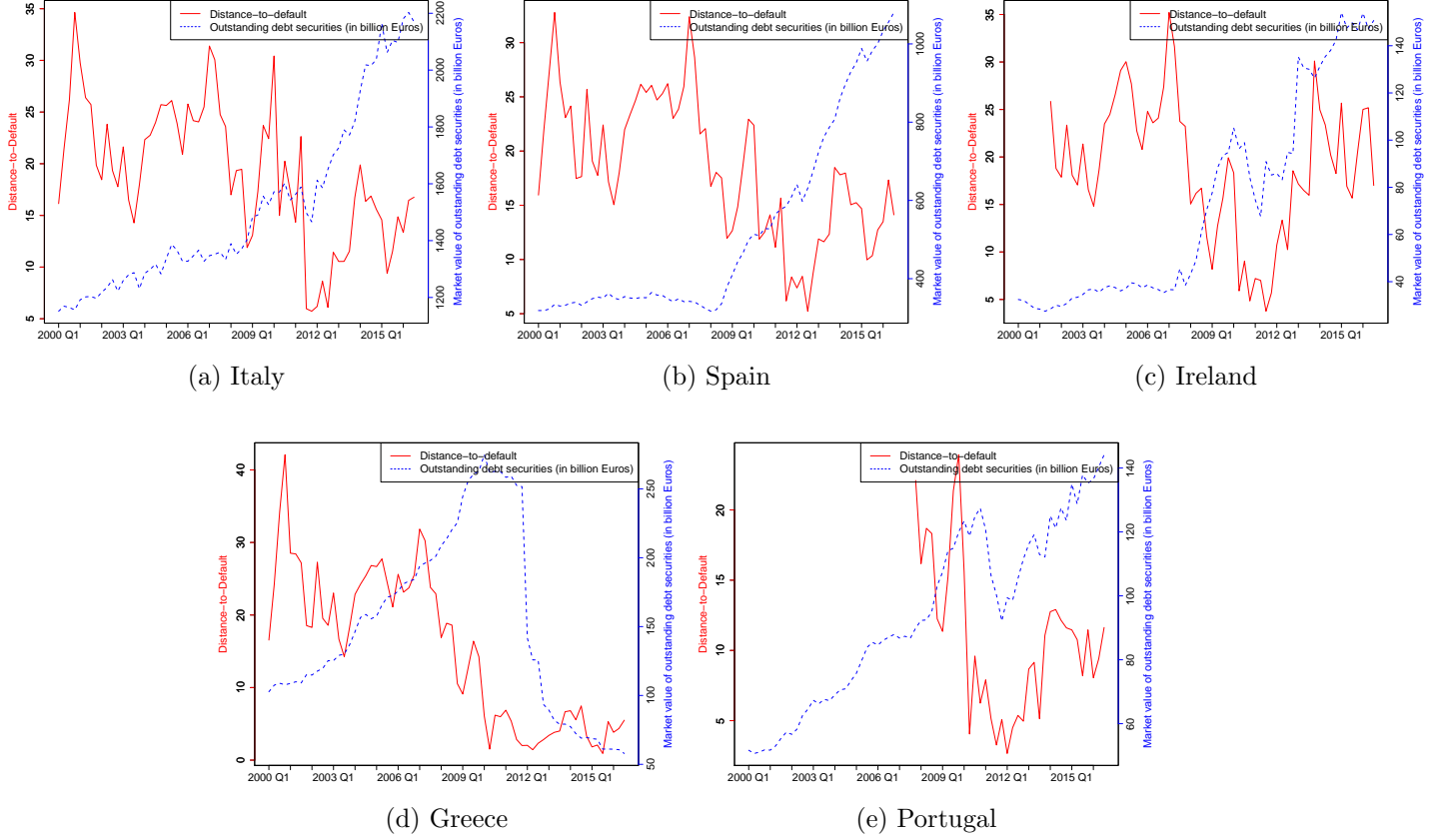
Note: The figure shows the evolution of general government gross debt as a percentage of GDP with sovereign *DtD* indices for individual peripheral EA countries.

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 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 three months daily volatility.[15] Figure 2 shows the evolution

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[15]To check the robustness of our results, we also calculate the volatility of sovereign debt using the 10-year

Figure 2: *DtD* vs Bond price volatility

(a) Italy

(b) Spain

(c) Ireland

(d) Greece

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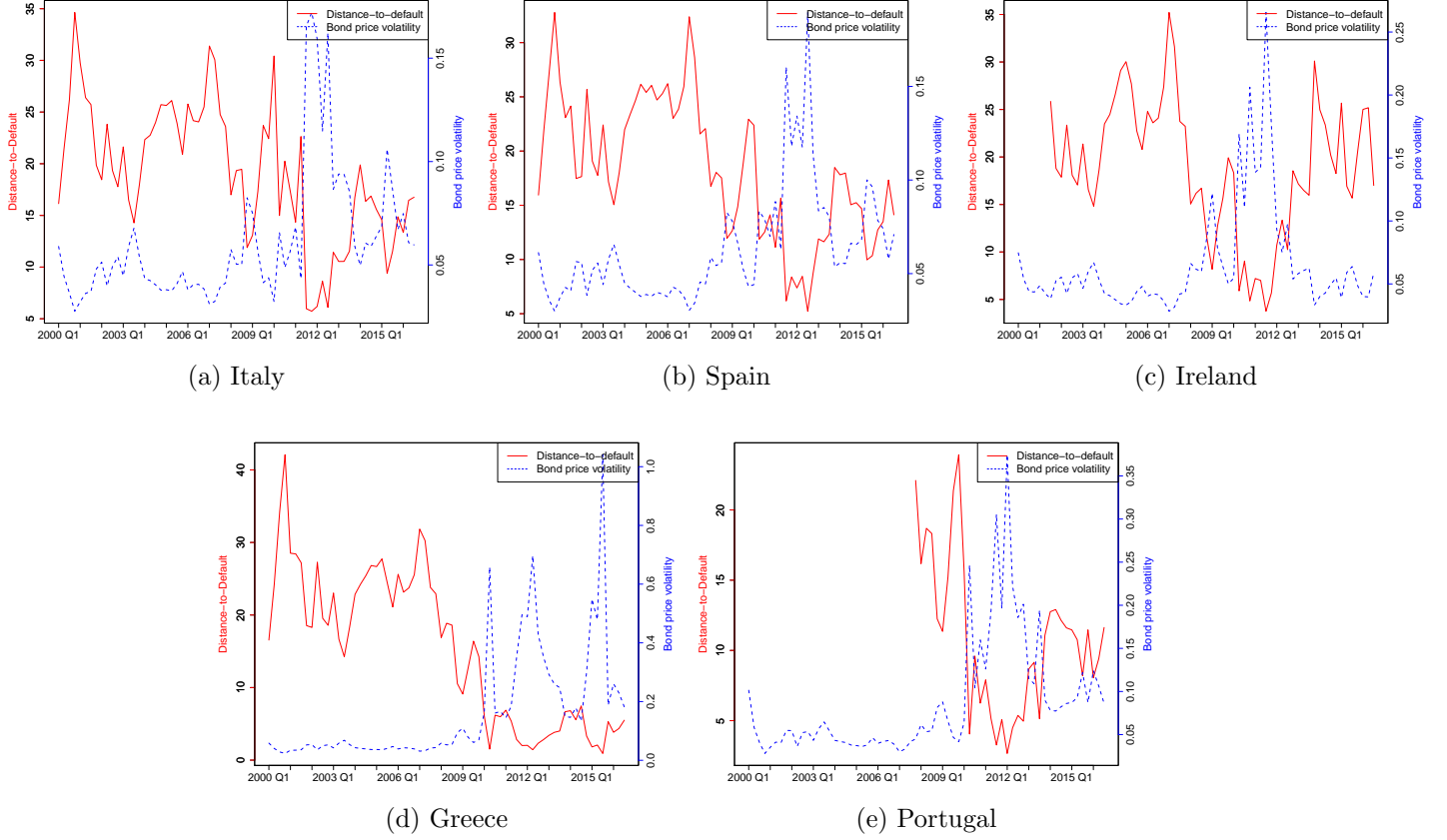
Note: The figure shows the evolution of sovereign's bond price volatility with sovereign *DtD* indices for individual peripheral EA countries.

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 res-

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 3: *DtD* vs Non-resident holding of government debt

(a) Italy
(b) Spain
(c) Ireland

(d) Greece
(e) Portugal
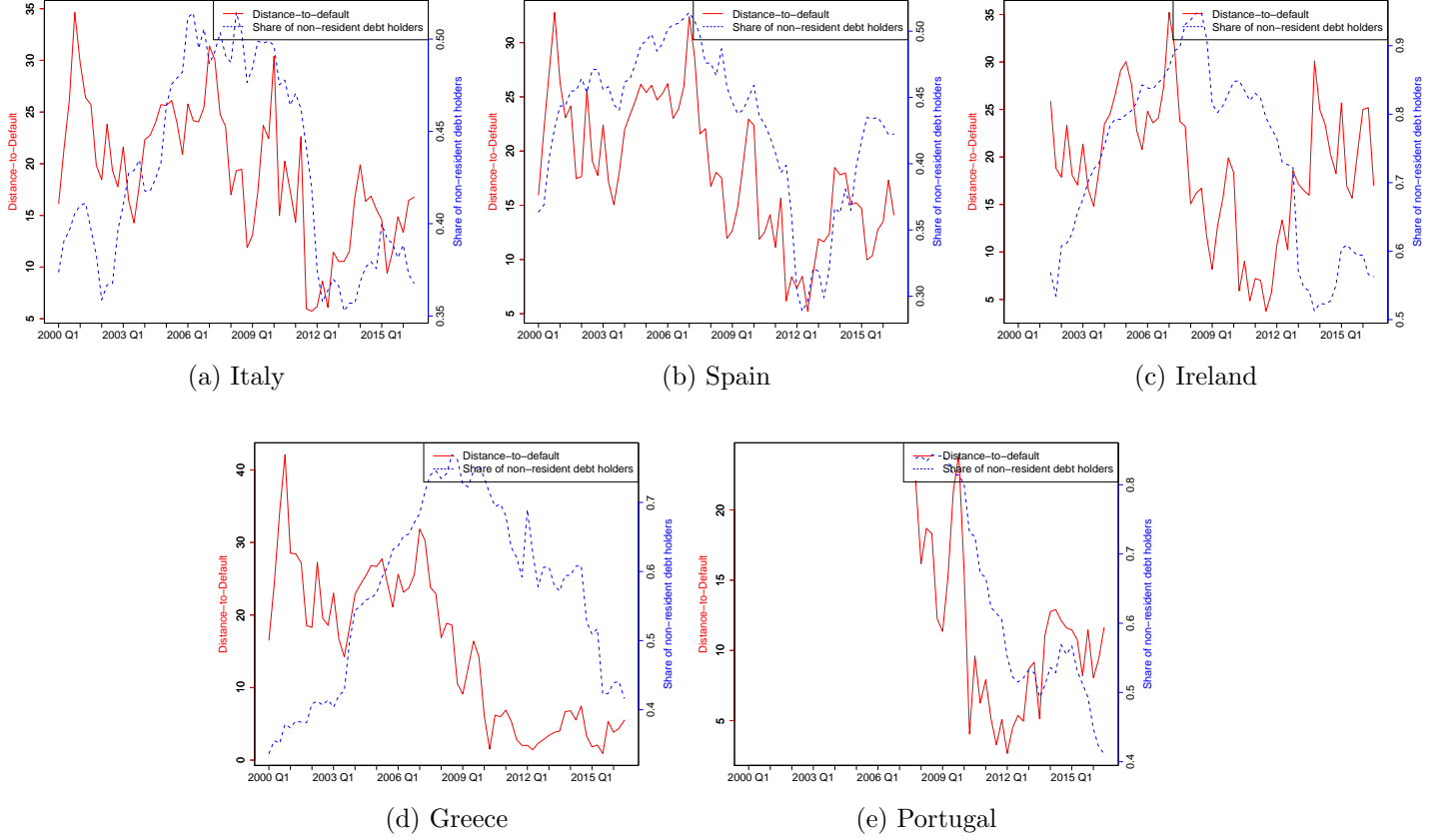
Note: The figure shows the evolution of the share of non-resident debt holding of general government gross debt with sovereign *DtD* indices for individual peripheral EA countries.

ident 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 3 plots the evolution of non-resident holding of general government debt with sovereign *DtD* indices for individual countries.

5.2. Methodology

Based on our discussion in Section 4, we consider the priority structure of creditors shown in Table 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

18

debt among the external debt holders. Since we don't 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. (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. 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 alternative specifications - (1) the sum of debt holdings to all external debt holders in nominal terms; (2) 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]; and (3) the sum of part one and 50% of the long-term debt where payment is due in more than one year 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 Appendix A to calculate the quarterly time series of sovereign DtD for individual EA countries.

Our focus is on five peripheral EA member states that have experienced a sovereign debt crisis: Greece, Italy, Ireland, Spain, and Portugal. Table 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.

5.3. Other sovereign risk measures

In this subsection, we consider other traditional sovereign credit risk measures in order to analyse and compare our sovereign DtD indicator with them. Since a large number of

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[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 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.

credit risk indicators are available in the marketplace, we need to be selective and narrow our analysis to sovereign yield spreads, CDSs and the credit ratings.
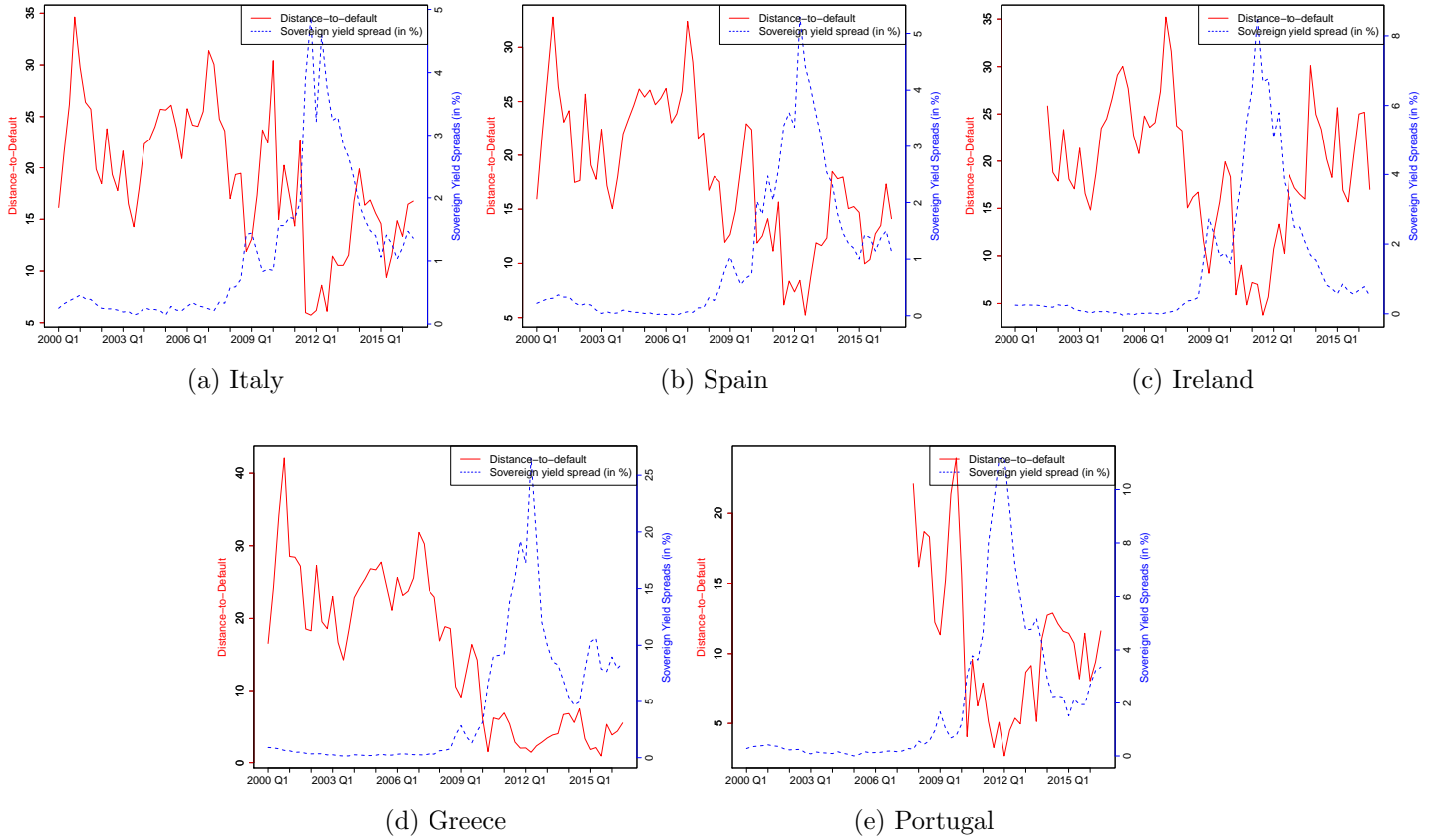
To calculate yield spreads for individual countries, we use the Maastricht criterion bond yields (the long-term interest rates). The series relates to interest rates for long-term government bonds denominated in national currencies. The data are based on central government bond yields on the secondary 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 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 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

Figure 4: *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 5: *DtD* vs 5-year benchmark sovereign CDS spreads

(a) Italy

(b) Spain

(c) Ireland

(d) Greece

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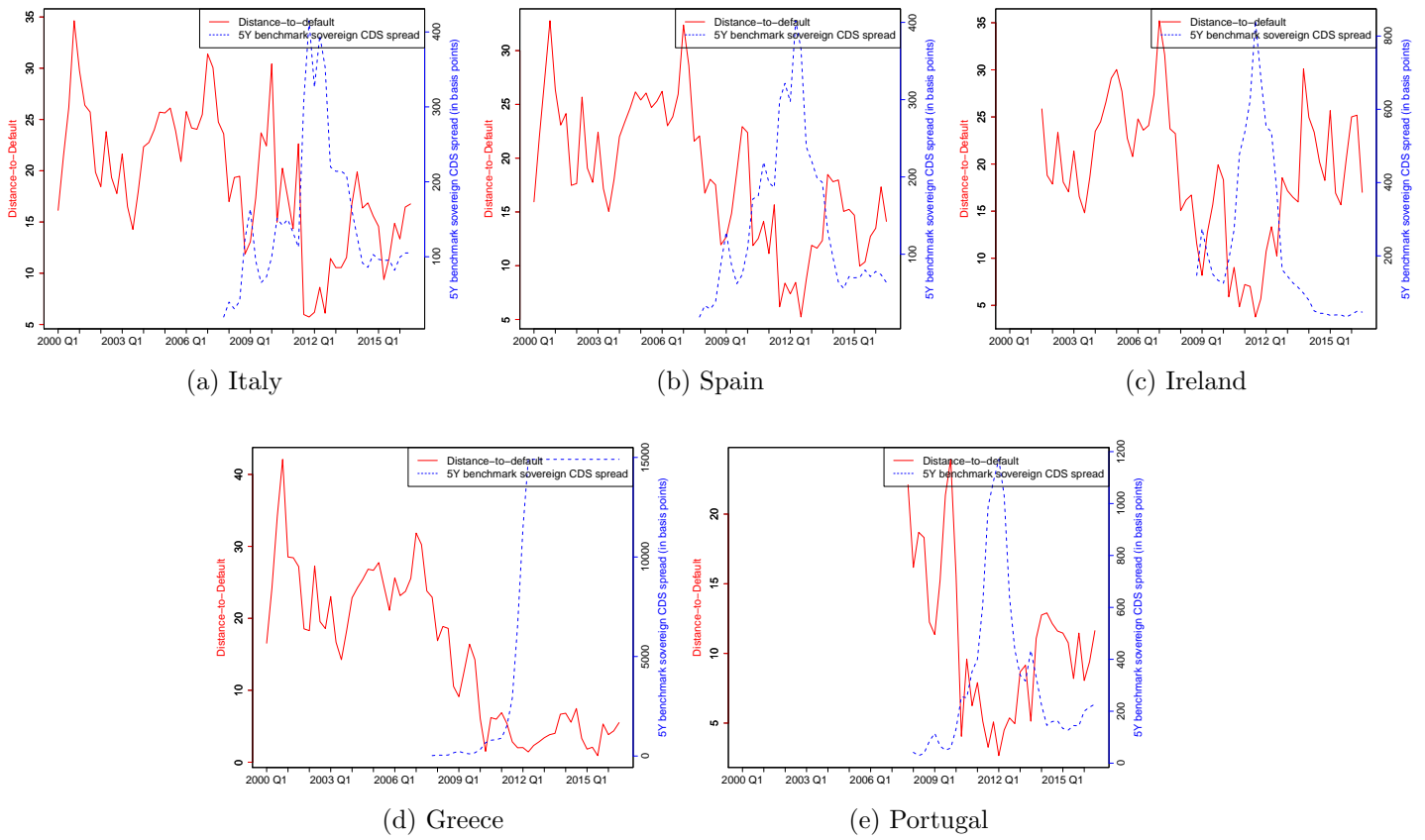
Note: The five-year benchmark sovereign CDS spreads data are available starting from 2007Q4. The Greek CDS spreads post the 2012 Greek debt restructuring experience are not reliable. Source: Datastream.

the lowest-rated debts. Therefore, by construction, the higher the value of RAT, the worse the rating categories. Figure 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.

Figure 6: DtD vs sovereign credit rating

(a) Italy

(b) Spain

(c) Ireland

(d) Greece

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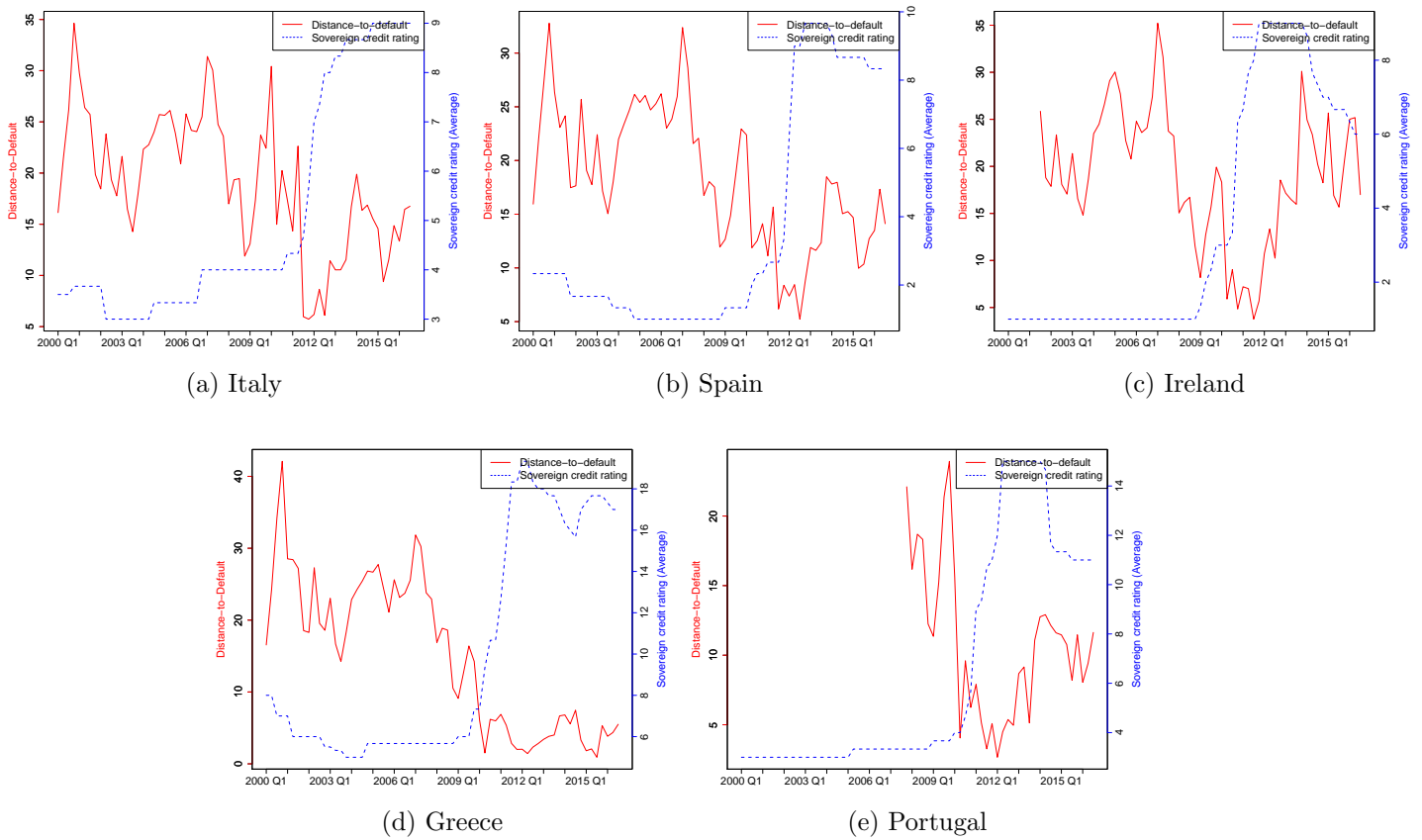
Note: Credit ratings data are built by averaging the ratings assigned to sovereign debt by Standard & Poor's, Moody's and Fitch. Using data compiled from Bloomberg, 21 different categories are considered. The first category is made up of highest-rated debts whereas the twenty first includes the lowest-rated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

Table 4 provides summary information for CDS, yield spreads and credit ratings which are selected here for comparison.

Table 4: 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).

6. Statistical 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.

6.1. 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 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.[18]

In Table 5, 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.[19]

6.2. 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

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[18]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.

[19]Results from principal component analysis (which are not shown here in order to save space, but are available from the authors upon request) provide further support to the hypothesis that the sovereign DtD contain additional information not present in the traditional risk measures under study.

25

Table 5: 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.

Wald statistics are reported in Table 6 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. Finally, we find evidence of a bi-directional relationship between DtD to rating for Greece, while for the remaining four countries we find statistically significant unidirectional 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.[20]

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[20]Results from Generalized Impulse-Response Functions provide further evidence of the additional infor-

Table 6: Granger causality test (Wald test probabilities)

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

6.3. 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 7), we consider both fundamental variables and market sentiment variables (see, e.g., Gomez-Puig et al. (2014) and references within). Three 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 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

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mation content of the proposed sovereign risk indicator in explaining the traditional ones when accounting for dynamic interrelationships between them. These additional results are not shown here to save space, but they are available from the authors upon request.

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 8 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 9 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 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).

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

Table 7: Variables that measure macroeconomic fundamentals and market sentiments

Variables that measure macroeconomic fundamentals

Variable	Description	Source
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 inter-annual 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 (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 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

Table 8: Regression results

Part I: Sovereign *DtD*s 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

Part II: 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

Part III: 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

Part IV: 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

Notes: In the ordinary brackets below the parameter estimates, the corresponding t-statistics are shown, based on the small-sample degree of freedom corrected, heteroskedasticity and autocorrelation consistent standard errors proposed by Newey and West (1987)

Table 9: Predictive power and relative contributions of the explanatory variables

Panel I: Sovereign *DtD* model

Country	Actual *DtD*	Predicted *DtD*	Individual Contributions (%)							Aggregate contribution (%)	
			CCI	CLIFS	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
Greece	15.07	15.04	0.00	3.47	79.12	0.00	0.00	17.42	0.00	96.53	3.47
Ireland	13.39	13.36	0.00	35.30	0.00	0.00	6.04	49.05	9.60	64.70	35.30
Italy	18.75	18.69	3.13	0.00	84.35	2.45	8.42	1.66	0.00	94.43	5.57
Portugal	10.78	10.73	0.00	5.26	78.00	0.00	0.00	14.96	1.77	94.74	5.26
Spain	17.57	17.51	0.00	0.00	55.86	8.30	0.00	31.88	3.97	91.70	8.30

Panel II: Sovereign CDS model

Country	Actual CDS	Predicted CDS	Individual Contributions (%)									Aggregate contribution (%)	
			CCI	VIX	CLIFS	FMU	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
Greece	8200.64	8185.88	79.42	10.11	3.65	0.00	0.00	0.00	0.00	6.81	0.00	6.81	93.19
Ireland	261.63	258.97	51.02	3.73	0.00	1.12	16.46	0.00	0.00	27.67	0.00	44.13	55.87
Italy	148.36	146.88	0.00	0.00	15.48	0.00	0.00	44.61	0.00	33.86	6.06	39.91	60.09
Portugal	318.58	315.77	88.79	4.07	0.00	0.00	0.00	0.00	0.00	4.25	2.89	7.14	92.86
Spain	140.77	139.22	54.32	8.73	11.32	0.00	0.00	0.00	4.09	21.53	0.00	25.63	74.37

Panel III: Sovereign yield spread model

Country	Actual yield spread	Predicted yield spread	Individual Contributions (%)									Aggregate contribution (%)	
			CCI	VIX	CLIFS	FMU	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
Greece	4.53	4.53	0.00	13.12	9.22	0.00	21.96	32.97	0.00	19.18	3.55	44.70	55.30
Ireland	1.53	1.52	0.00	0.00	59.61	10.61	13.37	0.00	0.00	16.40	0.00	29.78	70.22
Italy	1.13	1.11	6.81	31.64	2.96	0.49	0.00	21.86	0.00	36.24	0.00	36.24	63.76
Portugal	2.04	2.02	41.53	16.72	0.87	0.00	26.18	0.00	0.00	14.71	0.00	40.89	59.11
Spain	1.06	1.04	0.00	40.73	19.86	0.00	0.00	0.00	18.68	8.66	12.06	39.41	60.59

Panel IV: Sovereign credit ratings model

Country	Actual credit rating	Predicted credit rating	Individual Contributions (%)								Aggregate contribution (%)	
			CCI	VIX	CLIFS	FSI	EPU	DEF	DEBT	INF	Macroeconomic fundamentals	Market sentiment
Greece	10.01	9.91	42.27	4.35	3.16	0.00	6.09	0.00	44.12	0.00	44.12	55.88
Ireland	3.35	3.29	67.01	1.73	4.26	0.00	6.42	0.00	20.57	0.00	20.57	79.43
Italy	5.06	5.01	0.00	26.27	9.01	45.91	18.81	0.00	0.00	0.00	45.91	54.09
Portugal	6.46	6.40	38.51	2.65	0.67	36.43	21.74	0.00	0.00	0.00	36.43	63.57
Spain	3.77	3.77	25.75	3.95	4.25	0.00	27.54	0.00	36.97	1.53	38.50	61.50

Notes: The results are obtained based on the models presented in Table 8.

7. 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. The approach is particularly useful as it incorporates the adverse market sentiments by taking the sovereign bond prices and volatility as input in the measurement of the sovereign risk.

By analysing and comparing the behaviour of sovereign DtD with three of the most relevant market based sovereign credit risk indicators (i.e., CDS spreads, sovereign yield spreads and credit ratings), our results indicate that sovereign DtD shows better predictive ability (1-4 quarters) than the other three. Although we find high correlations between them, 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 the presence of predictive content. 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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Appendix A. Merton model equations for pricing contingent claims

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

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

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

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

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

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

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

Using Ito's formula one can show

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

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

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

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

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