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

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Abstract

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

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

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1. Introduction

Today, close to five years since the outbreak of the European Economic and Monetary Union (EMU) sovereign debt crisis in late 2009 – when the newly elected Greek government announced that the country's budget deficit was much larger than previously reported – we can see that its origin goes deeper than the fiscal imbalances in euro countries. The interconnection between private and public debt, and thus between banking and sovereign crises, is obvious. However, whether it was private debt that ultimately bankrupted sovereigns, or whether, conversely, it was excessive public debt that undermined the banking sector is a question that is not easily answered. Indeed, the main causes of the debt crises in Europe vary according to country. In some countries, the public sector was overwhelmed by the costs of cleaning up the banking system and was forced to seek bail-outs (e.g., Ireland and Spain); while in others, the main source of vulnerability was concentrated in the public sector balance sheet itself (e.g., Greece, Portugal and Italy).

Some authors (Brunnemeier *et al.*, 2011 and Reichlin, 2013, among them) describe the development of a "diabolic loop" in EMU countries as European banks, encouraged by the absence of any regulatory discrimination between bonds, held an excessive part of the national debt, which – far from being safe – fed never-ending speculation on the banks' solvency. In turn, sovereigns were in constant danger of having to rescue their banks, which, combined with the uncertainty regarding the kind of fiscal support they would receive from their European partners, increased the riskiness of their bonds. Finally, European policymakers lacked the institutions and resources to intervene in all the troubled sovereign debt markets. In this context, the European Central Bank (ECB) ended up holding the riskiest of the sovereign bonds as it became the sole source of financing for the troubled banks. Indeed, some authors (see Shambaugh, 2012) have pointed out that the euro area has faced three interlocking crises (banking, sovereign debt, and economic growth) which together challenged the viability of the currency union. According to this thinking, these crises connected with one another in several ways: the problems of weak banks and high sovereign debt were mutually reinforcing, and both were exacerbated by weak, constrained growth.

An analysis of the interrelationship between debt and growth – an unresolved issue of great importance, on which there is no consensus in the literature [see Krugman (2011), DeLong and Summers (2012), Cochrane (2011) or Reinhart & Rogoff (2010), to name just a few] – is beyond the scope of this paper. Rather, we will focus on the interconnection between banking and sovereign debt crises in EMU countries. While there is a substantial amount of literature exploring the determinants of either bank risk or sovereign risk in isolation, few papers to date have looked at the interdependence or contagion between the sovereign and the banking sectors. Exceptions are Alter and Schüler (2012), Gross and Kok (2013) and Alter and Beyer (2014), who applied different extensions of vector autoregressive models; and De Bruyckere *et al.* (2013) who investigated the presence of contagion by computing excess correlation (over and above what one would expect from fundamental factors). However, though they use different methodologies, all these papers applied the same measure of banking and sovereign risk: credit default swap (CDS)[1] spreads on 5-year senior debt contracts, since these are known to be the most actively traded and therefore the most liquid. Indeed, CDS markets (in both the sovereign and the banking sectors) have been quite illiquid since late 2008, well after the start of the US Financial crisis.

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

In this context, our paper makes two contributions to this branch of the literature. First, we apply indicators of bank and sovereign risk that have not been used in previous work. Our indicator of banking risk in each country is based on the Contingent Claim Analysis (CCA) framework. As far as we know, this is the first paper to use this measure to examine the interconnection between bank and sovereign risk in the euro area. Specifically, the average aggregate "distance-to-default" indicator in the banking sector in each EMU country will be the proxy of banking risk used in the analysis. This indicator, which is based on Merton's model (1974), is calculated and broadly explained in Singh *et al.* (2014). On the other hand, 10-year government yield spreads over Germany will be our measure of sovereign risk[2], since they reflect the premium that investors demand in order to bear the risk of a government default. The use of these indicators will allow us to examine the interconnection between the risk in the sovereign and the banking sectors from 2005 (more than three years before the onset of the global financial crisis).

Second, we use a methodology that has not been employed to date in this context. We apply dynamic Granger-causality tests between the two measures of risk in 10 of the countries that have belonged to the EMU from its inception, during the sample period

[2] Some authors contend that past CDS spreads improve the forecast quality of bond yield spreads (Palladini and Portes, 2011; Fontana and Scheicher, 2010). As Caporin et *al.* (2013) point out, unlike CDS, bond spreads may be affected by many other factors (they are, for example, more sensitive to monetary policy and the actions of the central bank and policymakers). However, CDS markets (in both the sovereign and the banking sectors) have been quite illiquid since late 2008, only one year before the onset of the euro sovereign debt crisis. This is why we decided to make use of 10-year yield spreads over euro-denominated German government bonds instead of CDS. We also decided to use the ten-year Bund yields as a proxy for the risk-free benchmark; they are considered as such in many academic studies because German sovereign debt has enjoyed a high credit rating for some time now and its returns can be seen as a good proxy for risk-free asset returns. For the sake of simplicity, this convention is maintained in the paper, although this decision means that Germany must be omitted from the analysis. Another alternative proxy for the risk-free benchmark would have been the interest rate swap (IRS). However, we decided against its use because the IRS might include systemic risk coming from the financial institutions (see Palladini and Portes, 2011).

2004-Q4 to 2013-Q3.[3] A clear advantage of this methodology is that it not only allows detection of contagion, but also a consideration of the asymmetry between banking and sovereign risk inter-linkages (impossible using correlation analysis, which does not give an indication of the direction of the spillover). Indeed, following Forbes and Rigobon (2002), contagion is associated with a significant, short-run abrupt increase in the causal linkages taking place exclusively during a period of crisis.

The rest of the paper is organized as follows. Section 2 reviews the linkages between sovereign and banking risk in EMU countries. An attempt to quantify both the banking and sovereign levels of indebtedness in each euro area country is presented in section 3. Section 4 briefly explains the creation of our banking risk indicator based on the CCA literature. The econometric methodology and data used in our analysis are presented in Section 5. Section 6 summarizes the main results and, finally, Section 7 offers some concluding remarks.

2. Inter-linkages between sovereign and banking risk

The financial crisis first erupted in the summer of 2007 but deepened and spread after the collapse of Lehman Brothers in the autumn of 2008. Following the Lehman Brothers crisis severe tensions emerged in financial markets worldwide, including the euro zone. In fact, the period of financial turmoil not only turned into a global financial crisis but also began to spread to the real sector, with a rapid, synchronized deterioration in most major economies. After a brief recovery (2010-2011), in 2012 the euro area plunged into a second recession, triggered by tensions in the sovereign debt market and more broadly in the

[3] Luxembourg is exempted from the present analysis, because of its very low level of outstanding sovereign bonds; Germany is also excluded since its yield is used as a benchmark in the sovereign risk calculation. Besides, Greece has been incorporated, although this country joined the euro in 2001.

financial system as a whole. On the one hand, the financial crisis put the spotlight on the macroeconomic and fiscal imbalances within EMU countries which had largely been ignored during the period of stability, when markets seemed to underestimate the possibility that governments might default (see Beirne and Fratzscher, 2013). Specifically, the announcement of Greece's distressed debt position in late 2009 triggered a sudden fall in investor confidence that led to a "flight-to-safety" and marked the beginning of the euro area sovereign debt crisis since yield spreads of euro area issues with respect to Germany spiralled.

On the other hand, in some EMU countries, when the sustainability of their high public debts was called into question, sovereign risk quickly spread to the banks because they held substantial amounts of government debt; while in others, problems in the banking sector spread to sovereign states because of the excessive debt issues made in order to save the financial industry. Therefore, a "two-way feedback" (see Acharya *et al.*, 2014 or Hau *et al.*, 2012)[4] truly existed between EMU sovereign and banking crises. To examine whether the trigger risk varies over time and depending on the country is one of the main objectives of this paper.

As the US subprime crisis unfolded, in parallel with the increase in global financial instability, the concern about exposure of euro area banks to bad assets rose. The banks'

[4] Acharya *et al.* (2014) recently used the term "two-way feedback" to describe the interdependencies that exist between the banking and the sovereign sector. According to these authors, a systemic banking crisis can induce a contraction of the entire economy, which will weaken public finances and transfer the distress to the government. This contagion effect is amplified when state guarantees exist for the financial sector. As a feedback effect, risk is further transmitted to holders of sovereign debt. An increase in the cost of sovereign debt will lead to a devaluation of government debt, which will impair the balance sheets of banks holding these assets. Hau *et al.* (2012) who examine the sensitivity of long-term bank ratings changes to sovereign rating changes suggest thaty it depends upon economic cycle and countries' economic conditions. These authors stand that two main sources of the interactions between bank risky debt and sovereign debt might be discussed. The first one is given by the structure of banks' assets, since in times of distress, they tend to increase their exposure to sovereign debt in order to preserve the value and the liquidity of their assets; whilst the second source of interactions comes from public authorities' capacity to support banks' risky debt.

exposure to the bonds of their own governments became a crucial question, in the absence of any regulatory discrimination between bonds; this absence meant that banks did not need to hold a capital buffer against their holdings of euro-denominated sovereign bonds, irrespective of the euro area country issuing the bond[5]. This home bias was clearly revealed in the results of the stress tests of the European Banking Authority (EBA) banks, which showed that banks tended to be heavily exposed to the sovereign debt of their own country, thus inducing stress transmission from the sovereign to the financial sector.

[Insert Figure 1a here]

Specifically, in seven out of the 10 EMU countries in our sample, the banks' exposure to their own countries' sovereign debt (see Figure 1a) was close to 50%, and even surpassed this threshold in December 2011. Therefore, it seems that banks in peripheral euro area countries (Spain: 81%, Ireland: 65%, Greece: 60%, Italy: 50% and Portugal: 49%) concentrated their portfolio of government bonds in the bonds of their own countries, rather than seeking safety by holding bonds of other countries. These results indicate (Figure 1b) that at the end of 2011, Greek commercial banks held the equivalent of 52% of Greek GDP in the form of Greek government bonds. Spanish banks held local sovereign debt equivalent to 44% of the country's GDP; whilst the comparable figures for Portugal, Italy and Ireland banks were 23%, 21% and 15% respectively.

[Insert Figure 1b here]

Besides, in the aftermath of the collapse of Lehman Brothers, when losses on exposures to this institution showed up in the balance sheets of banks around the globe, it became evident not only that the world was facing a "systemic" financial crisis, but also that it was driven by concerns over solvency which threatened the stability of the global financial system and could induce a contraction of the entire economy. In this context, in the

[5] See European Central Bank (2014)

autumn of 2008 the European Commission presented the European Economic Recovery Plan to deal with the consequences of the economic crisis in the European Union (EU) and gave governments the go-ahead for bank bailout programmes.

While mistrust between financial players causes funding markets to dry up, concerns over the solvency of financial institutions can severely affect the confidence of depositors and reveal the weaknesses of deposit insurance schemes. Besides, unlike liquidity concerns (which are understood to be a supranational issue to be addressed by the ECB) the question of bank solvency is treated as a national matter. Indeed, although banks in Europe operate across national borders, with the same currency and lender of last resort, they are subject to different supervisory authorities and lack any mutual bank support across countries. This is why national governments across the euro area stepped in to provide banks under their jurisdiction with funds or guarantees. Practically all euro-area governments adopted a series of extraordinary measures in early October 2008 in order to stabilize their banking systems which would have been unimaginable only months previously, with some institutions even being broken up. These measures included direct injection of capital into the banks, state guarantees of bank liabilities, loans to the banking sector, acquisition of bad assets, nationalization of some firms, and individual rescues (see Petrovic and Tutsch, 2009, Stolz and Wedow, 2010, Shambaugh, 2012 and Toader, 2013).

[Insert Table 1 here]

By mid-2010, total commitments (from capital injections to liability guarantees) ranged from roughly 4% to over 300% of GDP across euro-area countries. Table 1 shows that, with the exception of Ireland and Spain, the support given to the financial sector was higher in central than in peripheral countries. Based on the ratio of total commitment to GDP, the 10 EMU countries under study[6] can be ranked as follows (in descending order): Ireland, the Netherlands, Belgium, Austria, Finland, Spain, France, Greece, Portugal and

[6] Recall that Germany is excluded from our analysis.

Italy. They can also be clustered into three groups: high commitment (above 75% of GDP), Ireland; medium commitment (between 20% and 75% of GDP), the Netherlands, Belgium, Austria, Finland and Spain; and low commitment (below 20% of GDP), France, Greece, Portugal and Italy.

As the IMF (2011) highlights, these rescue operations not only increased national debt burdens and but also caused a deterioration of their public finances. So, when the rescue packages were put in place, the cost of insuring a bond against default fell sharply for the banks, as bonds were then perceived as being safer (Ejsing and Lemke 2011, Acharya *et al.* 2014). But at the same time, the correlation between the cost of insuring sovereign debt and general perceptions of financial risk in the world economy rose, as national governments were now responsible for the financial losses in many countries. The result was a "risk transfer" from banks to governments; not only was sovereign stress transmitted to the financial sector as we noted above, but also financial stress was transmitted to sovereigns (Mody and Sandri, 2012).

This is the background to the sudden loss of investor confidence in the euro area sovereign markets when, in late 2009, the Greek government announced the disastrous position of its public finances. Indeed, in May 2010 Greece's financial problems became so severe that the country needed to be bailed out. An important reason for providing financial support to Greece was the fear of contagion (see, for instance, Constâncio, 2012), since, from there, investors turned their attention to the fiscal imbalances within euro area countries. Nevertheless, since May 2010 not only has Greece been rescued twice, but Ireland, Portugal and Cyprus have also needed bailouts to stay afloat, and in the middle of the sovereign debt crisis, Spain requested financial assistance to recapitalize its banking sector.

In this context of financial distress and huge liquidity problems, the ECB and other central banks responded forcefully by implementing nonstandard monetary policies (i.e., policies beyond setting the refinancing rate).[7] In particular, the ECB's principal means of intervention, in times of crisis, was the system known as long term refinancing operations (LTRO). Through these operations the ECB expanded its balance sheet, increasing reserves on the liability side against mostly conventional assets (repo loans to banks) on the asset side. As the crisis unfolded, these policies involved maturity transformation (the term of the repo loans, one year in 2009, was extended to three years in 2011), as well as higher liquidity provision (banks were able to borrow as much as they liked at the fixed rate)[8]. At the same time there was also a relaxation of the collateral requirement and an increase in the eligible counterparties (see Lenza *et al.* 2010 for details).

[Insert Figure 1c here]

Figure 1c shows the volume of ECB LTRO operations from 1999 to the second quarter of 2013, jointly with the GDP growth in the euro area. Two peaks in LTRO volume are observed; each one followed the periods of recession in the euro area economy and thus increased the tension and lack of liquidity in the markets.

Although the LTRO may have been a crucial solution to banks' liquidity problems, if the banks used those funds to make still more sovereign debt purchases, then the connection

[7] When the crisis struck, big central banks like the US Federal Reserve slashed their overnight interest-rates in order to boost the economy. However, even cutting the rate as far as it could go (to almost zero) failed to spark recovery. Then, the Fed began experimenting with other tools to encourage banks to pump money into the economy. One of them was Quantitative Easing (QE). To carry out QE, central banks create money by buying securities, such as government bonds, from banks, with electronic cash that did not exist before. The new money swells the size of bank reserves in the economy by the quantity of assets purchased—hence "quantitative" easing. In the euro area, the principal means of intervention adopted by the ECB was the LTRO, which was notably different from the QE policies of the Federal Reserve, in which the Fed purchased assets outright rather than helping to fund banks' ability to purchase them. The LTRO is not the only non-standard monetary policy implemented by the ECB since the crisis. Other measures were the narrowing of the corridor, the change in eligibility criteria for collateral, interventions in the covered bonds market and, most importantly, the ECB's launch of the security market program in 2010, involving interventions in the secondary sovereign bond market. The latter program was discontinued in 2011.

[8] On 22 November, 2011, the ECB allotted 489.2 billion Euros for a period of 1134 days, whilst on 1 March, 2012 the amount allotted to banks was 529.5 billion Euros for a period of 1092 days.

between banks and sovereigns was strengthened as banks held even more sovereign debt which could endanger their safety down the road in the case of a sovereign default. Some authors (Uhlig, 2013, among them)[9] point out that pressure from governments on banks within their jurisdiction to buy their debt might be behind these high levels of country sovereign debt holdings in a context of recession. Acharya and Steffen (2013) present a careful empirical analysis of the "carry trade" by banks and argue that their choice to hold risky peripheral bonds was the result of their belief in the survival of the Eurozone, as ECB policy allowed them to finance their investments in short-term wholesale markets. Therefore, they report that the "home bias" increase (greater exposure of domestic banks to its sovereign bonds) was partly explained by the ECB's funding of these positions. As a result, some authors (see Acharya *et. al.*, 2014) have demonstrated that the cost of insuring bank bonds varies with the cost of insuring the sovereign debt that these banks hold. That is, the increased risk of sovereign default was directly translated in the market into an increased risk of bank default.

3. Banking and sovereign leverage in the euro area

In the last section we described the channels through which sovereign stress might have been transmitted to the financial sector, and financial stress to sovereigns. In this section our aim is to emphasize the reasons why both sectors were in a distressed position during the period under study. With this goal in mind, we attempt to quantify the levels of both public and private debt in each euro area country, during the period December 2002-

[9] This author argues that regulators in risky countries have an incentive to allow their banks to hold home risky bonds and risk defaults, while regulators in other "safe" countries will impose tighter regulation. As a result, governments in risky countries are able to borrow more cheaply, effectively shifting the risk of some of the potential sovereign default losses onto the common central bank. As a result, monetary union has become a system engineered to deliver underpriced loans from country banks to their sovereigns, and implicitly to shift sovereign default risk onto the balance sheet of the ECB and the rest of the Eurosystem.

September 2012. The variable we used to measure the public leverage ratio was the government debt-to-GDP, which is compiled on a quarterly basis from Eurostat. In addition, we built up a single dataset on private debt-to-GDP by sector (households, banks and non-financial corporations) in each EMU country with data taken from the ECB Statistics (the Monetary Financial Institutions (MFI) balance sheets) in each euro country. The construction and evolution over time of each private sectoral debt was described in detail in Gómez-Puig and Sosvilla-Rivero (2013). As regards banks' debt, in order to isolate it from the intermediation effect that would inflate the ratios, this variable was constructed by subtracting M3, banks' remaining liabilities and banks' capital and reserves from total MFI liabilities[10]; the final value was normalized in each country by its GDP.

[Insert Figure 2 here]

The graphs in Figure 2, which show the evolution of sovereigns' and banks' debt-to-GDP in both peripheral and central EMU countries, present some very interesting results. The ratio of public debt is very high in many euro area countries, and the ratio of banks' debt is also very high. In particular, while in some peripheral EMU countries (Greece and Italy) the ratio of sovereign debt is higher than that of the banking sector throughout the period, in the other countries, both peripheral (Ireland, Portugal and Spain) and central (Austria, Belgium, Finland, France and the Netherlands), we find the opposite situation since, in general, the banks' debt ratio began to increase from 2004. In particular, after the subprime crisis in August 2007, not only did the government level of indebtedness increase in the euro area (the ratio over GDP reached levels of 157%, 127%, 124%, 118%, 100%, 90% and 84% at the end of December 2012 in Greece, Italy, Portugal, Ireland, Belgium, France and Spain respectively) but private borrowing also recorded a sizeable increase. In

[10] The banks' debt variable we have constructed avoids the effects of intermediation, even though it can only be considered as an approximation of its real value. In addition, some caveats are in order: specifically, some deposits will appear as debt (those not included in M3) and some debt securities will not be considered as debt (those included in M3).

particular, as can be observed, at the end of 2012 banks' debt-to-GDP was huge in Ireland (449%), but was also high in all EMU countries with the exception of Finland. Portugal, France, the Netherlands, Austria and Spain recorded ratios over GDP of 194%, 189%, 188%, 164% and 152% respectively, while the ratio was around 100% in Greece and Belgium.

Thus, during the period 2008-2012, whereas the government debt-to-GDP ratio registered the highest increases compared to the period 2002-2007 in Ireland, Greece and Portugal (58%, 38% and 35%), there was a much steeper rise in the banks' debt-to-GDP ratio – over 190% in Ireland, close to 60% in Portugal and around 55% in Spain, Greece and Finland. These figures may help us to understand why the main causes of the debt crises in Europe vary according to the country. Therefore, the question of whether it was private debt which bankrupted sovereigns or whether on the other hand it was excessive public debt that undermined the banking sector is not an easy one to answer; in addition, it may vary depending on the country.

Finally, it is noticeable that in 2012 a deleverage process had already started in some countries. So, from the peaks reached in 2007-2008, the graphs in Figure 2 show a deleverage trend in the Irish financial market and in all central EMU countries' banking sectors, with the exception of Finland.

4. Assessing banking risk: the "distance-to-default" indicator

To assess the banking sector risk in individual EMU countries, we use a standard forward looking indicator based on contingent claim analysis: "Distance-to-default" (*DtD*). Contingent claim analysis has its genesis in Merton's general derivative pricing model (Merton (1974)) in a framework that combines market-based and balance sheet information to obtain a set of financial risk indicators. In this context, the liabilities are viewed as contingent claims against assets, with payoff determined by seniority. Since equity has limited liability and has the residual claim on the assets after all other obligations have been met, it becomes an implicit call option on the market value of assets with strike price defined by the debt barrier.

DtD is an indirect measure and is recovered implicitly from the observed measures of bank equity prices and liabilities. Since equity is a junior claim to debt, it can be modelled as a standard call option on the assets with exercise price equal to the value of risky debt. The model uses no arbitrage and assumes a frictionless market. We assume that the firm's asset returns follow a stochastic process with constant variance per unit time (σ_A). We also assume a simple capital structure with *N* shares of common stock with market capital *E* and zero coupon bonds with a face value of *D* with time to maturity *T*. The estimation methodology is as follows.

We use the value conservation equation:

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

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

$$E = AN(d_1) - De^{-\gamma(T-t)}N(d_2) \tag{2}$$

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

$$d_1 = \frac{\ln(A/D) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{(T-t)}} \tag{3}$$

$$d_2 = d_1 - \sigma\sqrt{(T-t)} \tag{4}$$

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

$$\sigma_E = N(d_1)\frac{A}{E}\sigma_A \tag{5}$$

The Merton model uses Equations 1 and 2 to obtain the implied asset value A and volatility σ_A, which are not observable and must be estimated by inverting the two relationships. Once numerical solutions for A and σ_A are found, the T periods ahead of *DtD* is calculated as:

$$DtD = \frac{(A-D)}{\sigma_A A} \tag{6}$$

As is carefully explained in Singh et *al.* (2014), using this model to quantify *DtD* requires some practical compromises. Real debt contracts are not all written with a single terminal date. To overcome this problem, a common procedure used by Moody's KMV, and also employed here, is to adopt a one year horizon *T*, but to weight longer term debt of maturity greater than one year at only 50% of face value. We also use the market value of firms' equity, average quarterly historical volatilities as equity price return volatility, and 10-year government bond yields as the risk-free interest rate.

Once individual banks' *DtDs* are calculated we aggregate the indicators in each country following Harada et *al.* (2013) and considering the systemic risk indicator as an average of individual *DtD* series. Specifically, two aggregate indicators can be used: the aggregate average *DtD* (a*DtD*) and the weighted average *DtD* (w*DtD*)[11]. The a*DtD* is obtained by taking the simple average across all credit institutions headquartered in a particular country:

[11] However, this aggregation method ignores the joint distribution properties. Some authors [Gray et *al.* (2007); Gray and Jobst (2010); Duggar and Miltra (2007); Gray et *al.* (2010) and Gray and Jobst (2013)] provide further extensions to incorporate inter-linkages using rolling correlations or extreme value theory, and developed an extension to analyse a wide range of macro-financial issues.

$$aDtD = \left(\frac{1}{N}\right)\sum_{j=1}^{N} DtD_{j,t} \qquad (7)$$

where $DtD_{j,t}$ is the individual *DtD* at time t of credit institution j, whilst the w*DtD* is based on the market capital-weighted average of *DtD* for all credit institutions headquartered in a particular country:

$$wDtD = \sum_{j=1}^{N} w_{j,t} DtD_{j,t} \qquad (8)$$

5. Econometric Methodology and Data

The term "contagion", generally used in contrast to "interdependence", conveys the idea that after a shock there may be breaks or anomalies in the international transmission mechanism which arguably reflect switches across multiple equilibria, market panics unrelated to fundamentals, investors' herding, and the like. Contagion has been defined in many different ways in the literature,[12] including the transfer of any shock across countries (Edwards, 2000). Eichengreen and Rose (1999) and Kaminsky and Reinhart (1999) define it as the situation in which knowledge of crisis in one country increases the risk of crisis in another one.

Much of the empirical work on measuring the existence of contagion is based on comparing correlation coefficients during a relatively stable period with a crisis or a period of turbulence (see, e. g., Forbes and Rigobon, 2002 and Corsetti *et al.*, 2005). In fact, Forbes and Rigobon (2002) argue that "contagion is a significant increase in cross-market co-movements after a shock". These authors stress that this notion of contagion excludes a constant high degree of co-movement that exists in all states of the world since; in that

[12] Gómez-Puig and Sosvilla-Rivero (2014) present a detailed literature review of the different definitions of financial contagion and the most important strategies used in its empirical analysis.

case, markets would be just interdependent. This definition is sometimes referred as "shift-contagion"; this very sensible term clarifies that contagion arises from a shift in cross-market linkages, and also avoids taking a stance on how this shift occurs.[13]

In our study we apply this definition of contagion and directly investigate changes in the existence and the intensity of causality between banking and sovereign risk among a sample of 10 euro area countries. To test for contagion, we adopt a dynamic approach in order to assess the evolving nature of the Granger causal linkages and to detect episodes of significant and transitory increases in the pair-wise Granger causal relationships which we identify with contagion. The intuition is that if the causal linkage intensifies during a period of turmoil relative to a period of tranquillity, this intensification is considered contagion, since the propagation of shocks from one risk to the other increases during this episode[14].

Our econometric methodology has several advantages over the alternative approach of focusing on contemporaneous correlations (corrected or not for volatility). First, while our correlation is a symmetrical measure, Granger-causality is an asymmetrical one, so our procedure provides information on the direction of the contagion (from sovereign to banking risk, from banking to sovereign risk, or both). Second, the lag structure offers valuable information for understanding the information flow between the two types of risk. Third, by investigating dynamic causal linkages through a rolling window, we examine how the strength of the relationships evolves over time, allowing us to detect episodes of sudden and temporary increases in these relationships which we identify with contagion. Fourth, we establish an approximate periodization for contagion effects by looking directly into the data (i.e., without making *a priori* conjectures on the time periods during which the

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[13] See Forbes and Rigobon (2001).

[14] Masson (1998) has labelled these unanticipated situations as "pure contagion", as distinct from "simple contagion" caused by "monsoonal effects" and "linkages". "Monsoonal effects" are random aggregate shocks that hit a number of countries in a similar way, while "linkages" are normal interdependencies, such as those produced by trade and financial relations between countries. Only when the transmission process itself changes on entering a crisis period do we talk of contagion in the sense of Masson's "pure contagion".

contagion process might have started to spread). Additionally, like the VAR approach, our methodology enables us to capture the dynamic structure of the variables and offers a convenient framework for separating long-run and short-run components of the data generation process (DGP).

5.1. Testing procedure

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

Tests of Granger causality typically use the same lags for all variables. This poses a potential problem, since Granger-causality tests are sensitive to lag length.[15] In this paper we use Hsiao's (1981) sequential method to test for causality to determine the optimal lag structure for each variable, combining Akaike's final predictive error (FPE, from now on) and the definition of Granger-causality.[16] Essentially, the FPE criterion trades off the bias that arises from under-parameterization of a model against a loss in efficiency resulting from its over-parameterization, removing the ambiguities of the conventional procedure.

Consider the following models,

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

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

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \varepsilon_t \quad (9)$$

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \sum_{j=1}^{n} \gamma_j Y_{t-j} + \varepsilon_t \quad (10)$$

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

i) Treat X_t as a one-dimensional autoregressive process (9), and compute its FPE with the order of lags *m* varying from 1 to *m*[17]. Choose the order which yields the smallest FPE, say *m*, and denote the corresponding FPE as FPE_X (m, 0).

ii) Treat X_t as a controlled variable with *m* number of lags, and treat Y_t as a manipulated variable as in (9). Compute again the FPE of (10) by varying the order of lags of Y_t from 1 to *n*, and determine the order which gives the smallest FPE, say *n*, and denote the corresponding FPE as FPE_X (m,n)[18].

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

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

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

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[17] FPE_X(m,0) is computed using the formula: $FPE_X(m,0) = \frac{T+m+1}{T-m-1} \cdot \frac{SSR}{T}$, where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (9)

[18] FPE_X(m,n) is computed using the formula: $FPE_X(m,n) = \frac{T+m+n+1}{T-m-n-1} \cdot \frac{SSR}{T}$, where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (10)

$$\Delta X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \varepsilon_t \quad (11)$$

$$\Delta X_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta Y_{t-j} + \varepsilon_t \quad (12)$$

where Z_t is the OLS residual of the cointegrating regression ($X_t = \mu + \lambda Y_t$), known as the error-correction term. Note that, if X_t and Y_t are I(1) variables, but they are not cointegrated, then β in (12) is assumed to be equal to zero.

In both cases [i.e., X_t and Y_t are I(1) variables, and they are or are not cointegrated], we can use Hsiao's sequential procedure substituting X_t with ΔX_t and Y_t with ΔY_t in steps i) to iv), as well as substituting expressions (9) and (10) with equations (11) and (12). Proceeding in this way, we ensure efficiency since the system is congruent and encompassing (Hendry and Mizon, 1999).

As explained above, since the presence and intensity of Granger-causality may vary over time, we adopt a dynamic analysis to detect episodes of contagion associated with a significant, short-run abrupt increase in the causal linkages. To assess the dynamic Granger-causality between sovereign and banking risk, we carry out rolling regressions using a window of four quarterly observations.[19] In each estimation, we apply the Hsiao (1981)'s sequential procedure outlined above to determine the optimum FPE (m, 0) and FPE (m, n) statistics in each case.

5.2. Data

As indicated above, both a*DtD*s and w*DtD*s can be used as aggregate indicators of the banking risk in each country. Nevertheless, in this paper, we will focus our analysis on the a*DtD* indicators. As shown in Singh *et al.* (2014), the evolution of the two indicators is quite

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

similar but, given the structure of the banking sector in individual EMU countries, the a*DtD* seems to capture the general trend and fluctuation better and avoids sudden jumps due to the bankruptcy (or nationalization) of a particular firm with excessive weight. Calculations of distance to default are made on a quarterly basis. However, while most of the institutions report their numbers each quarter, many others only report them on a half-yearly basis. So, to ensure data consistency, balance sheet variables are interpolated for intermediate dates using cubic splines.

The sample used to compute the *DtD* and aggregate *DtD* series is based on all monetary institutions publicly listed and traded in EMU countries between 2004-Q4 to 2013-Q4. First, an exhaustive list of all listed/delisted financial institutions is selected from Bankscope. Pure-play insurance, pension and mortgage banks are then dropped out using Datastream as additional information source. All listed, delisted, restructured or nationalised firms are considered in the dataset as long as they were traded on a public exchange. The list of variables used in the analysis is summarized in Table 2.

[Insert Table 2 here]

While Table 3 summarizes the list of banks by countries and Figure 3 displays the number of banks by countries analysed during each period.

[Insert Table and Figure 3 here]

Ten-year bond yield spreads with respect to the German bund, which have been calculated from data drawn from Datastream, will be the proxy used in this paper to measure sovereign risk in nine EMU-founding countries plus Greece. Therefore, our sample contains 10 EMU countries, five central (Austria, Belgium, Finland, France and the Netherlands) and five peripheral (Greece, Ireland, Italy, Portugal and Spain) and we use quarterly data from 2004-Q4 to 2013-Q3 (i. e., T=34 observations), since this is the period for which data were available for the construction of the a*DtD* indicator (see Singh *et al.* 2014).

Graphs in Figure 4 display the evolution of both sovereign and banking risk in the 10 countries in our sample during the crisis period: from 2007-Q1 to 2012-12.[20] The left axis corresponds to the banking risk indicator (a*DtD*) and the right axis to the sovereign risk indicator (the 10-year yield spread over Germany).

[Insert Figure 4 here]

These graphs show that the sovereign risk indicator registered major increases in all countries (even though the levels reached in peripheral economies were much higher than those observed in central economies) after the announcement of Greece's distressed debt position in late 2009. However, banking risk fell below 2 (the threshold below which it is considered that the banking sector in a country is in distress) coinciding with the collapse of Lehman Brothers (October 2008) in Greece, Ireland, Belgium and Finland. From then until the end of the period, it continued to display a downward trend in Greece and Ireland, but then recovered and achieved levels above 2 one year later in Finland and during 2010-2011 in Belgium, coinciding with the brief economic recovery registered in the euro area. In the rest of the countries the banking risk indicator presented a value above 2 throughout the period. Only in Spain and Italy did it approach the threshold value at the end of 2008 and 2011 in both cases, and also at the end of 2012 in Spain (just after this country requested financial assistance to recapitalize its banking sector).

It is also worth noting that, with the sole exception of Austria, from the beginning of the EMU sovereign crisis both indicators (recall that the lower the value of the banking risk

[20] Sovereign risk (measured as 10-year bond spreads over Germany) presented values close to zero during 2005-2007. Actually, after the launch of the euro, sovereign bond spreads were more or less stable in most cases until early 2001, followed by a period of compression of the spreads which lasted until 2007 (see European Central Bank, 2014).

indicator, the higher the risk) present similar evolution since one seems to be the mirror image of the other. This result highlights the important interconnection and bidirectional linkages between banking and sovereign risk in euro area countries, which was stressed in Section 2.

In order to examine the time-varying behaviour of contagion between the two risks, we follow the Bank for International Settlements (2009) and divide the entire time span (2005:Q2 to 2013:Q3[21]) into eight stages (stages 2 to 7 correspond to BIS stages 1 to 6).

The first stage, which ran from 2005:Q2 to 2007:Q2, is a period of stability just before the beginning of the economic and financial crisis (starting in June 2007, when losses from subprime mortgages began to expose large-scale vulnerabilities). The second stage began in 2007:Q3 and ends in 2008:Q1. This was the first period of the crisis, characterized by concerns over losses on US subprime mortgage loans which escalated into widespread financial stress (on 9 August 2007, the turmoil spread to the interbank markets). In brief, what initially appeared to be a problem affecting only a small part of the US financial system quickly spread more widely, including European Banks. The third stage ran from 2008:Q2 to 2008:Q3. During this period, after a short respite following the takeover of Bear Stearns on 16 March 2008, financial asset prices came under renewed pressure. A distinctive feature of the period up to mid-September was an increased investor focus on signs that the US recession had spilled over to other major economies, triggering a synchronized economic downturn (indeed, the euro area officially entered recession in the last quarter of 2008 when its GDP fell -2.1%). The collapse of Lehman Brothers in mid-September 2008 defined the beginning of the fourth stage, which ended in 2009:Q1. This stage of the crisis was marked by concerns about a deepening of the global recession and the repercussions of the Lehman Brothers bankruptcy, since the balance sheets of banks all

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

around the globe indicated exposure to their assets. Therefore, policy action was implemented on an international scale as governments sought to support market functioning and to cushion the blow of rapid economic contraction. In the European context, the ECB announced liquidity to support European Banks (in September 2008 the Irish government already guaranteed all the deposits/debts of the country's banks), while the European Commission adopted the European Recovery Plan and allowed governments to implement measures to bailout banks. Stage 5 started in 2009:Q2, when the first signs of recovery appeared and global uncertainty receded (announcements by central banks concerning balance sheet expansions, and the range and the amount of assets to be purchased, led to significant relief in the financial markets) and ends in 2009:Q3 just before the newly elected Greek government announced that the country's budget deficit was much larger than previously reported, marking the beginning of the sovereign debt crisis in Europe. The sixth stage began in 2009:Q4 and ended in 2011:Q3. This period was marked by concerns about European sovereign debt due to fears that Greece's debt crisis would spread to EMU peripheral countries. Indeed, during this period rescue packages were put in place in Greece (May 2010), Ireland (November 2010) and Portugal (April 2011). At the end of the period the ECB announced its second covered bond purchase programme. The seventh stage of the crisis, which began in 2011:Q4 when Mario Dragi replaced Jean-Claude Trichet as President of the European Central Bank and ended in 2012:Q2, was still a period of high turmoil in European markets. Italy was in the middle of a political crisis and the main rating agencies lowered the ratings not only of peripheral countries, but also of Austria and France. In this context of financial distress and huge liquidity problems, the European Central Bank responded forcefully by implementing (along with other central banks) nonstandard monetary policies, i.e., policies beyond setting the refinancing rate. In particular, the ECB's principal means of intervention were the so-called long term refinancing operations (LTRO). In November 2011 and March 2012, the ECB allotted to banks an amount close to 500 billion Euros for a three-year period. However, in March 2012 the second rescue package to Greece was approved and in June 2012 Spain requested financial assistance to recapitalize its banking sector. Finally, the last stage of the crisis began in 2012:Q3 after Mario Draghi's statement that he would do "whatever it takes to preserve the euro", which had a healing effect on markets and finished at the end of the sample period in 2013:Q3.

6. Results

As a first step, we tested the order of integration of the a*DtD*s, and the 10-year bond yield spreads by means of Augmented Dickey-Fuller (ADF) tests. Then, following Cheung and Chinn (1997)'s suggestion, we confirmed the results using the Kwiatkowski *et al.* (1992) (KPSS) tests, where the null is a stationary process against the alternative of a unit root. The results, not shown here to save space but available from the authors upon request, decisively reject the null hypothesis of non-stationarity in the first regressions. They do not reject the null hypothesis of stationarity in the first differences, but strongly reject it in levels, in the second differences. So, they suggest that both variables can be treated as first-difference stationary.

As a second step, we tested for cointegration between each of the 20 pair relationships using Johansen (1991, 1995)'s approach. The results suggest[22] the absence of long-run cointegration between the a*DtD* and the 10-year yield spread. Therefore, we tested for Granger-causality in first differences of the variables, with no error-correction term added [i. e., equations (11) and (12) with $\beta=0$].

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

6.1. Empirical results

To summarize the results, in Figures 5 we plot the evolution over time of the difference between FPE (m, 0) and FPE (m, n) statistics in each case. Therefore, these graphs provide us with a view of the dynamic bidirectional influence that exists between sovereign and banking risks for each EMU country and constitute our indicator of contagion based on time-varying Granger-causality analysis.

[Insert Figures 5 here]

In Figure 5a we present the graphs corresponding to the five peripheral EMU countries included in the sample (Greece, Ireland, Italy, Portugal and Spain), whilst Figure 5b displays the graphs corresponding to the five central EMU countries in our sample (Austria, Belgium, Finland, France and the Netherlands).

Note that if the difference is positive and statistically significant at the 1% level in the case of, say, the banking to sovereign risk relationship, this indicates the existence of a significant, transitory increase in the Granger-causality relationship running from country banking risk towards sovereign risk, which we identify with a contagion episode. Therefore, the contagion episodes that are significant at the 1% confidence level during each of the above mentioned stages, as well as the direction of the contagion and the countries involved, [23] are shown in Table 4.

[Insert Table 4 here]

Some important observations can be drawn from Figures 5 and Table 4. During the first stage, before the financial crisis, contagion mainly took place from sovereigns to banks. We find evidence of at least one contagion episode in this direction in seven out of the 10 cases studied, the exceptions being Greece, Italy and France. It is noticeable that these episodes are mainly concentrated in the second semester of 2005 and in the first semester of 2007,

[23] Recall that we associate contagion with a significant, abrupt increase in the short-run causal linkages.

coinciding with a period of economic stagnation in EMU countries in the first case and with the beginning of a downturn in GDP growth from 2007 in the euro area, which after peaking in the last quarter of 2006 (3.7%) began to decrease until it reached negative values at the end of 2008. Not a single contagion episode is detected in stages 2 and 3. These findings may imply that the US subprime crisis had a scarce impact on European financial markets.

However, following the collapse of Lehman Brothers (stage 4), fears of losses in the European banks which were more exposed to US assets triggered contagion episodes from banks to sovereigns, mostly in central EMU countries. Indeed, we detect episodes of contagion in this direction in Austria, Finland and the Netherlands. These results might indicate that central EMU markets were hit more by the international financial crisis than peripheral markets. This finding is in accordance with the results presented in Table 1 indicating governments' commitments to supporting the banking system during the period October 2008-May 2010 and showing that in mid-2010 they were clearly higher in central than in peripheral countries (with the exception of Ireland). In particular, the government commitment to bail out banks in the three countries above mentioned was between 20% and 75% of their GDP.

During stage 5, some slight signs of recovery were noted as well as an atmosphere of some relief in the financial markets; however, in Spain there were also episodes of contagion from sovereigns to banks. In the middle of a serious economic crisis (Spanish GDP fell 4.0% and 2.6%, in 2009:Q3 and 2009:Q4 respectively), as some authors point out, there may have been some pressure from governments on banks within their jurisdiction to buy their debt. Indeed, at the end of 2011 (see Figure 1a and 1b), the home share of all Spanish banks' sovereign exposure was 81% (the highest in the euro area) and they held the equivalent of 44% of Spanish GDP in the form of domestic bonds. This may have broadened concerns about their exposure to bad assets and may have fed speculation about their solvency. Besides, episodes of contagion from banks to sovereigns in this stage were detected in only two central countries (France and the Netherlands).

It is noticeable that during stage 6, a period in which concerns about European sovereign debt crisis contagion were at their peak and rescue packages to Greece, Ireland and Portugal were put in place, episodes of contagion from sovereigns to banks were detected in two peripheral countries (Italy and Portugal) and in four central countries (Austria, Belgium, Finland and the Netherlands). During this stage, contagion episodes from banks to sovereigns were identified in all the peripheral countries. These findings suggest the following ideas: (1) In Portugal and Italy, contagion from the sovereign to the banking sector can be easily understood, since the main source of vulnerability in those countries was concentrated in the public sector itself (see Figure 2). Moreover, Portuguese and Italian banks held the equivalent of 23% and 21% of their countries' GDP in the form of domestic bonds (see Figure 1b) which, as we stated above, might have fed speculation regarding their solvency; (2) The sudden drop in investor confidence induced fears of contagion in all euro area countries and led to "flight-to-safety" investments, which increased the demand for the German Bund and also caused a sharp rise in yield spreads of EMU central countries. This increase in risk in the sovereign sector may have been transmitted to their banking sectors[24]; (3) Not only in Ireland (where banks' debt-to-GDP was close to 450% at the end of 2012), but also in Portugal, Spain, Italy and Greece (see Figure 2) the high leverage registered in the banking sector (194%, 150%, 110% and 100%

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

of their GDP respectively, at the end of 2012) may have increased tensions in their already vulnerable and distressed public sector.

Besides, during the seventh stage, coinciding with the nonstandard monetary policies implemented by the ECB (two LTRO) to support the banking system, episodes of contagion from banks to sovereigns were found mainly in peripheral countries (Greece, Ireland, Italy and Portugal). Recall that in spring 2011, the three programme countries (Greece, Ireland and Portugal) made up more than 50% of total liquidity provided through both the main refinancing operations (MRO) and the LTRO windows – although some episodes were also detected in this direction in Austria, France and the Netherlands. It is also noticeable that in Spain, a country that requested financial assistance to recapitalize its banking sector in June 2012, one episode of contagion from the sovereign to the banking sector was identified just after the rescue (2012:Q3). This result suggests that in the Spanish case, even though the country only requested assistance for its financial sector, the banking sector risk was clearly transferred to the sovereign risk.

The last stage ran from July 2012 till the end of the sample period. Despite the healing effects of Mario Draghi's words on financial markets, some episodes of contagion were still found from sovereigns to banks in Italy and Finland and from banks to sovereigns (Portugal, Spain, France and the Netherlands). We should keep in mind that, although turbulence in financial markets fell sharply, the economic recession entered its second dip during this eriod (see Figure 2c). Thus, as Shambaugh (2012) pointed out, not only did the problems of weak banks and high sovereign debt reinforce each other, but were both exacerbated by weak economic growth.

Finally, it is worth noting that from early 2005 till the collapse of Lehman Brothers, more than 90% of the total contagion episodes detected were from sovereigns to banks, whereas after the last quarter of 2008, coinciding with the beginning of the financial crisis and the implementation of government measures to support financial institutions, the direction of contagion underwent a change. In this second sub-period the majority of the contagion episodes (around 63% of the total) ran from banks to sovereigns: specifically, in the cases of France, Greece, and Ireland (where contagion episodes were detected only in this direction), and Portugal and the Netherlands (where they accounted for more than 70% of the total episodes). Conversely, in Belgium and Finland contagion was mainly identified from sovereigns to banks, whilst in Spain, Italy and Austria there were similar numbers of contagion episodes in both directions.

7. Concluding remarks.

In recent years the euro area has faced three interlocking crises (banking, sovereign debt, and economic growth) which together have challenged the viability of the currency union (see Shambaugh, 2012). The interrelationship between debt and growth is a matter of great importance; however, its analysis is beyond the scope of this paper, which focuses on the interconnection between banking and sovereign debt crises in EMU countries. Whereas there is a substantial amount of literature exploring the determinants of either bank risk or sovereign risk in isolation in the euro area context, few papers to date have looked at the interdependence or contagion between the sovereign and the banking sectors.

Based on indicators of bank and sovereign risk which have not been used previously in the literature, and applying a dynamic approach to testing for Granger-causality, we investigate the possible existence of contagion between the two measures of risk in ten of the countries that have belonged to the EMU since its inception (only Luxembourg and Germany are excluded from the analysis). Our direct analysis of the data allows us to detect episodes of sudden and temporary increases in pairwise Granger-causal relationships which we identify with contagion. To contextualize the empirical results, we follow the Bank for

International Settlements (2009) and divide the entire time span (2005:Q2 to 2013:Q3) into eight stages.

The main conclusions that can be drawn from our analysis are the following. First, from early 2005 till the collapse of Lehman Brothers (stages 1 to 3), more than 90% of the total contagion episodes detected were from sovereigns to banks and coincided with a period of economic stagnation in EMU countries or with the beginning of a downturn in GDP growth in the euro area. Second, after the last quarter of 2008, coinciding with the beginning of the financial crisis and the implementation of government measures to support financial institutions, the direction of the contagion underwent a change. In this second sub-period (stages 4 to 8) the majority of the episodes (around 63% of the total) ran from banks to sovereigns. Specifically, in the cases of France, Greece, Ireland (only contagion episodes in this direction were detected), Portugal and the Netherlands (where they account for more than 70% of the episodes). Conversely, in Belgium and Finland contagion was mainly from sovereigns to banks, while in Spain, Italy and Austria there were similar numbers of episodes of contagion in both directions.

It is also noticeable that during stage 6, when concerns about European sovereign debt crisis contagion were at their peak and rescue packages were provided for Greece, Ireland and Portugal, episodes of contagion from sovereigns to banks were detected in two peripheral countries (Italy and Portugal) and in four central countries (Austria, Belgium, Finland and the Netherlands), whereas contagion episodes from banks to sovereigns were identified in all peripheral countries. These findings may suggest that the sudden drop in investor confidence induced fears of contagion in all euro area countries and led to "flight-to-safety" investments, which in turn increased the demand for the German Bund and also caused a sharp rise in yield spreads in central EMU countries. This increase in risk in the sovereign sector might have been transmitted to the banking sectors which held significant amounts of sovereign debt. Besides, not just in Ireland, but in the other peripheral EMU countries as well, the high leverage registered in the banking sector may have increased tensions in their already vulnerable and distressed public sectors.

Moreover, during the seventh stage, coinciding with the nonstandard monetary policies implemented by the ECB (two LTRO) to support the banking system, episodes of contagion from banks to sovereigns were found mainly in peripheral countries (Greece, Ireland, Italy and Portugal). This is consistent with the fact that in spring 2011, the three programme countries (Greece, Ireland and Portugal) made up more than 50% of total liquidity provided through both the main refinancing operations (MRO) and the LTRO windows. Finally, in the last stage, from July 2012 till the end of the sample period, despite the healing effects of Mario Draghi's words on financial markets, we still detect some episodes of contagion in both directions. We should keep in mind that, although the turbulence in the financial markets dropped sharply, the economic recession entered its second dip in stage 8 of our sample period. This supports the idea that the problems of weak banks and high sovereign debt not only reinforced each other, but they were both exacerbated by weak economic growth.

All in all, our findings present empirical evidence about the existence of bidirectional linkages between bank and sovereign risk (i.e., a "diabolic loop" as suggested by Brunnemeier *et al.*, 2011, or a "two-way feedback" transmission channel as advocated by Acharya *et al.*, 2014, which have been broadly explained in Section 2 and represented a key element in the European sovereign crisis). Therefore, in order to avoid further market distorsions in the future, both national and supra-national efforts should be made. Indeed, since our results suggests that markets become increasingly integrated during episodes marked by a global financial crisis, they should be beneficial for regulators and policymakers who are interested in analysing interactions between sectoral crises and in understanding the behaviour and reaction of euro area markets especially during episodes marked by a major financial recession. The debate around the creation of a European Banking Union stimulates more interest in studying the distortions characterizing European banking systems. Moreover, our findings may also be useful to to investors, portfolio managers, pension fund managers and other institutional investors who are contemplating investing in international European banks, in order to make more informed portfolio allocation decisions.

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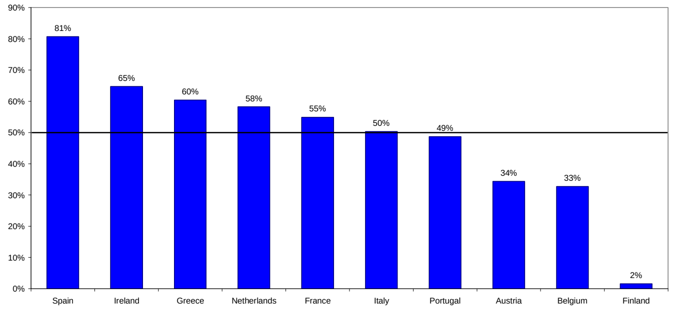
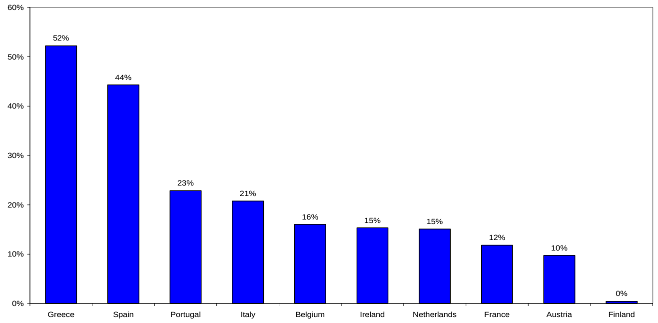
Figure 1

Figure 1.a. Home share of total banks' sovereign exposure (gross direct long exposure)-December 31, 2011



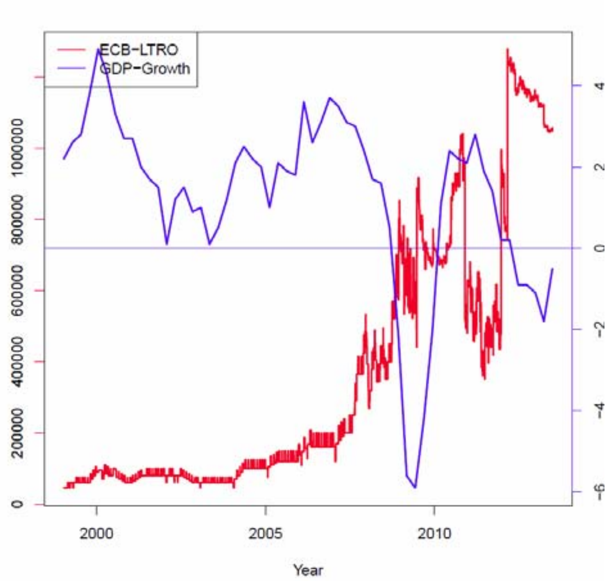
Source: European Bank Authority: http://www.eba.europa.eu/risk-analysis-and-data/eu-wide-stress-testing/2011/results

Figure 1.b. Banks' sovereign exposure to their own country bonds-to-GDP, December 2011



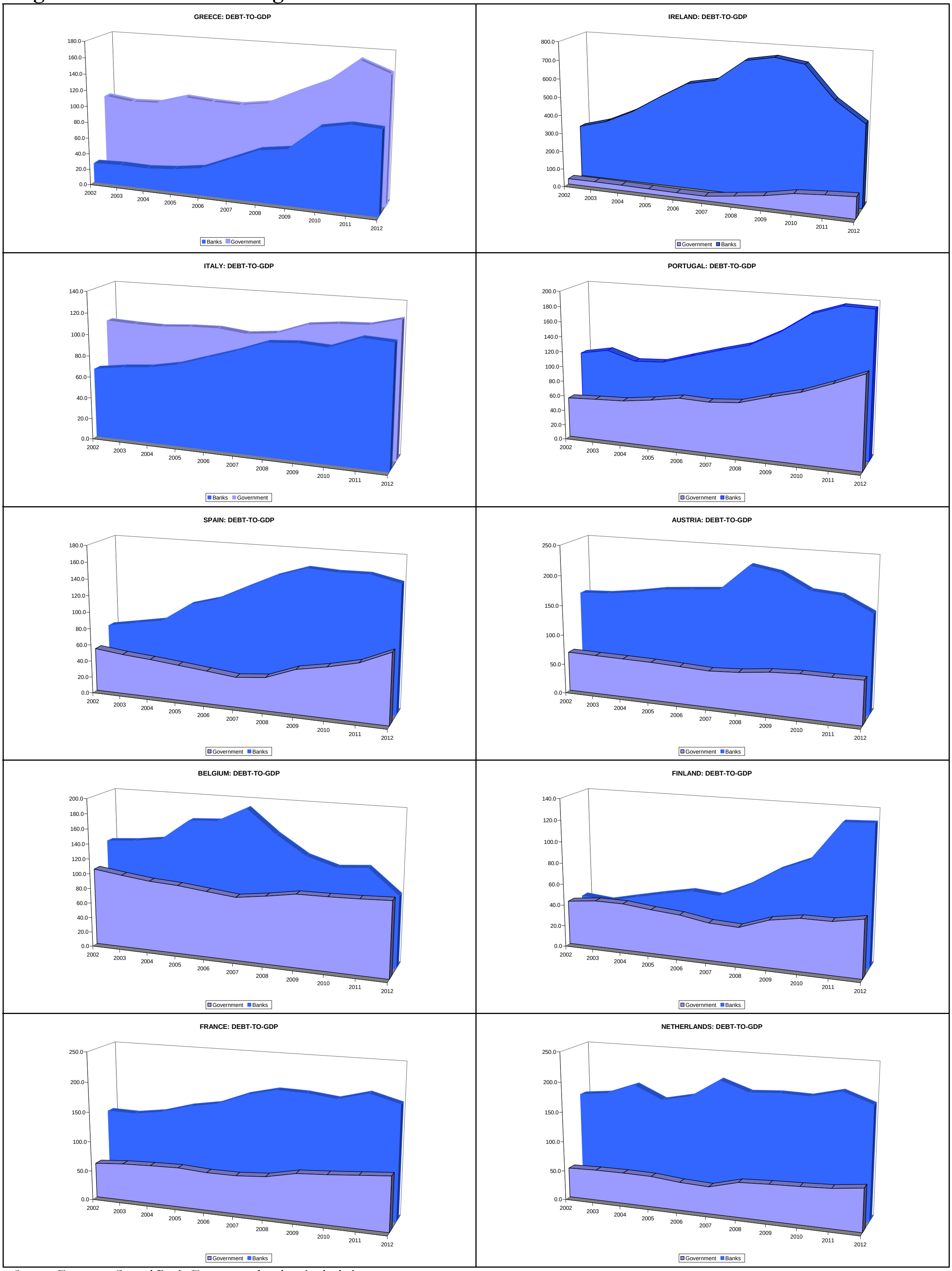
Source: European Bank Authority, stress-tests 2011 and Eurostat

Figure 1.c. ECB long-term refinancing operations (LTRO) and GDP growth: 1999-2013



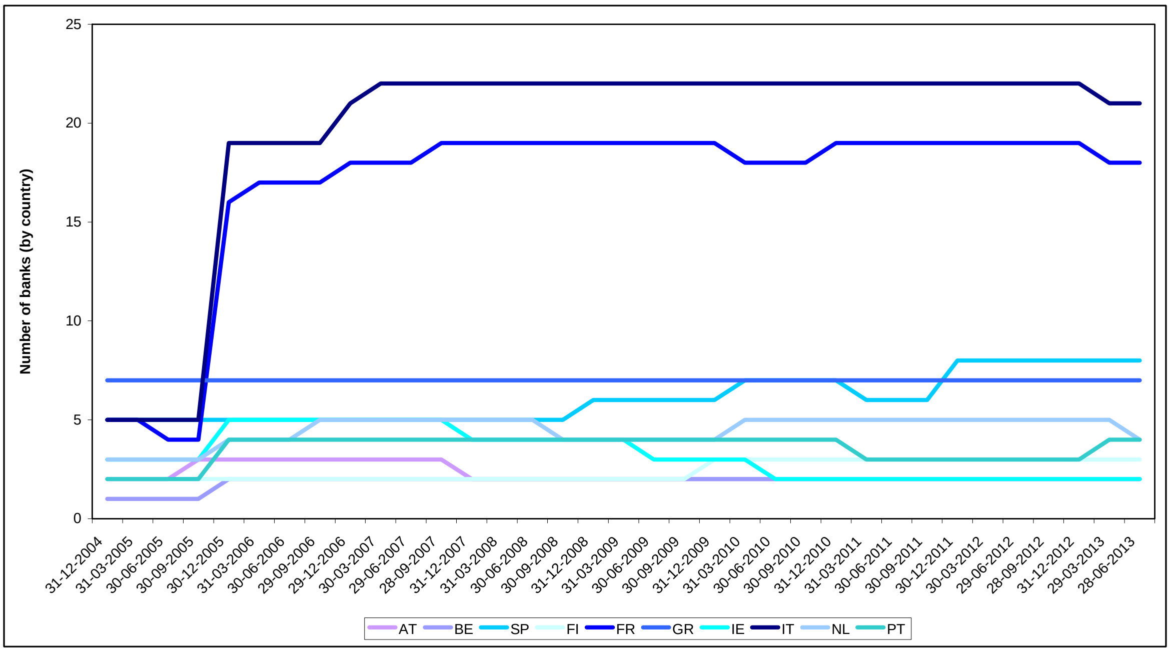
Source: European Central Bank: http://www.ecb.europa.eu/mopo/implement/omo/html/top_history.en.html and Eurostat

Figure 2. Banks and Sovereign debt-to-GDP: 2002-2012



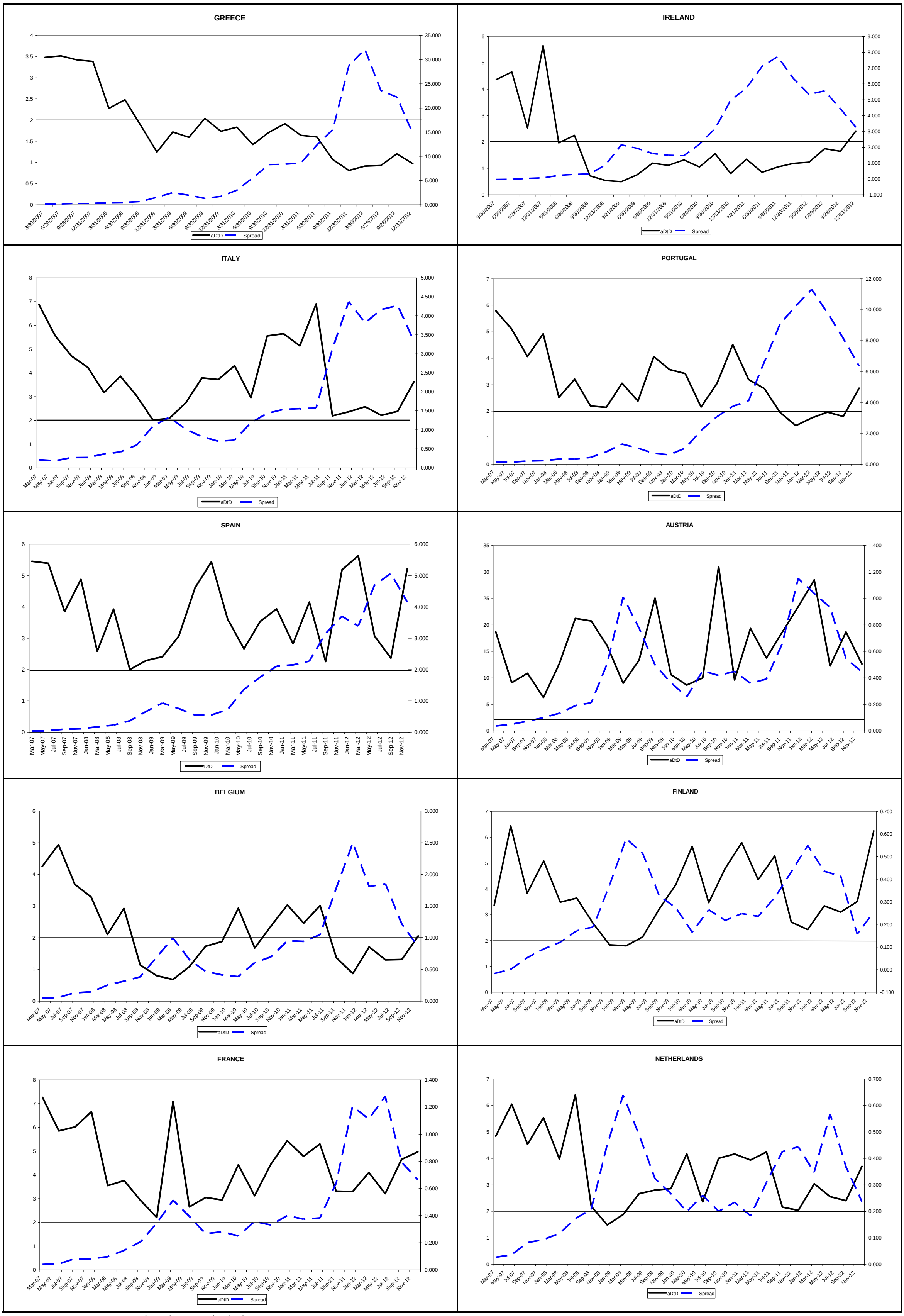
Source: European Central Bank, Eurostat and authors' calculations.

Figure 3. Number of banks used in each period by each country



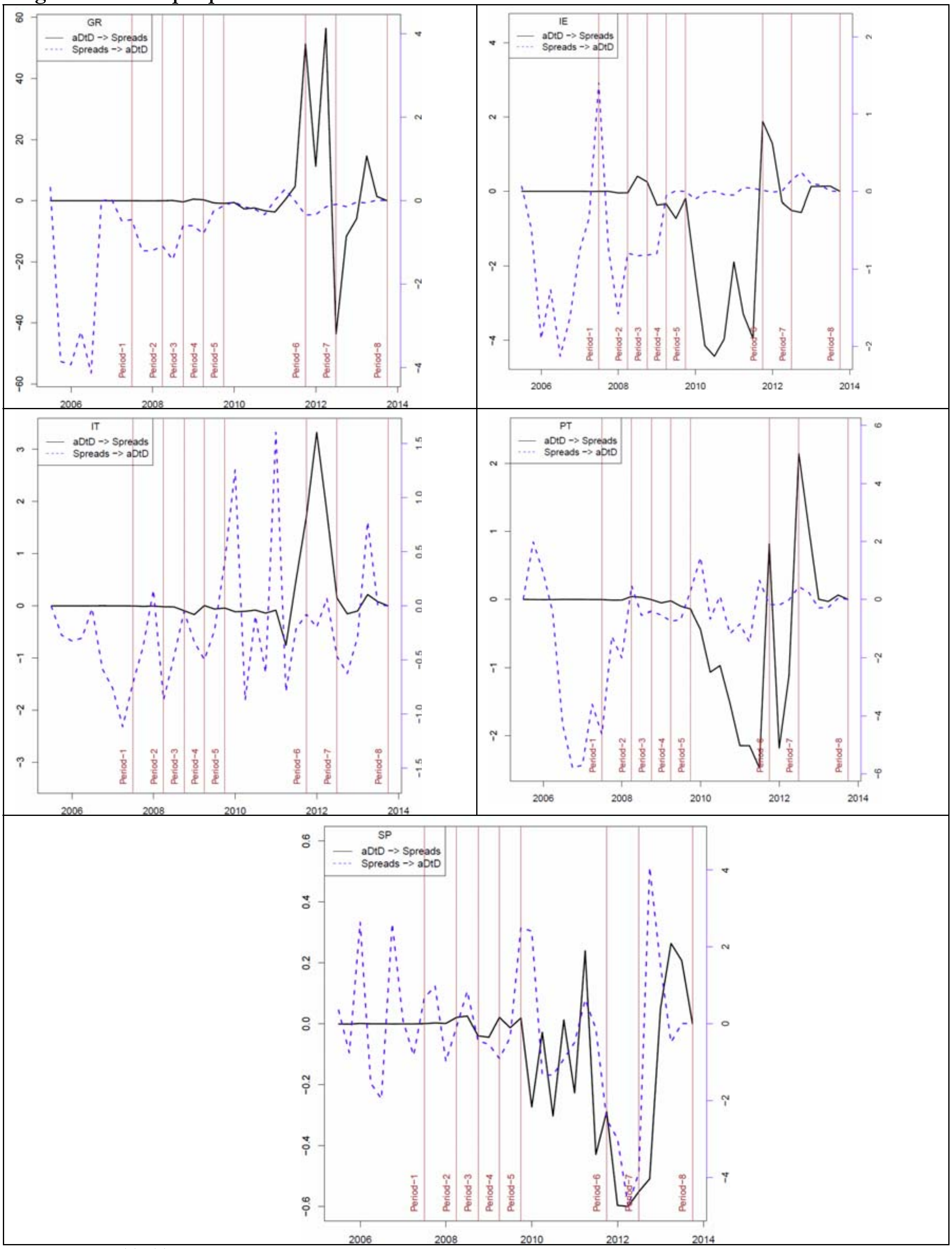
Source: Authors' calculations.
Notes: AT, BE, FI, FR, GR, IE, IT, NL, PT and SP stand for Austria, Belgium, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal and Spain respectively.

Figure 4. Banking and Sovereign risk in EMU countries: 2007-2012



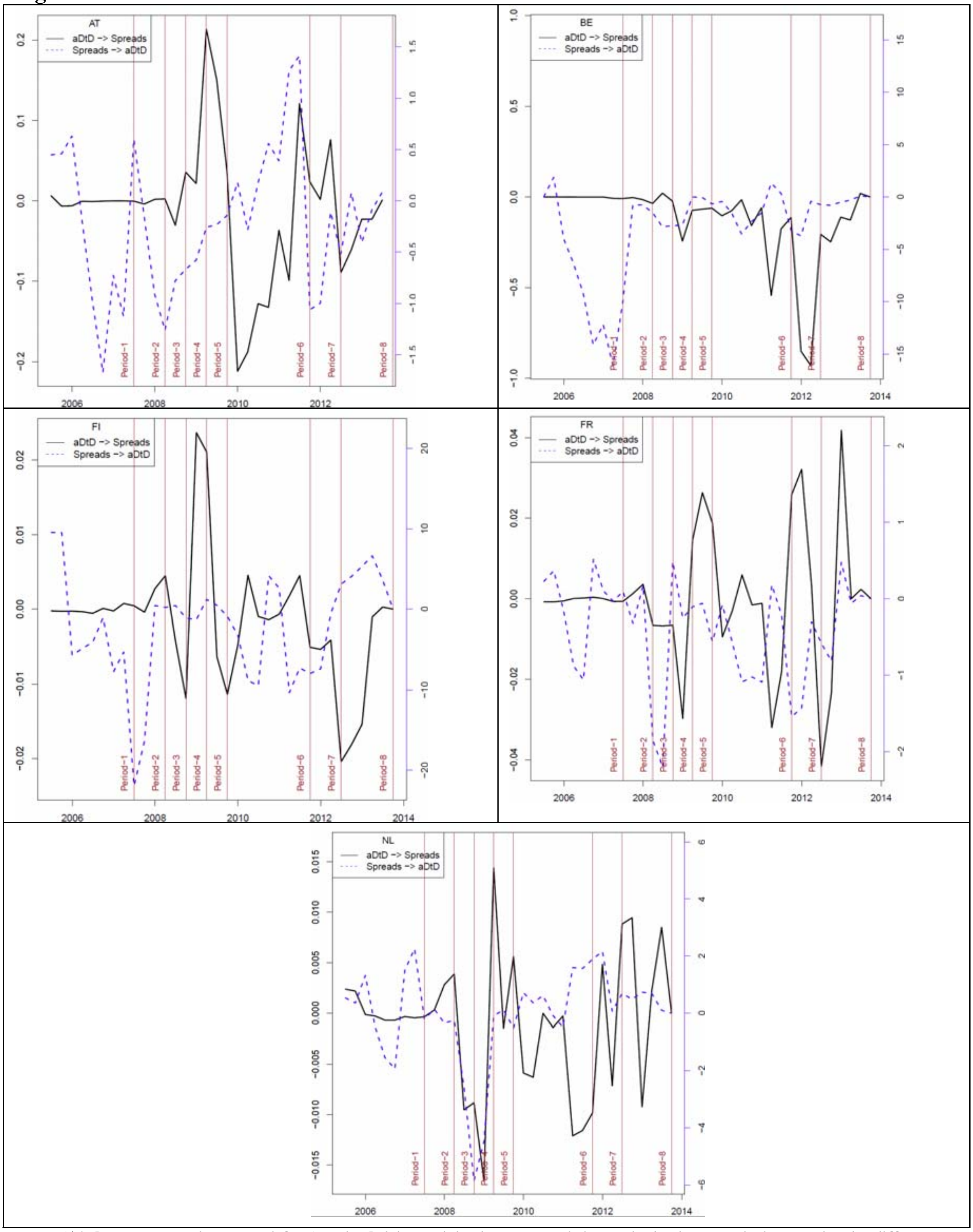
Source: Datastream and authors' calculations.

Figure 5. Time-varying causality between sovereign and banking risk, 2005:Q2-2013Q3
Figure 5a. EMU peripheral countries.



Note: GR, IE, IT, PT and SP stand for Greece, Ireland, Italy, Portugal and Spain respectively. We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past a*DtD* series (a*DtD*→Spreads) and the differences between FPE obtained when estimating the a*DtD* series using only the information contain in past a*DtD* series and the FPE obtained using also the information contained in past sovereign spread series (Spreads→a*DtD*). We associate contagion from country banking risk towards sovereign risk with those episodes where the difference a*DtD*→Spreads (left axis) is positive and statistically significant at the 1% level, and contagion from sovereign risk towards country banking risk with those episodes where the difference Spreads→a*DtD* (right axis) is positive and statistically significant at the 1% level.

Figure 5. Time-varying causality between sovereign and banking risk, 2005:Q2-2013Q3
Figure 5b. EMU central countries.



Note: AT, BE, FI, FR and NL stand for Austria, Belgium, Finland, France and the Netherlands respectively. We plot the differences between the FPE obtained when estimating sovereign spread series using only the information contained in past sovereign spread series and the FPE obtained also using the information contained in past a*DtD* series (a*DtD*→Spreads) and the differences between FPE obtained when estimating the a*DtD* series using only the information contain in past a*DtD* series and the FPE obtained using also the information contained in past sovereign spread series (Spreads→a*DtD*). We associate contagion from country banking risk towards sovereign risk with those episodes where the difference a*DtD*→Spreads (left axis) is positive and statistically significant at the 1% level, and contagion from sovereign risk towards country banking risk with those episodes where the difference Spreads→a*DtD* (right axis) is positive and statistically significant at the 1% level.

Table 1. Government support measures for financial institutions (October 2008-May 2010)

Country	Capital injection		Liability guarantees		Asset support		Total commitment as % of 2008 GDP	Deposit insurance in Euros
	Within schemes	Outside schemes	Guaranteed issuance of bonds	Other guarantees, loans	Within schemes	Outside schemes		
Austria	5.8 (15)	0.6	21.8 (75)	0	- (-)	-	32	Unlimited
Belgium	- (-)	19.9	34 (-)	90.8	-(-)	16.9	47	100,000
Finland	-(4)	-	-(50)	0	-(-)	-	29	50,000
France	8.3 (21)	3	134.2(320)	0	-(-)	-	18	70,000
Greece	3.2 (5)	-	14.4 (30)	0	4.4 (8)	-	18	100,000
Ireland	12.3 (10)	7	72.5 (485)	0	8(90)	-	319	Unlimited
Italy	41.1 (12)	-	-(-)	0	-(50)	-	4	103,291
Netherlands	10.2 (20)	16.8	54.2(200)	50	-(-)	21.4	52	100,000
Portugal	-(4)	-	5.4 (16)	0	-(-)	-	12	100,000
Spain	11 (99)	1.3	56.4 (100)	9	19.3 (50)	2.5	24	Unlimited

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

Table 2. Variables used in the "Distance-to-Default" indicator

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

Table 3. List of banks by countries used in the "Distance-to-Default" indicator

Name	Status	Country	ISIN
Austria			
UniCredit Bank Austria AG	Delisted	AT	AT0000995006
Erste Group Bank AG	Listed	AT	AT0000652011
Raiffeisen Bank International AG	Listed	AT	AT0000606306
Belgium			
Dexia	Listed	BE	BE0003796134
KBC Groep NV	Listed	BE	BE0003565737
Spain			
Banco Santander SA	Listed	SP	ES0113900J37
Banco Bilbao Vizcaya Argentaria SA	Listed	SP	ES0113211835
Caixabank, S.A.	Listed	SP	ES0140609019
Bankia, SA	Listed	SP	ES0113307021
Banco de Sabadell SA	Listed	SP	ES0113860A34
Banco Popular Espanol SA	Listed	SP	ES0113790226
Caja de Ahorros del Mediterraneo CAM	Listed	SP	ES0114400007
Bankinter SA	Listed	SP	ES0113679I37
Renta 4 Banco, S.A.	Listed	SP	ES0173358039
Finland			
Pohjola Bank Plc	Listed	FI	FI0009003222
Aktia Bank Plc	Listed	FI	FI4000058870
Alandsbanken Abp-Bank of Aland Plc	Listed	FI	FI0009001127
France			
Credit Agricole Sud Rhône Alpes	Listed	FR	FR0000045346
Paris Orléans SA	Listed	FR	FR0000031684
Credit Agricole de la Touraine et du Poitou	Listed	FR	FR0000045304
Credit Agricole Alpes Provence	Listed	FR	FR0000044323
Crédit Agricole Nord de France	Listed	FR	FR0000185514
Crédit Agricole d'Ile-de-France	Listed	FR	FR0000045528
Crédit Agricole Loire Haute-Loire	Listed	FR	FR0000045239
Crédit Industriel et Commercial	Listed	FR	FR0005025004
Banque Tarneaud	Delisted	FR	FR0000065526
Caisse régionale de crédit agricole mutuel de Normandie-Seine	Listed	FR	FR0000044364
Caisse Régionale de Crédit Agricole Mutuel du Languedoc	Listed	FR	FR0010461053
Natixis	Listed	FR	FR0000120685
Crédit Agricole de l'Ille-et-Vilaine	Listed	FR	FR0000045213
Crédit Agricole d'Aquitaine	Delisted	FR	FR0000044547
Société Générale	Listed	FR	FR0000130809
Crédit Agricole S.A.	Listed	FR	FR0000045072
BNP Paribas	Listed	FR	FR0000131104
Boursorama	Listed	FR	FR0000075228
Crédit Agricole du Morbihan	Listed	FR	FR0000045551
Crédit Agricole Brie Picardie	Listed	FR	FR0010483768
Société Alsacienne de Développement et d'Expansion	Delisted	FR	FR0000124315
Greece			
National Bank of Greece SA	Listed	GR	GRS003003019
Piraeus Bank SA	Listed	GR	GRS014003008
Eurobank Ergasias SA	Listed	GR	GRS323003004
Alpha Bank AE	Listed	GR	GRS015013006
Marfin Investment Group	Listed	GR	GRS314003005
Attica Bank SA-Bank of Attica SA	Listed	GR	GRS001003003
General Bank of Greece SA	Listed	GR	GRS002003010
Ireland			
Depfa Bank Plc	Delisted	IE	IE0072559994
Irish Bank Resolution Corporation Limited-IBRC	Delisted	IE	IE00B06H8J93
Permanent TSB Plc	Delisted	IE	IE0004678656
Bank of Ireland	Listed	IE	IE0030606259
Allied Irish Banks plc	Listed	IE	IE0000197834

Italy			
UniCredit SpA	Listed	IT	IT0004781412
Intesa Sanpaolo	Listed	IT	IT0000072618
Banca Monte dei Paschi di Siena SpA	Listed	IT	IT0001334587
Unione di Banche Italiane Scpa	Listed	IT	IT0003487029
Banco Popolare – Società Cooperativa	Listed	IT	IT0004231566
Mediobanca SpA	Listed	IT	IT0000062957
Banca popolare dell'Emilia Romagna	Listed	IT	IT0000066123
Banca Popolare di Milano ScaRL	Listed	IT	IT0000064482
Banca Carige SpA	Listed	IT	IT0003211601
Banca Popolare di Sondrio Societa Cooperativa per Azioni	Listed	IT	IT0000784196
Credito Emiliano SpA-CREDEM	Listed	IT	IT0003121677
Credito Valtellinese Soc Coop	Listed	IT	IT0000064516
Banca popolare dell'Etruria e del Lazio Soc. coop.	Listed	IT	IT0004919327
Credito Bergamasco	Listed	IT	IT0000064359
Banco di Sardegna SpA	Listed	IT	IT0001005070
Banco Desio - Banco di Desio e della Brianza SpA	Listed	IT	IT0001041000
Banca Ifis SpA	Listed	IT	IT0003188064
Banca Generali SpA	Listed	IT	IT0001031084
Banca Intermobiliare di Investimenti e Gestioni	Listed	IT	IT0000074077
Banca Popolare di Spoleto SpA	Listed	IT	IT0001007209
Banca Profilo SpA	Listed	IT	IT0001073045
Banca Finnat Euramerica SpA	Listed	IT	IT0000088853
Netherlands			
SNS Reaal NV	Delisted	NL	NL0000390706
RBS Holdings NV	Delisted	NL	NL0000301109
ING Groep NV	Listed	NL	NL0000303600
Delta Lloyd NV-Delta Lloyd Group	Listed	NL	NL0009294552
Van Lanschot NV	Listed	NL	NL0000302636
BinckBank NV	Listed	NL	NL0000335578
Portugal			
Montepio Holding SGPS SA	Delisted	PT	PTFNB0AM0005
Banco Comercial Português, SA	Listed	PT	PTBCP0AM0007
Banco Espirito Santo SA	Listed	PT	PTBES0AM0007
Banco BPI SA	Listed	PT	PTBPI0AM0004
BANIF - Banco Internacional do Funchal, SA	Listed	PT	PTBAF0AM0002

Source: Bankscope

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

Table 4. Evolution of contagion episodes

	Stage	Contagion	Direction of contagion	Peripheral countries	Central Countries
Before Lehman Brothers Collapse	**First stage:** (2005:Q2 to 2007:Q2)	*Yes*	*Sovereign to banks*	*Ireland (2007:Q2)* *Portugal (2005:Q3)* *Spain (2005:Q4)* *Spain(2006:Q3)*	*Austria (2005:Q4)* *Austria(2007:Q2)* *Belgium (2005:Q3)* *Finland (2005:Q2)* *Finland (2005:Q3)* *Netherlands (2007:Q1)*
		No	Banks to sovereigns	-	-
	Second stage: (2007:Q3 to 2008:Q1)	***No***	*Sovereign to banks*	-	-
		No	Banks to sovereigns	-	-
	Third stage: (2008:Q2 to 2008:Q3)	***No***	*Sovereign to banks*	-	-
		No	Banks to sovereigns	-	-
After Lehman Brothers Collapse	**Fourth stage:** (2008:Q4 to 2009:Q1)	***No***	*Sovereign to banks*	-	-
		Yes	Banks to sovereigns	-	Austria (2009:Q1) Finland (2008:Q4) Finland (2009:Q1) Netherlands (2009:Q1)
	Fifth stage: (2009:Q2 to 2009:Q3)	*Yes*	*Sovereign to banks*	*Spain (2009:Q3)* *Spain (2009:Q4)*	-
		Yes	Banks to sovereigns	-	France (2009:Q2) France (2009:Q3) Netherlands (2009:Q3)
	Sixth stage: (2009:Q4 to 2011:Q3)	*Yes*	*Sovereign to banks*	*Italy (2009: Q4)* *Italy (2010:Q4)* *Portugal (2009:Q4)*	*Austria (2010: Q3)* *Austria (2011:Q1)* *Austria (2011:Q2)* *Belgium (2011:Q1)* *Finland (2010:Q3)* *Netherlands (2011:Q3)*
		Yes	Banks to sovereigns	Greece (2011:Q3) Ireland (2011:Q3) Italy (2011:Q3) Portugal (2011:Q3) Spain (2011:Q1)	Austria (2011:Q2) France (2011:Q3)
	Seventh stage: (2011:Q4 to 2012:Q2)	*Yes*	*Sovereign to banks*	*Spain (2012:Q3)*	*Netherlands (2011:Q4)*
		Yes	Banks to sovereigns	Greece (2012:Q1) Ireland (2011:Q4) Italy (2011:Q4) Italy (2012:Q1) Portugal (2012:Q2)	Austria (2012:Q1) France (2011:Q4) Netherlands (2012:Q2)
	Eight stage: (2012:Q3 to 2013:Q3)	*Yes*	*Sovereign to banks*	*Italy (2013:Q1)*	*Finland (2012:Q4)* *Finland (2013:Q1)*
		Yes	Banks to sovereigns	Portugal (2012:Q3) Spain (2013:Q1) Spain (2013:Q2)	France (2012:Q4) Netherlands (2012:Q3) Netherlands (2013:Q2)

Notes: Contagion episodes are significant at the 1% level.

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