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Article

The effect of the PSI in the relationship between sovereign and bank credit risk : evidence from the euro area

The Effect of the PSI in the Relationship Between Sovereign and Bank Credit Risk: Evidence from the Euro Area

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This study examines the nexus between sovereigns and banks during a crisis with a focus on the effects of PSI, the voluntary exchange program of Greek sovereign bonds with private sector involvement. The effectiveness of the program is evaluated through its impact on credit default swaps of 8 Eurozone countries and 21 banks, using daily data from 2009 to 2014. Using linear and nonlinear causality analyses, it is found that the link between sovereign and bank risk weakened after PSI, while the persistence and magnitude of lead-lag interactions also declined in the same period. A difference-in-difference model confirms this result. The findings are also robust to second moment filtering, with GARCH-BEKK residuals indicating the presence of significant albeit declining nonlinear causal effects. The empirical evidence suggests that sovereign debt restructuring initiatives, such as PSI, could be an effective policy measure to ease off pressure on the nexus between banks and their sovereigns. (JEL: F34, F42, G28, H12, H63)

Keywords: CDS spreads; PSI; sovereign/bank credit risk; contagion; nonlinear causality

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I. Introduction

The global financial crisis (GFC) that began in the US as a sub-prime mortgage crisis in 2007 and quickly spread to the other side of the Atlantic, triggered an economic and banking crisis in parts of the European Union coincident with a sovereign crisis in parts of the European periphery, most notably in Greece. Banks, which in the years before the crisis, had taken considerable if not excessive risks to expand size and scope in the quest for higher profits, were confronted with adverse pressures incited by a dramatic reduction of liquidity in the interbank money market.

With continuing financial market turbulence, falling lending volume, rising defaults, compounded by exposures to distressed sovereigns, European banks found it even more difficult to remain profitable, if not viable post-GFC. Consequently, stronger emphasis was placed on economic support from Government to the banking sector. While the ECB's newly established long-term-refinancing-operations (LTRO) program was providing some financial sector relief, nagging concerns were raised about the interconnectedness of Eurozone governments with their banks, a situation that looked set to be further embedded, given how many banks had been willing subscribers to the politicians' view that the LTRO money should be invested in sovereign debt.[1] The financial crisis soon turned into a fiscal crisis.

Addressing sovereign solvency problems is much more complex than corporate solvency, since sovereigns cannot be liquidated. And sovereign debt restructuring is more likely to have major repercussions for both the borrower and creditor economies, as evident by international experience beset with disorderly sovereign debt restructuring episodes.[2] This study sets out to assess the extent and direction of the relationship between banks and their sovereigns in Eurozone countries during a crisis.[3] More specifically, it focuses on the

1. See The Economist (2011).

2. Bini Smaghi (2011) argues that debt workouts in the public sector are quite different involving not only financial but also political and social adjustment costs. Sovereign defaults can have costly spillovers beyond sovereign credit markets with high haircuts being a signal of untrustworthy economic policies (Cole and Kehoe 1998). There can also be adverse effects on trade (Rose 2005), private sector access to credit (Arteta and Hale 2008), or for the financial sector (Acharya and Rajan 2013).

3. Paltalidis et al. (2015) provide evidence that sovereign credit risk is the primary

effects of the Greek sovereign debt crisis around a specific event, namely, the 2011/2012 Greek debt restructuring program. The key hypothesis is that large restructuring programs involving large haircuts such those under PSI intensify the nexus between sovereigns and banks.

Admittedly, Greece is the Eurozone country which faced the most severe problems since the onset of the financial crisis.[4] The country's potential insolvency would directly affect banks and other creditors with significant exposures to Greek sovereign debt, raising the probability of transmitting risk to private creditors and countries, e.g. a Greek default could trigger 'runs' on other euro sovereigns and their banks, while widening the spreads of sovereign and bank Credit Default Swaps (hereafter CDS). Normally, it would be expected that during a financial crisis an increasing share of the variability of sovereign credit risk to be explained by bank credit risk (see, e.g., Lahmann, 2012; Vergote, 2016). However, Greece is different insofar the trouble started from public finances and then moved on to banks. This means that price discovery would be expected to move from sovereign to bank CDS recognizing the potential costs of contagion were not limited to the loss of Greek assets only. Countries with weaker banking sectors and public finances (e.g. Ireland, Italy, Portugal and Spain) were particularly vulnerable to contagion.

A series of important measures were put in place during the crisis, aimed at reducing country-specific credit risk, systemic credit risk in the Eurozone, and the strong nexus between sovereign and bank credit risk. Among these measures, was the program of the 'voluntary' exchange of Greek bonds with the participation of the private sector (Private Sector Involvement -PSI- 10/2011). The intent of PSI was to put forward a sustainable and credible debt restructuring program in place, reducing

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source of systemic risk in the Eurozone countries through its effects on the banking system.

4. The Greek crisis became public in October 2009 after the newly elected centre-left government announced that public finances were far worse than previously thought with the 2009 budget deficit forecast revised upwards from 3.7% (April) to 12% (October) and eventually to 15.6% of GDP, boosting public debt to more than 120% of GDP. By late 2010, it had become fairly clear that any hopes of debt sustainability had quickly evaporated, and at the October 2010 Deauville Summit, France and Germany put forth a proposal for the creation of a permanent crisis resolution mechanism inclusive of a sovereign debt restructuring process with the participation of the private sector. While the intent of the new plan was to prevent contagion spreading among Eurozone countries in the event of an ensuing debt crisis by one of the weaker members, the announcement increased turmoil in the financial markets with European periphery bond spreads rising sharply, as investors fretted over wider Eurozone sovereign debt haircuts amidst dismal Eurozone growth prospects.

the debt to GDP ratio to 120 percent by 2020,[5] by transferring part of the debt burden to the private sector and consequently to private financial institutions,[6] which held a significant amount of Greek public debt in their portfolios. The program was perceived as a strong signal from the International Monetary Fund (IMF) and the European authorities to the private sector, that fully funded bailouts of banks and their sovereigns were no longer tolerable. As noted by The Economist "the impact of laying out a credible path to debt sustainability could be powerful. Greeks could start to believe they have a way out of the crisis; investors could put money in the country with more certainty. It could create a positive circle of confidence and growth." (The Economist 10 Nov. 2012).

However, the 'voluntary' participation of the banking sector to the PSI program had important consequences for their capital adequacy ratios because of the replacement of the Greek government bonds that they held in their portfolios, with new ones, whose nominal value was greatly reduced.[7] The situation exacerbated bank credit risk pressure as banks were forced to raise capital at higher cost to offset their investment portfolio losses, commensurate with the rise of sovereign credit risk.[8] Adding to the uncertainty were concerns about the mere size of the program, lack of experience (the first time a major sovereign debt restructuring program being managed away from Washington DC), and complications arising from time delays and amendments to the program.[9] According to Zettelmeyer, Trebesch and Gulati (2013) the

5. Euro Summit Statement of October 26, 2011.

6. The press release of the Hellenic Ministry of Finance on February 24, 2012, specifies, in detail, the terms of the PSI program.

7. There was a significant rise of the sovereign CDS spreads of Greece, as well as those of Ireland, Italy, Portugal and Spain following an announcement at the Euro Summit of 21 July, 2011 that the ECB would not participate in the voluntary PSI program involving an estimated net contribution of EUR 37 billion by banks and insurance companies.

8. An important element in the program was a promise by the Eurogroup to compensate through recapitalizations Greek banks for their PSI losses, thereby avoiding a major banking crisis in Greece which was more than likely to emerge since Greek banks had already suffered losses of about EUR 38 billion or about 170 percent of their total Core Tier I capital in 2011.

9. Cruces and Trebesch (2013) show that achieving a higher degree of debt relief at present can have benefits in the short-run but may also worsen borrowing conditions in the future. More precisely, they find that higher haircuts are associated with (i) higher post-restructuring spreads; and (ii) longer duration of exclusion from capital markets. While this is also evident from the recent experience of Greece culminated in its on and off long

PSI contributed to the avoidance of a financial collapse in Greece and beyond (except for Cypriot banks which were not compensated for restructuring related losses as Greek banks) but at the same time a number of costly policy mistakes were made with respect to the timing, design and execution of the exchange.[10] They contend that the debt restructuring was necessary, albeit not sufficient, to deal with an increasingly dire situation.

As far as the collateral damages caused by the PSI are concerned, the program created a "doom loop between sovereigns and banks with severe adverse effects on banking systems and economies throughout the periphery of the euro area (see Orphanides, 2014). PSI had a major negative impact on Cypriot banks owing to their exposure on Greek debt, triggering a negative feedback loop between banks and their sovereign in light of the sheer size of the Cypriot banking system and faltering public finances.[11] Banking sector difficulties in Cyprus first appeared on October 2011, with Emergency Liquidity Assistance (ELA) borrowing from the Central Bank increasing sharply from EUR 0.1 billion in August to EUR 2.7 billion, while total bank borrowing from the Eurosystem, jumped from EUR 5.8 billion in August to EUR 8.0 billion, an amount close to half the country's GDP (see Hardouvelis, 2016). The two largest Cypriot banking institutions lost almost 4 billion euros from the haircut of Greek Government bonds (see Zenios, 2016). While both banks had major operations in Greece, they did bear the brunt of losses whereas banks in Greece were fully supported through a mechanism of recapitalizations. Under these conditions, an unprecedented for the Eurozone bail-in program was necessary for the recapitalization of the Cypriot banks through losses imposed on uninsured depositors and bank bond holders as the Cypriot government was unable to rescue its banks and prevent a financial crunch.[12]

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exclusions from capital markets, the important question is about the counterfactual, namely the extent and pervasiveness of the problem without restructuring.

10. They estimate that implementing a deep restructuring earlier could have saved at least 10 billion euros in bond amortizations between July 2011 and early 2012.

11. The Cypriot banking system was the largest in the Eurozone expressed as a percentage of the country's GDP, with assets totaling over 8 times GDP (see Zenios, 2013). It was our intension to include Cyprus in the sample; however, CDS data were not available for Cypriot banks.

12. According to Demetriades (2018) "the crisis was triggered by losses from the Greek PSI in late 2011 in the island's two biggest banks. But its roots were in the doubling of the

This study examines the dynamic causal interactions between sovereign and bank CDS spreads during the period of the Eurozone sovereign debt crisis. Specifically, it investigates the lead-lag relationship between sovereign and bank credit risk of 8 Eurozone countries and 21 banking institutions during the period January 2009 to May 2014, paying particular attention to the causal effects of the PSI program. For this reason, the sample period is split around the formal announcement of the program on 26 October 2011. The Chow breakpoint test shows that the date of the PSI announcement is a significant structural break in the data, supporting the choice to divide the sample period based on the event date. Using different econometric techniques, the present study addresses the following questions. Was the PSI program effective in mitigating the nexus between banks and their sovereigns? Were such effects more pronounced in the causal relationship running from Greek sovereign CDS to bank CDS? Which countries were more vulnerable?

A step-by-step procedure is followed to test empirically linear and nonlinear causal relationships between the sovereign and bank CDS series. First, linear causality between sovereign and bank CDS spreads for the periods before and after the PSI program is assessed, utilizing Granger and Hsiao causality tests combined with Impulse Response (IR) and Forecast Error Variance Decomposition (FEVD) analysis. For robustness, a difference-in-difference model is also employed, to study the causal relationships between the sovereign and bank CDS premiums over the full sample period. Second, nonlinear causal effects between the CDS series are assessed in both subperiods, applying the nonlinear dependence BDS[13] test and the non-parametric Diks and Panchenko (2006) (hereafter D&P) causality test. In addition, nonlinear causality tests are performed on VAR- or VECM- filtered residuals, thereby removing systematic linear causality patterns from the data. This enables to check if any observed causality is strictly nonlinear (see

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banking system in the previous six years due to large capital inflows, primarily from Russia and Ukraine." Thus, Cyprus was different insofar the core problem there was massive inflows mainly from Russia with the consequent exposure to Greek sovereign debt to ascertain a return that was high enough to offer Russian depositors an enticing return on their investments. It was a risky gamble that did not pay off. For banks in the core Eurozone countries, the exposure to Greek debt was more a portfolio allocation issue with obvious repercussions but not a gamble. The situation for Greek banks was also different in that they were coerced to buy into Greek debt, whereas this was not the case for Cypriot banks.

13. Brock et al. (1996).

Bekiros and Diks, 2008). GARCH effects are a potential source of nonlinearities between the CDS series, which in turn may affect the robustness of causality tests. Autoregressive conditional heteroskedasticity is filtered out using a bivariate GARCH-BEKK (1,1) model and re-run the non-parametric causality test using standardized residuals. The aim is to capture higher-order causal relationships by using volatility-filtered series, in order to ascertain if nonlinear causal relationships in the data persist after second moment filtering rather than being driven purely by volatility spillover effects.

The tests reveal significant linear and nonlinear dynamic causal relationships between the CDS series. Causal effects are found to be bidirectional in the majority of cases, especially during the first period, and this finding is preserved as we move from linear to nonlinear causality testing. A public-to-private risk transfer, consistent with the aim of PSI, is observed. In particular, it is found that the strength of both linear and nonlinear causal effects between banks and sovereigns appears to ease-off in the period following the implementation of the PSI program. Moreover, it is observed that volatility spillovers underpin the nonlinear Granger causal relationships. However, the interconnectedness between the series persists after first and second moment filtering. This implies that any nonlinear causal linkages between the CDS series are not solely due to volatility effects. It is concluded that the PSI appears to have had some success in containing the nexus between sovereign and bank credit risk during the sovereign crisis.

The paper contributes to the existing literature in two directions: First by applying a more comprehensive econometric approach comprising linear and nonlinear causality tests to analyze the nexus between banks and sovereigns, and second by providing new empirical evidence on the relationship between sovereign and bank credit risk in view of an important policy intervention, the PSI effect. The nonlinear econometric framework extends previous research by capturing the complex interlinkages between the CDS series during a period of highly volatile conditions.

The remainder of the paper is structured as follows. Section II reviews the existing literature on the relationship between sovereign and bank credit risk. Section III describes the data. Section IV presents the methodology and discusses the empirical results. Section V summarizes the main conclusions.

II. Literature review

Since the global financial crisis, much empirical research in cross-country studies has focused on the relationship between sovereign and bank credit risk. The consensus is that this relation has developed beyond a simple local affair into interdependence and contagion between countries and banks.

Contagion is an elusive concept with several definitions on offer in the literature.[14] The World Bank, for example, regards that contagion occurs when transmission of shocks between countries increases in times of crisis, compared to the corresponding transmission in tranquil periods.[15] Constâncio (2012) defines financial contagion as a situation in which instability in a specific market or institution is transmitted to one or several other markets or institutions, with the transmission process causing non-expected, abnormal relationships between markets or intermediaries. Under this situation a crisis reaches systemic dimensions. In the same vein, Forbes and Rigobon (2002) define contagion as an extraordinary increase in cross-market linkages after a shock to one country or a group of countries. In the case where the co-movement remains stable after a shock in relation to a tranquil period then any increase in the correlation between two markets or economies is due to the existence of interdependence. In this case, the transmission mechanism is driven by market fundamentals.

Since we focus solely on a crisis period, it is reasonable to assume that there has been already a structural change in the transmission process.[16] Hence the question is one of degree and scope, viz. whether contagion risk was heightened and widened across countries and banks in the transition from the financial to the sovereign crisis (e.g. as a result of a shift from a bad equilibrium before PSI to another bad equilibrium after PSI). As in Sander and Kleimeier (2003), a narrow definition of contagion is used focusing on changes in the presence and direction of causality during different phases of a crisis, while maintaining the

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14. Dungey et al. (2005) provide a detailed review of different methods used to identify contagion.

15. www.econ.worldbank.org.

16. As evident from the sharp rise of CDS spreads and their volatility in the European periphery which may be difficult to reconcile on the basis of fundamental drivers, recognising that economic conditions (i.e. market fundamentals) in the majority of these countries were only changing gradually (Delatte, Fouquau and Portes 2014).

assumption that multiple equilibria may exist.

Masson (1999) contends that a crisis in one country or market could influence investors' expectations causing contagion effects and spreading the crisis to another country or market due to a shift from a good to a bad equilibrium. These expectations are not driven by changes in macroeconomic fundamentals - as may be the case under a good equilibrium - but emanate from uncertainties about multiple equilibria. Based on this approach, contagion arises when self-fulfilling beliefs about bad equilibria locally are diffused to other countries or markets, with contagion effects expected to be more pronounced in countries or institutions with weaker economic fundamentals. This is arguably the case in Greece where both the sovereign and its financial institutions were in serious trouble because of rapidly worsening economic conditions, whereby a bad situation was getting worse because of loss of confidence and increasing investor risk aversion.

Much literature is devoted in analyzing the feedback relationship between sovereign and bank credit risk. Brunnermeir et al. (2011, 2016) refer to the relationship between sovereign and bank credit risk as "diabolic loop": European banks hold too much of their national debts, which, far from being safe, encourage speculation on the solvency of the banks. Sovereigns, in turn, face a constant risk of having to rescue their banks, which, combined with the uncertainty on what fiscal support they will receive from their European partners, increases the riskiness of their bonds.

During normal times, a strong relationship between bank and sovereign CDS would not be expected, with the causality more likely to run from bank CDS to sovereign CDS rather than the other way around. However, this is likely to change during crises periods, especially with increasing incidence of stress in the banking system coupled with weak fiscal fundamentals. A host of studies provide empirical evidence on the nexus between banks and their sovereigns. Alter and Schüler (2012) analyze CDS spreads of 7 Eurozone countries and their domestic banks during the period from June 2007 to May 2010 using a vector error correction framework. They find that in the period before the bailout of financial institutions, sovereign credit risk is driven mainly by bank credit risk. However, this result is reversed in the period after the bailout of the banking sector.

Acharya, Drechsler and Schnabl (2014) develop a novel theoretical model describing a 'two-way' feedback between financial sector and sovereign credit risks that accounts for both - "an ex post deadweight cost of sovereign default in external markets and an internal cost to the financial sector through bank holdings of government bonds". They verify empirically, using a sample of Eurozone countries during the period 2007 to 2011 that "such a feedback loop is indeed present due to the financial sector's implicit and explicit guarantees and holdings of sovereign bonds". Sovereign CDS spreads rise significantly reflecting a rise in sovereign credit risk, with the worsening of the sovereign's creditworthiness feeding back into a weakened financial sector, confirming the bank-sovereign loop. In a recent study, Yu (2017), using a sample of European countries and banks from 2006 to 2012, finds no significant interaction between sovereign and bank CDS spreads, at the country level, in the period before the financial crisis. However, the dynamic causal linkages become significant after the onset of the subprime crisis, before they recede again until the Greek debt crisis. She concludes that before the bankruptcy of Lehman Brothers, bank CDS spreads were the leading factor influencing sovereign CDS spreads, while during the Eurozone debt crisis sovereign CDS spreads assume this role because bank guarantees and bailout programs weakened fiscal conditions.

Demirguc-Kunt and Huizinga (2013) highlight the reverse credit risk channel from sovereigns to banks using an international sample of banks. They find that bank CDS spreads in fiscally strapped countries rose remarkably during the financial crisis because these countries were deemed fiscally weak to safeguard financial stability. Thus, stressed sovereigns are not able to provide support to the large financial institutions, which have become too big to be saved. Mody and Sandri (2012) analyze the feedback loop between the joint occurrence of public debt accumulation and deterioration of banks' balance sheets. By examining the determinants of weekly changes in the sovereign bond spreads of 10 Eurozone countries over the period January 2006 to May 2011, they find that countries with weaker competitiveness were prone to greater sovereign stress resulting from financial sector weakness. The empirical analyses highlighted two nonlinearities: First, sovereign spreads in countries with a slower growth potential are more adversely affected by financial sector shocks. Second, financial shocks have a larger impact on countries with higher public debt ratios. These results are in accordance with our findings, where causal effects from sovereign to bank CDS are more pronounced after PSI in countries with weaker fiscal fundamentals.

In addition, several studies support the main conclusion of this paper that the strength of the causal linkages between banks and sovereigns has been restricted after the implementation of the PSI program. More specifically, Alter and Beyer (2014) show that during the European sovereign debt crisis, and more generally during periods of distress, the interaction between CDS spreads increases significantly, while policy interventions diminish the spillover effects between sovereigns and banks in the Eurozone. Similarly, Vergote (2016) shows that there are significant feedback causal effects between sovereigns and financial institutions in the Euro area, particularly during the intense phases of the crisis. However, the spillover effects from sovereigns to financial institutions are reduced after policy interventions aimed at confronting the European sovereign crisis. On the other hand, the effects from the financial sector to the sovereigns are not diminished, despite banking sector reform.

Tamakoshi and Hamori (2013) analyze causality between the CDS index of the banking sector of the Eurozone and the sovereign CDS spreads of Greece, for the period of 2008 to 2011. Before the debt crisis, they identify unidirectional transmission of credit risk from bank CDS to the sovereign CDS spreads of Greece. However, during the crisis, the situation is different as there is a significant influence of Greek sovereign CDS spreads on bank CDS. In a similar vein, Bhanot et al. (2014) find that an increase in Greek sovereign yield spreads, during the turbulent debt crisis period, had significant spillover effects on the financial sectors of different Eurozone countries driven in part by ratings downgrades and other negative events about Greece.

Drawing on such an argument can be made in support of PSI, recognizing that well designed and well supported debt restructuring programs may be successful in reducing market uncertainty and hence the nexus between banks and their sovereigns.[17] Admittedly, Greece had reached a point of distress making a default almost unavoidable with the overriding question being one of collateral damage inflicted on private creditors, mainly financial institutions, but also on other sovereigns through contagion. With Italy and Spain dragged into the crisis by

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17. Alexakis et al. (2018) argue that the debt restructuring process (PSI) in Greece did not bring the expected results since it was not combined with the appropriate structural reforms and effective policy measures. They propose a series of remedies - economic growth-linked bonds, fiscal balances over the growth cycle, structural reforms, the use of real option analysis in relevant public policy areas - that could be useful for the restriction of the distress in Greece and the Eurozone as a whole, and the attainment of stability and sustainable growth.

mid-2011, decisive action was imperative to deal with an increasingly dire situation. While not problem free, the PSI program was embedded with sufficient sweeteners to creditors to make best of what was feasible under the circumstances, avoiding the financial collapse of Greece while minimizing risks to other sovereigns (Zettelmeyer, Trebesch and Gulati, 2013).

However, it is not suggested that CDS spreads will be lower in the immediate period following the PSI announcement, irrespective of whether the program is ultimately deemed to be successful or not. We concede that there is high degree of uncertainty surrounding a major debt restructuring initiative, from its announcement to the period immediately after its implementation. With the benefit of hindsight, the program was successful in achieving 96.9 percent participation on the total nominal debt amount, in part as a result of the attractive terms offered.[18,19] Our results verify that the causal effects between the sovereign CDS spreads of Greece and bank CDS of other Eurozone countries have been contained.

Recognizing the nonlinear structure in bank and sovereign CDS spreads, during a turbulent period for Eurozone, where significant structural changes are potential sources of a nonlinear causality pattern between them, an alternative methodological approach is applied to test (1) whether the nonlinear causal interlinkages between sovereign and bank CDS are amplified after PSI; and (2) if these effects are driven by volatility spillover effects. To our knowledge, this is the first study in the relevant literature aiming to capture nonlinearities in the transmission mechanism across countries and banks.

The majority of studies in the empirical literature use parametric linear Granger causality tests based on VAR models to examine the causal linkages between sovereign and bank credit risk. However,

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18. The main terms were a near cash offer of EUR 15 billion in short-term EFSF securities, an upgrade of governing law with new bonds of varied maturities issued under English rather than Greek law, and more importantly a co-financing agreement with EFSF which in essence meant that it would not be possible for Greece to default on the new bonds without at the same time defaulting on the EFSF loan. An added feature to the program, and one that would enhance greater creditor participation was a clause ascertaining that no CDS would be triggered before the bond exchange was initiated.

19. According to Coudert and Gex (2013), the main reasons for this “bloodless” settlement were the following: the arrangement concerned only the net positions of the investors, protection sellers did not have extra demands as guarantees for this settlement due to regular margin calls, bond-holders were compensated for their shortfalls by protection sellers to the face value of their bonds.

nonlinear feedback relationships are likely to be more pronounced during financial crises.[20] Nonlinear causality tests have been developed by Baek and Brock (1992) and modified by Hiemstra and Jones (1994) (hereafter H&J) to allow each series to exhibit weak temporal dependence. D&P (2005) show that the H&J test tends to over-reject the non-causality null hypothesis, since it does not take into account the possible variation in conditional distributions under the null, especially when the size of the sample increases and bandwidth values are low. In a follow up paper, D&P (2006) propose a non-parametric causality test as a modified version of the Baek and Brock (1992) and H&J tests.

Dajcman (2015) investigates nonlinear interdependence between sovereign bond markets in the Eurozone during the European sovereign debt crisis using the D&P nonlinear Granger causality test. The results show that there are significant nonlinear causal effects between the time series for the period before the crisis, while spillover effects decline in the period after the onset of the sovereign debt crisis.

Caporin et al. (2018) use sovereign CDS spreads to study nonlinearities in the transmission of sovereign credit shocks in the Eurozone. Applying nonlinear, quantile and Bayesian quantile regressions that allow for heteroskedasticity, they find no evidence of change in the intensity of the transmission of shocks since the onset of GFC. They interpret this finding as absence of sovereign risk contagion among Eurozone countries recognizing their sample period ending just before the PSI (September 2011) announcement may not be long enough to identify significant changes in the propagation mechanism. Amisano and Tristani (2011) study nonlinearities in the transmission of sovereign credit risk in the Eurozone using a regime-switching model over the period from January 1999 to December 2010. The model captures abnormal variations of sovereign yield spreads after a shift from a 'normal' to a 'crisis' regime. They find that the probability of entering the crisis regime increases when a country's fiscal position worsens, and this increase is amplified by contagion mainly driven by an increase in market risk aversion.

Billio et al. (2012) apply bivariate linear and nonlinear Granger

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20. Brock, Hsieh and LeBaron (1991) contend that nonlinear causality tests are able to detect the existence of higher-order causal relationships between the series, in contrast to those solely focusing on the conditional mean, such as the linear Granger causality test. This is important since linear causality tests may incorrectly identify a unidirectional relationship between two series when in fact the relationship may be nonlinear and bidirectional (see H&J, 1994).

causality tests and principal component analysis using monthly stock returns of hedge funds, brokers/dealers, insurance companies and banks, to model the diffusion of the systemic risk during the financial crisis. They find significant causal linkages among the different financial sectors. Furthermore, Billio et al. (2014) model the interconnectedness among countries, banks and insurance institutions in a multi-country framework, by using credit spreads. Based on contingent claim analysis and network measures, they show that there are significant dynamic interactions among sovereigns, banks and insurance companies during the GFC and the European sovereign crisis. However, the effects arising from sovereigns to banks and insurers are more significant during the European sovereign debt crisis.

III. Data description

Daily prices of senior unsecured sovereign CDS spreads on 5-year government bonds are used, considered as those with higher liquidity,[21] and the respective senior unsecured bank CDS spreads. The sample period ranges from 1 January 2009 to 30 May 2014. The higher the value of CDS spreads, the less likely a country or a banking institution will be able to meet its debt obligations. In the empirical literature, it is observed that CDS premiums have established as the main proxy for credit risk, since the inception of the global financial crisis.[22]

Daily data on CDS spreads are extracted from Thomson Reuters Datastream and Bloomberg. In the analysis, we consider those countries of the Eurozone that experienced major debt problems during the recent financial turmoil, viz. Greece (GR), Italy (IT), Ireland (IR), Portugal (PT), and Spain (SP) known by the acronym GIIPS. Moreover, the Netherlands (NL), France (FR) and Germany (DE) are included. These countries possessed in their portfolios major shares of GIIPS debt. The selection of the sample of banking institutions in each country is based on their total assets and on the availability of the data for the period under review.

The CDS spreads are expressed in basis points (bps) and transformed into natural logarithmic values recognizing the wide

21. Hull, Nelken and White (2004).

22. Fontana and Scheicher (2010).

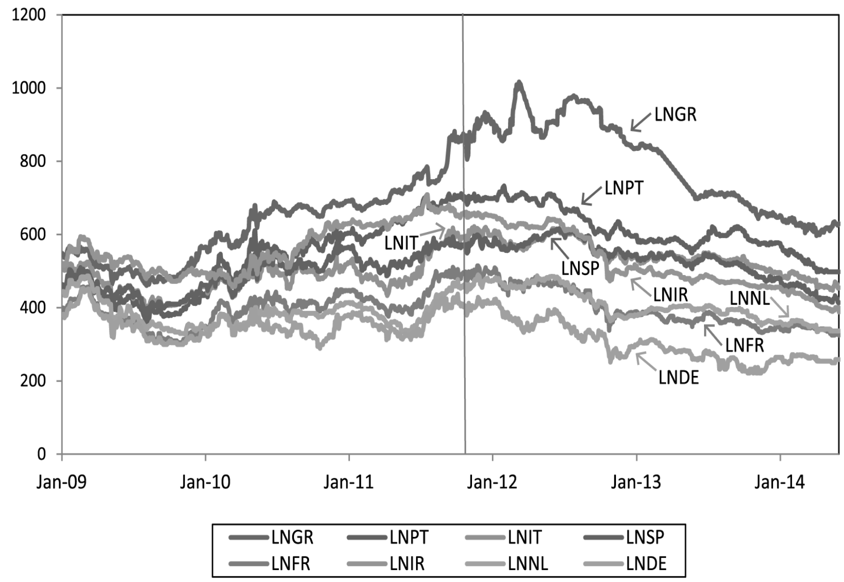

FIGURE 1.— Daily Sovereign log CDS series multiplied by 100 - 01/01/2009 - 30/05/2014

variations in spreads for some countries and banks during the period of analysis.[23] The bank CDS spreads in the sample are weighted by using their total liabilities in each year to calculate the index of bank CDS spreads for each country. Furthermore, in order to study the nexus between the CDS series at the aggregate level, new CDS series are calculated by weighting the sovereign CDS spreads for the eight eurozone countries based on their gross domestic product each year, and the corresponding banking sector CDS spreads according to the annual liabilities of each banking institution. For robustness, the unweighted sovereign and bank aggregate CDS series are also employed.

To analyze changes in the lead-lag interaction between sovereign and bank credit risk as a result of the PSI program the reporting period is divided into two subperiods. The break point is determined exogenously to be 26 October 2011, the date of the announcement of the decision of the European Summit for the implementation of the 'voluntary' exchange program of Greek bonds with the participation of

23. Forte and Pena (2009).

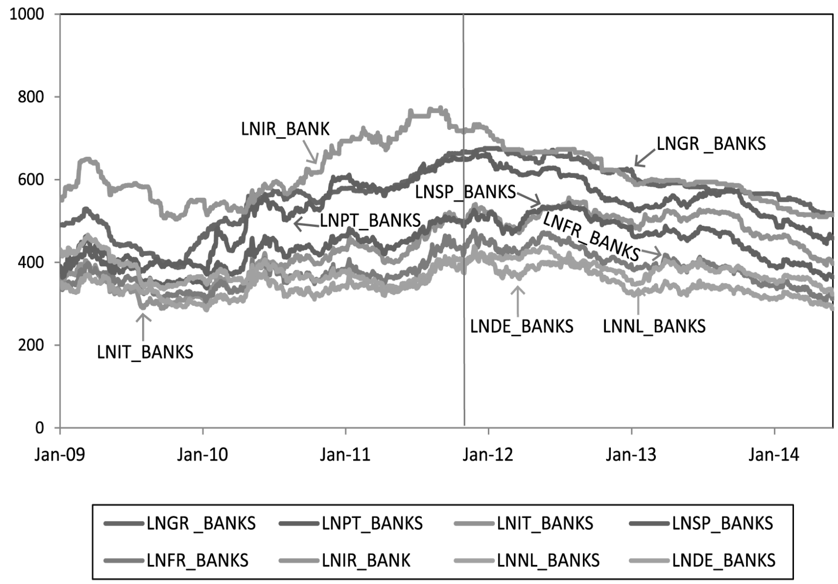

FIGURE 2.— Daily Bank log CDS series multipiled by 100 - 01/01/2009 - 30/05/2014

the private sector. Chow breakpoint test results verify that this date is a significant structural break in the relationship between all pairs of CDS series.

Figures 1 and 2 illustrate the evolution of the log CDS series (multiplied by 100) during the sample period. The vertical line indicates the PSI announcement date that separates the sample. It is evident that the CDS series of most countries and banks are close to their maximum levels around the PSI period; however, they start to decline soon after. Greek sovereign CDS spreads continue to rise to exceptional levels during the period of the PSI program although they too decline eventually. The steep rise of Greek sovereign CDS spreads in March of 2010 is indicative of heightened concerns about a Greek sovereign default, with the country losing access to the bond markets in April 2010. The effects are spreading to other Eurozone countries, especially those with weak fiscal fundamentals, triggering large increases in Italian, Irish, Portuguese and Spanish sovereign CDS premia. Although, France, Germany and the Netherlands have stronger fundamentals, a similar upward trend in their CDS spreads during the period leading the

TABLE 1. Descriptive Statistics

Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
A. Descriptive statistics of sovereign CDS spreads - Period 1 (1 Jan 2009 - 26 Oct 2011)							
GR	735	900.47	1168.94	100.27	6751.79	2.99	12.40
PT	735	320.48	304.39	37.00	1227.89	1.36	3.98
IT	735	141.66	79.05	48.00	482.04	1.90	6.73
SP	735	158.26	76.90	47.00	378.81	0.60	2.53
IR	735	356.87	237.85	96.92	1191.15	0.88	2.81
FR	735	60.53	29.28	21.00	164.93	1.19	4.48
NL	735	51.93	23.63	26.49	130.00	1.49	4.55
DE	735	36.74	14.86	17.96	92.50	1.41	4.95
AllCountries (Weighted)	735	112.51	68.50	36.09	387.09	1.88	6.95
AllCountries (Unweighted)	735	253.37	226.03	54.03	1225.02	2.16	7.96
B. Descriptive statistics of bank CDS spreads - Period 1 (1 Jan 2009 - 26 Oct 2011)							
GR_Banks	735	250.20	173.34	48.11	797.88	1.23	4.35
PT_Banks	735	218.02	178.76	37.44	690.08	0.92	2.87
IT_Banks	735	56.25	35.25	17.94	183.64	1.49	5.08
SP_Banks	735	72.69	33.52	29.28	165.42	0.84	3.11
IR_Banks	735	677.74	567.48	155.00	2298.98	1.23	3.39
FR_Banks	735	40.56	14.58	21.06	103.98	1.72	6.47
NL_Banks	735	45.38	15.75	25.65	106.03	1.60	5.18
DE_Banks	735	30.07	8.16	17.30	63.03	1.32	5.04

(*Continued*)

TABLE 1. (Continued)

Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
B. Descriptive statistics of bank CDS spreads - Period 1 (1 Jan 2009 - 26 Oct 2011)							
AllBanks (Weighted)	735	58.56	25.69	26.20	144.61	1.22	4.20
AllBanks (Unweighted)	735	173.86	121.18	47.88	507.27	1.11	3.17
C. Descriptive statistics of sovereign CDS spreads - Period 2 (27 Oct 2011 - 30 May 2014)							
GR	677	5399.97	5432.59	391.63	25960.76	1.22	3.99
PT	677	557.90	348.21	143.95	1521.45	0.81	2.21
IT	677	249.67	106.21	87.73	498.66	0.59	2.32
SP	677	233.47	106.31	62.83	492.07	0.33	2.30
IR	677	261.51	212.75	48.65	729.19	0.84	2.08
FR	677	62.66	36.96	25.79	171.56	1.01	2.76
NL	677	65.11	30.51	28.46	133.84	0.74	2.10
DE	677	24.63	15.48	9.16	72.35	1.26	3.52
AllCountries (Weighted)	677	239.69	168.75	50.84	744.72	0.73	2.41
AllCountries (Unweighted)	677	82.30	31.27	31.40	158.34	0.29	1.99

(*Continued*)

TABLE 1. (Continued)

Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
D. Descriptive statistics of bank CDS spreads - Period 2 (27 Oct 2011 - 30 May 2014)							
GR_Banks	677	476.85	214.78	177.04	859.49	0.41	1.70
PT_Banks	677	322.84	172.93	85.83	799.67	0.78	2.65
IT_Banks	677	152.05	45.78	51.00	259.74	-0.35	2.52
SP_Banks	677	121.02	50.46	36.17	230.19	0.11	2.09
IR_Banks	677	551.54	340.55	163.99	1530.14	1.03	3.36
FR_Banks	677	58.61	23.50	21.57	118.19	0.44	2.29
NL_Banks	677	49.49	12.44	25.27	79.46	0.32	2.33
DE_Banks	677	35.78	12.44	17.82	80.19	0.75	2.61
AllBanks (Weighted)	677	768.29	725.02	100.52	3560.48	1.11	3.59
AllBanks (Unweighted)	677	221.02	103.64	72.80	471.13	0.55	2.24

Note: GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

PSI program is observed, recognizing riskiness is pervasive in the derivatives market. CDS premia reached very high levels during the third quarter of 2011, indicative of the market's perception of disorderly restructuring spilling into other credit markets.

A high degree of co-movement between Greek sovereign and bank CDS series for the whole sample period is observed, albeit banking sector CDS spreads do not rise as high as sovereign CDS. Irish banks exhibit the highest CDS premia. In fact, they are higher than Irish sovereign CDSs throughout the entire period. German and Dutch banks exhibit the lowest CDS premia. The concurrent variation of the sovereign and bank CDS spreads are indicative of the strong interlinkages between government and bank credit risk. Most of CDS series decrease during the second quarter of 2012 after the implementation of PSI (completed on 25 April 2012).

Table 1 reports the descriptive statistics of the sovereign and bank CDS spreads in the sample. The spreads increase significantly during the second subperiod, except for the sovereign spreads of Ireland, Germany and Irish banks. The average sovereign CDS spread in the first subperiod is 253bps, while in the second subperiod is 857bps, which is mainly due to the surge of the Greek risk premium. The corresponding averages, excluding Greece, are 161bps and 208bps. Aside from Greece, sovereign CDS of Italy, Portugal and Spain are much higher in the second period. The bank CDS spreads averages are 174bps and 221bps, for the first and the second subperiod, respectively. Standard deviations also increase in the second subperiod indicative of intensified volatility, uncertainty and risk. In contrast, the standard deviations are lower for Irish, Portuguese and Dutch banks during the second subperiod.

Pairwise correlations of sovereign and bank CDS spreads in logarithmic first-differences show significant correlations, greater than 0.3 with the exception of Greece and Ireland during the second subperiod.[24] However, there is considerable reduction in the correlations between CDS spreads during the second subperiod.

IV. Methodology and empirical results

A. Stationarity and cointegration

The stationarity properties of the (log) level CDS series are examined

24. Correlation results are available from the authors upon request.

applying the Phillips-Perron, Augmented Dickey-Fuller tests (under the unit root null) and for robustness, the Kwiatkowski-Phillips-Schmidt-Shin test (under the stationarity null). All the series are found to be non-stationary unit root processes. This is confirmed by testing the first-differences of the log CDS series.

We test for cointegration between the non-stationary CDS series applying the Johansen (1995) test for each subperiod.[25] We recognize that using a cointegration approach over a relatively short period may entail some problems. Nevertheless, we believe it is justified given the high-frequency data that are employed, in particular since the resulting cointegrating relationships could be interpreted as reflecting systematic temporary patterns.[26] The number of lags in the VAR for the cointegration test is selected using the Akaike Information Criterion (AIC). In the first subperiod, a significant cointegrating relationship is observed between the sovereign and banking sector CDS of Greece, Portugal, Spain and Ireland. There is also evidence of cointegration between Greek sovereign and Portuguese bank CDS, and between the weighted aggregate sovereign and bank CDS. In the second subperiod, we find cointegrating relationships between Greek, Spanish, Irish sovereign and bank CDS spreads, and between Greek sovereign and Irish bank CDS series. Moreover, the sovereign CDS spreads of Greece and the unweighted bank CDS are cointegrated in both subperiods.[27] It is observed that for the majority of CDS pairs there is no evidence of a cointegrating relationship between them, in both subperiods. While this implies absence of a common trend or risk factor driving the series, there is still the possibility of temporal causal effects driven by nonlinear dynamics.

B. Linear causality

Observed correlation between two CDS series under consideration does not imply the existence of a causal relationship between them. As per standard practice, we first study the causal relationship between CDS series using the notion of Granger causality (1969) based on a time lag

25. Chen and Lin (2004) draw attention to the possibility that misleading conclusions about causal relationships may be drawn if the cointegration relationships between the CDS series are not accounted for in the causality test.

26. See Sander and Kleimeier (2003) who justify their approach on similar grounds.

27. The results are available from the authors upon request.

TABLE 2. Linear Granger Causality Results

Dependent Variable	Independent Variable	Raw Data (p-value) Period 1	Raw Data (p-value) Period 2
A.			
GR	GR_Banks	**0.0635***	**0.1957**
PT	PT_Banks	**0.1350**	0.1466
IT	IT_Banks	0.0243**	0.4990
SP	SP_Banks	**0.0005*****	**0.0893***
IR	IR_Banks	**0.2925**	**0.0000*****
FR	FR_Banks	0.0005***	0.0000***
NL	NL_Banks	0.0064***	0.2599
DE	DE_Banks	0.0187**	0.3223
GR_Banks	GR	**0.0000*****	**0.9638**
PT_Banks	PT	**0.0000*****	0.0000***
IT_Banks	IT	0.0001***	0.0016***
SP_Banks	SP	**0.0000*****	**0.0087*****
IR_Banks	IR	**0.0869***	**0.0512***
FR_Banks	FR	0.0051***	0.0001***
NL_Banks	NL	0.0000***	0.0030***
DE_Banks	DE	0.0001***	0.5322
B.			
GR	PT_Banks	**0.0012*****	0.9843
GR	IT_Banks	0.0165**	0.1272
GR	SP_Banks	0.0006***	0.0093***
GR	IR_Banks	0.0246**	**0.8240**
GR	FR_Banks	0.0609*	0.0058***
GR	NL_Banks	0.0072***	0.3585
GR	DE_Banks	0.0004***	0.3511
PT_Banks	GR	**0.0000*****	0.0115**
IT_Banks	GR	0.0000***	0.0344**
SP_Banks	GR	0.0002***	0.0841*
IR_Banks	GR	0.0054***	**0.0028*****
FR_Banks	GR	0.0000***	0.0235**
NL_Banks	GR	0.0000***	0.0287**
DE_Banks	GR	0.0150**	0.0131**

(*Continued*)

TABLE 2. (Continued)

Dependent Variable	Independent Variable	Raw Data (p-value) Period 1	Raw Data (p-value) Period 2
C.			
AllCountries (Weighted)	AllBanks (Weighted)	**0.0312****	0.2185
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0724*	0.1259
GR	AllBanks (Weighted)	0.0029***	0.0374**
GR	AllBanks (Unweighted)	0.0060***	**0.3603**
AllBanks (Weighted)	AllCountries (Weighted)	**0.0001*****	0.2800
AllBanks (Unweighted)	AllCountries (Unweighted)	0.0000***	0.1451
AllBanks (Weighted)	GR	0.0208**	0.0230**
AllBanks (Unweighted)	GR	0.0016***	**0.3167**

Note: The table reports the p-values of the Granger causality test, using a VAR or VEC model with raw data in Periods 1 and 2. The lag length of the models was determined by AIC. The null hypothesis is that there is no Granger causality between the sovereign and bank CDS spreads. Bold values indicate the pairs of sovereign and bank CDS series in which a long-term relation is observed in each subperiod. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively. GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

between cause and effect. The linear Granger causality tests are performed within a VAR or VEC framework depending on the stationarity properties of the underlying series and linear combination thereof. If the series are non-stationary unit root processes and cointegrated a Vector Error Correction (VEC) model is used to test for causality, otherwise a VAR model in first-differences.[28] The models are estimated in each subperiod using the Johansen (1995) maximum likelihood procedure, and are tested for autocorrelation. If there is

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28. We check the residuals of the VAR or VEC model, and if there are outliers greater than 3 standard deviations, then a series of point dummy variables to capture specific abnormal events during the period under study is included. The results are robust to a range of threshold values between 2.5 and 3.5 standard deviations.

autocorrelation, we increase the lag length of the VAR or VEC model.[29]

Table 2 summarizes the results of the linear Granger causality test between banks and their sovereigns (Panel A), Greek sovereign CDS and bank CDS (Panel B), and aggregate CDS series (Panel C). In the first subperiod, before the PSI announcement, there is evidence of strong bidirectional causal relationships for the majority of the CDS pairs. Evidence of causality is weaker during the second subperiod, especially causality running from banks to their sovereigns (see Panel A) and from European banks to the Greek sovereign (see Panel B). However, there is no evidence of weaker causality running from Greek sovereign CDS to bank CDS in the post PSI period aside from some differences in the degree of statistical significance (see Panel B). In the majority of cases, causality is unidirectional in the second period. A rather surprising result in this period is the absence of causality between Greek sovereign and bank CDS. Causality is also weaker between the aggregate CDS series in the second subperiod (see Panel C). Another interesting result is that linear causality vanishes in most cases after VAR/VEC filtering in both periods. We surmise nonlinear causality effects may be present albeit not captured by linear causality tests.

We provide for robustness purposes a further test of causal changes between the two periods using the Hsiao (1981) causality test, a modified version of the Granger test, allowing more flexibility in the choice of the dynamic lag structure. Based on the difference of FPEs between the two periods, we infer a reduction in the magnitude of the dynamic interlinkages between sovereign and bank default risk for most CDS pairs.[30]

Impulse response and variance decomposition analysis are carried out in cases, in which a causal relationship between the CDS series is identified. Impulse response plots depict the responses of sovereign CDS spreads, after a one standard deviation shock to the bank CDS spreads, and vice versa, over a 10-day horizon.[31] The overall results are generally in agreement with the findings from the Granger causality tests. Strong effects from sovereign CDS spreads to the corresponding bank CDS spreads are found, both in the period before and after the PSI

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29. If the VAR model is of p-order, the VECM should be of (p-1)-order.

30. The results of changes of causality based on Hsiao (1981) causality test are given in table A1. The full set of results of the Hsiao causality test are available upon request. Gomez-Puig and Sosvilla-Rivero (2013) use a similar approach to test for Granger-causal relationships among 10-year government bonds in 5 Eurozone countries.

31. The impulse response and variance decomposition results are available from the authors upon request.

program. In particular, we find stronger response of Greek, Irish, Portuguese and Spanish bank CDS to their sovereign CDS in the first subperiod, and Spanish bank CDS to sovereign CDS in the second subperiod. These findings indicate that the linkages are stronger in countries with weaker fiscal fundamentals. Conversely, the impact of bank CDS on sovereign CDS is low, in most cases, especially in the second subperiod. The impact on bank CDS after a shock to the sovereign credit spreads of Greece is weaker during the second subperiod. Lower persistence and magnitude in the effects of CDS shocks are also found in the same subperiod.

Forecast error variance decomposition analysis shows that in the first subperiod, the largest fraction of variability in all sovereign CDS spreads is explained by their own shocks and only a small proportion by bank CDS spreads. On the contrary, sovereign CDS spreads account for a significant proportion of the variation in bank CDS. The results in the second subperiod are similar albeit not as strong. There is no evidence of strong influence from the sovereign CDS spreads of Greece to the bank CDS spreads of the other countries, with the French bank CDS spreads being the only exception.

C. Difference-in-Difference model

A difference-in-difference model is used to assess the robustness of the empirical findings. For this purpose, a dummy variable, PSI, is defined, which takes the value of zero for the period before the PSI announcement and is equal to one otherwise. Specifically, the following equation is estimated:

$$\Delta Y_{it} = d_0 + d_1 PSI + d_2 INT + d_3 \Delta X_{it} + d_4 PSI\ Z_{t-1} + u_{it} \qquad (1)$$

where X and Y denote pairs of bank and sovereign CDS series, $INT = PSI * \Delta X_{it}$ and Z_t is the residual of the long-run equation, assuming that the two series cointegrate, otherwise the error correction term is omitted. The coefficient of the interaction variable (*INT*) is the main parameter of interest since it reflects the change in the degree of interaction between the two CDS series.

Consistent with the analysis thus far, the estimation results show that in the majority of cases *PSI* has the effect of weakening the nexus between the CDS series.[32]

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32. The results are reported in table A2 in the appendix A.

D. Nonlinear causality

The relationship between sovereign and bank CDS series varies during crises periods, propagated by changes in the nexus between sovereigns and banks. This implies that nonlinear interlinkages may arise between sovereign and bank CDS, whereby the same change in fundamentals can have a much larger impact on spreads than was the case previously (see Delatte, Fouquau and Portes 2014). Heterogeneous market assessments for a possible default may also induce nonlinearities in the causal relationships between sovereign and bank CDS series by amplifying sovereign risk. A linear model may fail to adequately capture a nonlinear structure in the relationship among different variables, which may lead to erroneous conclusions regarding spillover causal effects among them (see Billio et al., 2012). For this reason, we turn next to study nonlinear dynamics in the relationship between the CDS series.[33]

Diks and Panchenko non-parametric Granger causality test

The D&P (2006) test is a non-parametric nonlinear causality test. Under the null hypothesis there is no causality from X_t to Y_t for two strictly stationary time series (X_t, Y_t, $t \geq 1$), with finite lags l_X and l_Y, (l_X, l_Y, ≥ 1), formally stated as:

$$H_0 : Y_{t+1} \left| \left(X_t^{l_X}, Y_t^{l_Y} \right) \sim Y_{t+1} \right| Y_t^{l_Y} \tag{2}$$

where $X_t^{l_X} = \left(X_{t-l_X+1}, \ldots, X_t \right)$ and $Y_t^{l_Y} = \left(Y_{t-l_Y+1}, \ldots, Y_t \right)$ are lagged vectors. The null hypothesis is rejected, when current and past information of $X_t^{l_X}$ contributes to better prediction of Y_{t+1}.

D&P test nonlinear causal spillover effects by considering the joint and marginal distributions of the ($l_X + l_Y + 1$) dimensional stationary vector $W_t = \left(X_t^{l_X}, Y_t^{l_Y}, Z_t \right)$ where $Z_t = Y_{t+1}$, which under the null yield the following statistic:

$$q \equiv E\left[f_{(X,Y,Z)}(X,Y,Z) f_Y(Y) - f_{X,Y}(X,Y) f_{Y,Z}(Y,Z) \right] = 0 \tag{3}$$

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33. Preliminary analysis confirms possible nonlinear dependence in the data. The BDS test rejects the null of linear dependence in the raw as well as VAR or VEC- filtered series. However, for GARCH-BEKK (1,1) filtered series, in the majority of cases the BDS statistic is not statistically significant. Results are available upon request.

where $f_{(.)}$ denote the associated joint and marginal densities. Defining a local square kernel density estimator $\hat{f}_w(W_i)$ of a d_W-variate random vector W at W_i such that: $\hat{f}_w(W_i) = \frac{(2e_n)^{-d_W}}{n-1}\sum_{j,j\neq i} I_{ij}^W$, where $I_{ij}^W = I\left(\left\|W_i - W_j\right\| < \varepsilon_n\right)$, $I_{(.)}$: is the indicator function, $\|.\|$ is the maximum norm and ε_n is the bandwidth, D&P show that the test statistic reduces to:

$$T_n(\varepsilon) = \frac{(n-1)}{n(n-2)}\sum_i \left(\hat{f}_{X,Y,Z}(X_i,Y_i,Z_i)\hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i,Y_i)\hat{f}_{Y,Z}(Y_i,Z_i)\right) \quad (4)$$

For $l_X = l_Y = 1$, and, if the bandwidth is calculated as $\varepsilon n = Cn^{-\beta}$ (where n is the sample size, C>0, and $\beta \in \left(\frac{1}{4},\frac{1}{3}\right)$), D&P (2006) show that the distribution of the test statistic given by (4) converges to the standard normal distribution under the null given by:[34]

$$\sqrt{n}\frac{(T_n(\varepsilon_n) - q)}{S_n} \xrightarrow{d} N(0,1) \quad (5)$$

where $\xrightarrow{d}$ denotes convergence in distribution and $S_n(.)$ is an estimator of the asymptotic variance of $T_n(.)$ (D&P, 2006, Bekiros and Diks, 2008).

Table 3 presents the results of the D&P nonlinear causality test for the CDS series with the number of lags set at l_x=l_y=1,2,3,4,5,6.[35,36] In the first subperiod, there is strong evidence of bidirectional nonlinear causal

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34. According to D&P (2006), when the local bias tends to zero at a rate of ε^2, then the optimal bandwidth that gives the T_n estimator with the smallest mean-squared-error is calculated based on $\varepsilon_n = Cn^{-2/7}$, where $\beta = 2/7$ is the optimal rate. Since unrealistically large values of the bandwidth may arise in small samples, based on the optimal value of C, D&P suggest the choice of bandwidth should be truncated by ε_n = max ($Cn^{-2/7}$, 1.5).

35. Following Bekiros and Diks (2008), we set the constant term C^* equal to 7.5 and the optimal bandwidths at 1.14 for the first period and 1.17 for the second period. For robustness, the D&P test is performed for different bandwidths with no noticeable effects on the results.

36. The causal relations are significant at lower lags l_x= l_y, in the range of 1 to 6. For larger lag lengths, the causal effects between the series vanish.

TABLE 3. Nonlinear D&P Granger Causality Results in Raw Return Data

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
A.							
GR	GR_Banks	0.0000***	0.0022***	0.0099***	0.0083***	0.0116**	0.0389**
PT	PT_Banks	0.0000***	0.0004***	0.0094***	0.0382**	0.0376**	0.1044
IT	IT_Banks	0.0051***	0.0344**	0.0106**	0.0273**	0.0609*	0.1542
SP	SP_Banks	0.0138**	0.0101**	0.0061***	0.0354**	0.2992	0.3978
IR	IR_Banks	0.4631	0.1746	0.7089	0.8666	0.7220	0.8404
FR	FR_Banks	0.0280**	0.0101**	0.0213**	0.0236**	0.0227**	0.0437**
NL	NL_Banks	0.0102**	0.0217**	0.0537*	0.0777*	0.1213	0.0815*
DE	DE_Banks	0.0104**	0.0002***	0.0057***	0.0346**	0.0507*	0.0455**
GR_Banks	GR	0.0069***	0.1130	0.5237	0.5707	0.9485	0.9720
PT_Banks	PT	0.0021***	0.0002***	0.0012***	0.0048***	0.0233**	0.0493**
IT_Banks	IT	0.0554*	0.0734*	0.0252**	0.0852*	0.1582	0.3811
SP_Banks	SP	0.0050***	0.0003***	0.0012***	0.0094***	0.0288**	0.0598*
IR_Banks	IR	0.6199	0.4956	0.4761	0.5245	0.7991	0.7916
FR_Banks	FR	0.0016***	0.0019***	0.0358**	0.0752*	0.2094	0.1821
NL_Banks	NL	0.0556*	0.0524**	0.2923	0.4755	0.5250	0.7409
DE_Banks	DE	0.0034***	0.0037***	0.0019***	0.0051***	0.0106**	0.1507

(Continued)

TABLE 3. (Continued)

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
B.							
GR	PT_Banks	0.0002***	0.0017***	0.0093***	0.0300**	0.0396**	0.0740*
GR	IT_Banks	0.0014***	0.0011***	0.0065***	0.0176**	0.0436**	0.0965*
GR	SP_Banks	0.0197**	0.0400**	0.1966	0.3159	0.3451	0.2465
GR	IR_Banks	0.3446	0.1915	0.6836	0.5715	0.5009	0.5274
GR	FR_Banks	0.0130**	0.0187**	0.0603*	0.0699*	0.0516*	0.1808
GR	NL_Banks	0.0008***	0.0010***	0.0056***	0.0052***	0.0175**	0.0220**
GR	DE_Banks	0.0301**	0.0060***	0.0454**	0.2464	0.2578	0.3843
PT_Banks	GR	0.0480**	0.0410**	0.0899*	0.0734*	0.4331	0.7544
IT_Banks	GR	0.0213**	0.0111**	0.0108**	0.0378**	0.2839	0.4187
SP_Banks	GR	0.0762*	0.0479***	0.0184**	0.0239**	0.1021	0.2361
IR_Banks	GR	0.9217	0.4991	0.5702	0.7167	0.7947	0.8395
FR_Banks	GR	0.0869*	0.0719*	0.2304	0.2495	0.4196	0.2716
NL_Banks	GR	0.1109	0.1540	0.1156	0.0683*	0.1471	0.2816
DE_Banks	GR	0.1062	0.0640*	0.2240	0.1504	0.3952	0.3681

(*Continued*)

TABLE 3. (Continued)

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
C.							
AllCountries (Weighted)	AllBanks (Weighted)	0.0009***	0.0036***	0.0069***	0.0260**	0.0981*	0.1906
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0314**	0.0517*	0.1577	0.2405	0.2435	0.3668
GR	AllBanks (Weighted)	0.0066***	0.0092***	0.0441**	0.0857*	0.1128	0.2975
GR	AllBanks (Unweighted)	0.0185**	0.0206**	0.1069	0.0917	0.2336	0.4103
AllBanks (Weighted)	AllCountries (Weighted)	0.0675*	0.0140**	0.0347**	0.0454	0.2617	0.2347
AllBanks (Unweighted)	AllCountries (Unweighted)	0.7927	0.5979	0.4016	0.3731	0.7286	0.7742
AllBanks (Weighted)	GR	0.1794	0.0612*	0.1945	0.2878	0.5204	0.5975
AllBanks (Unweighted)	GR	0.4885	0.2319	0.3671	0.5378	0.7874	0.8874

(*Continued*)

TABLE 3. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
A.							
GR	GR_Banks	0.2383	0.2798	0.1905	0.1391	0.1401	0.1543
PT	PT_Banks	0.5467	0.8285	0.9686	0.7497	0.6264	0.5632
IT	IT_Banks	0.47068	0.0309**	0.0170**	0.0464**	0.1093	0.1730
SP	SP_Banks	0.0127**	0.0537*	0.1411	0.2737	0.5438	0.6041
IR	IR_Banks	0.5793	0.1843	0.3133	0.2333	0.1826	0.2020
FR	FR_Banks	0.0027***	0.0025***	0.0148**	0.0783*	0.0877*	0.2091
NL	NL_Banks	0.0215**	0.0820*	0.0994*	0.2425	0.4568	0.3191
DE	DE_Banks	0.1310	0.1161	0.3063	0.4271	0.3197	0.4601
GR_Banks	GR	0.3448	0.1078	0.3326	0.1091	0.0531*	0.0665*
PT_Banks	PT	0.0216**	0.2118	0.3685	0.6087	0.4171	0.4455
IT_Banks	IT	0.0154**	0.1361	0.1794	0.4643	0.1696	0.2199
SP_Banks	SP	0.0404**	0.1295	0.2464	0.2973	0.2031	0.2841
IR_Banks	IR	0.9561	0.9294	0.9644	0.2573	0.3309	0.4757
FR_Banks	FR	0.0005***	0.0101**	0.0982*	0.0457**	0.1061	0.6556
NL_Banks	NL	0.9357	0.5441	0.3034	0.8148	0.8073	0.8310
DE_Banks	DE	0.0366**	0.3273	0.6935	0.1706	0.0885*	0.0340**

(*Continued*)

TABLE 3. (Continued)

		Period 2					
Dependent Variable	Independent Variable	*l* = 1	*l* = 2	*l* = 3	*l* = 4	*l* = 5	*l* = 6
B.							
GR	PT_Banks	0.0668*	0.1942	0.4256	0.6378	0.3809	0.3515
GR	IT_Banks	0.0845*	0.1311	0.1481	0.0817*	0.1358	0.1941
GR	SP_Banks	0.0887*	0.1679	0.0493**	0.1016	0.1648	0.1463
GR	IR_Banks	0.1469	0.6871	0.9849	0.9538	0.5464	0.5288
GR	FR_Banks	0.0330**	0.0051***	0.0170**	0.0187**	0.0136**	0.0747*
GR	NL_Banks	0.4208	0.6325	0.4486	0.4403	0.4578	0.5796
GR	DE_Banks	0.3041	0.2323	0.5456	0.5183	0.7978	0.8797
PT_Banks	GR	0.0708*	0.1670	0.6344	0.8280	0.8556	0.8295
IT_Banks	GR	0.1981	0.3395	0.2261	0.4571	0.5312	0.7230
SP_Banks	GR	0.0257**	0.1531	0.0656*	0.1545	0.1450	0.4425
IR_Banks	GR	0.7980	0.3800	0.2301	0.0949*	0.1227	0.1826
FR_Banks	GR	0.001***	0.0008***	0.0012***	0.0162**	0.0103**	0.0220**
NL_Banks	GR	0.6542	0.9192	0.8781	0.8957	0.5453	0.7305
DE_Banks	GR	0.0112**	0.0883*	0.2000	0.3080	0.2273	0.4764

(*Continued*)

TABLE 3. (Continued)

Dependent Variable	Independent Variable	Period 2					
		$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
C.							
AllCountries (Weighted)	AllBanks (Weighted)	0.0427**	0.0693*	0.0646	0.0865*	0.3120	0.6213
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0328**	0.0843*	0.1078	0.3647	0.2163	0.2688
GR	AllBanks (Weighted)	0.0619*	0.0755*	0.0539*	0.0312**	0.0763*	0.3258
GR	AllBanks (Unweighted)	0.5435	0.2443	0.5266	0.3571	0.2856	0.5287
AllBanks (Weighted)	AllCountries (Weighted)	0.0195**	0.0343**	0.0056***	0.0181**	0.0637*	0.1315
AllBanks (Unweighted)	AllCountries (Unweighted)	0.0498**	0.0254**	0.0160**	0.0284**	0.0590*	0.0101**
AllBanks (Weighted)	GR	0.0197**	0.0234**	0.0268**	0.0793*	0.0468**	0.1823
AllBanks (Unweighted)	GR	0.5274	0.1953	0.1610	0.1780	0.1260	0.1579

(*Continued*)

TABLE 3. (Continued)

Note: The table reports p-values of the nonlinear D&P Granger causality test on the raw return data for lags $l_X = l_Y = 1, 2, 3, 4, 5, 6$. We test the null hypothesis that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively. GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

effects for the majority of the pairs of CDS series. There is no evidence of causality between the sovereign and bank CDS spreads of Ireland (see Panel A), and between the Irish bank CDS spreads and sovereign credit spreads of Greece (see Panel B).

In the second subperiod, the results show weaker nonlinear causal relationships albeit their number is greater than those reported in table 2 above. There is also stronger evidence of bidirectional causality in comparison to the results of table 2, especially in the relationship between Greek sovereign CDS and European bank CDS (see Panel B).

We also investigate nonlinear causal relationships between the series by re-applying the D&P (2006) test to the estimated residual series that are obtained from the VAR or VEC models. Using VAR or VEC filtered residuals helps us identify whether the effects shown in table 3 above are strictly driven by nonlinear causality.[37] A decrease in the number of causal relationships after first moment filtering is observed. The change is more notable for the CDS between banks and their sovereigns (see Panel A) in the first subperiod, and between the sovereign CDS of Greece and European bank CDS in the second period (see Panel B). These findings suggest that nonlinear dynamics are less likely to dominate the nexus between sovereign and bank CDS spreads in the second subperiod.

A bivariate diagonal GARCH-BEKK (1,1) model

H&J (1994) and D&P (2005) among others, stress the importance of filtering out autoregressive conditional heteroskedasticity, when examining potential nonlinear relationships between time series. Conditional heteroskedasticity could bias causality tests adversely affecting their power.[38,39] This is because volatility effects may in part or in whole account for nonlinear causal linkages between series.[40] A

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37. These results are reported in table A3 in the appendix A.

38. D&P (2006) provide evidence that the results of the Baek and Brock (1992) test could be biased because of the existence of conditional heteroskedacity in the data.

39. Forbes and Rigobon (2001) contend that correlation coefficient tests for contagion are biased upward during a crisis because of the presence of heteroskedasticity in market returns. The authors assume that there are no endogeneity and omitted variables issues in order to adjust the tests for this bias. After the adjustments for heteroskedasticity they conclude that there was not contagion during specific crisis periods but only interdependence. These findings are in line with those of Pericoli and Sbracia (2003).

40. Many financial series are characterized by time-varying conditional variance

second moment filtering using a bivariate diagonal GARCH-BEKK (1,1) model is performed.

The Engle and Kroner (1995) GARCH-BEKK (p, q, K) model is defined as:

$$H_t = C'C + \sum_{k=1}^{K} \sum_{j=1}^{q} A'_{ik} u_{t-i} u'_{t-i} A_{ik} + \sum_{k=1}^{K} \sum_{i=1}^{p} B'_{ik} H_{t-i} B_{ik} \qquad (6)$$

where C is an (N×N) upper triangular matrix, A is an (N×N) matrix of parameters specifying the relation between the current conditional variance and lagged squared errors, B is an (N×N) matrix of parameters, with its diagonal elements specifying the impact of past conditional variances on current conditional variances, u_t is the vector of disturbances, while H_t is the conditional variance-covariance matrix of the error terms at time t, which is assumed to be positive definite. The other elements of the matrices A and B specify the corresponding cross-market effects on the conditional variance and covariance. N is the number of variables in the model (N=2 in our model).

For simplicity, it is assumed that K=1, as per standard practice in empirical research. In this case, the BEKK (p, q, 1) model is defined as:

$$H_t = C'C + \sum_{i=1}^{q} A'_i u_{t-i} u'_{t-i} A_i + \sum_{i=1}^{p} B'_i H_{t-i} B_i \qquad (7)$$

Thus, the GARCH-BEKK (1, 1, 1) model can be written as follows:

$$H_t = C'C + A'_1 u_{t-1} u'_{t-i} A_1 + B'_1 H_{t-1} B_1 \qquad (8)$$

A diagonal GARCH-BEKK model, with diagonal matrices A and B, is applied. The results of the D&P nonlinear causality test after GARCH-BEKK filtering are shown in table 4.[41] The persistence and significance of nonlinear causal relationships are lower than those reported previously. This reduction corroborates the presence of

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exhibiting clustering, especially series measured at higher frequencies. Using daily data on sovereign and bank CDS spreads, it is prudent that we control for GARCH effects.

41. There is a possibility of higher-order conditional moments between the CDS series, if nonlinear causal effects persist after GARCH-BEKK filtering.

TABLE 4. Nonlinear D&P Granger Causality Results for GARCH-BEKK- Filtered Data

		Period 1					
Dependent Variable	Independent Variable	*l* = 1	*l* = 2	*l* = 3	*l* = 4	*l* = 5	*l* = 6
A.							
GR	GR_Banks	0.0459**	0.0721*	0.0397**	0.0202**	0.0174**	0.0490**
PT	PT_Banks	0.0009***	0.0062***	0.0576*	0.1265	0.3103	0.0993*
IT	IT_Banks	0.1326	0.2658	0.2529	0.3180	0.3243	0.3961
SP	SP_Banks	0.0322**	0.0413**	0.0731*	0.2730	0.6959	0.6717
IR	IR_Banks	0.6546	0.4523	0.9430	0.7930	0.8335	0.8536
FR	FR_Banks	0.1781	0.1431	0.1922	0.3960	0.3858	0.5378
NL	NL_Banks	0.0559*	0.1068	0.0468**	0.1079	0.1846	0.2189
DE	DE_Banks	0.4692	0.0165**	0.0202**	0.0445**	0.0417**	0.0656*
GR_Banks	GR	0.0281**	0.1281	0.4164	0.3497	0.7253	0.7788
PT_Banks	PT	0.2802	0.1507	0.0997*	0.0645*	0.1375	0.2528
IT_Banks	IT	0.4775	0.3997	0.6127	0.8166	0.5829	0.5166
SP_Banks	SP	0.1970	0.2061	0.1539	0.4697	0.1202	0.1960
IR_Banks	IR	0.7497	0.4490	0.3924	0.2452	0.3663	0.4482
FR_Banks	FR	0.7494	0.4287	0.5607	0.8133	0.7064	0.5447
NL_Banks	NL	0.4702	0.6822	0.4885	0.7779	0.8429	0.8973
DE_Banks	DE	0.2209	0.1772	0.0875*	0.2151	0.4671	0.5912

(*Continued*)

TABLE 4. (Continued)

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
B.							
GR	PT_Banks	0.1448	0.5692	0.2415	0.0875*	0.2614	0.4062
GR	IT_Banks	0.7086	0.2000	0.0314**	0.1182	0.2536	0.5066
GR	SP_Banks	0.2970	0.2185	0.3055	0.3876	0.5471	0.5519
GR	IR_Banks	0.6792	0.6436	0.8663	0.7561	0.2984	0.1050
GR	FR_Banks	0.2025	0.2329	0.1307	0.2649	0.5270	0.7944
GR	NL_Banks	0.8240	0.2694	0.1417	0.1027	0.0606*	0.0645*
GR	DE_Banks	0.6507	0.3324	0.7139	0.7581	0.9774	0.9319
PT_Banks	GR	0.0462**	0.3608	0.1476	0.1454	0.3467	0.5471
IT_Banks	GR	0.2498	0.4085	0.6327	0.6744	0.2940	0.2388
SP_Banks	GR	0.0570*	0.1652	0.0965	0.1100	0.1612	0.2347
IR_Banks	GR	0.8514	0.6550	0.5159	0.3689	0.6155	0.5276
FR_Banks	GR	0.1667	0.6730	0.6127	0.6798	0.5297	0.3754
NL_Banks	GR	0.1994	0.2175	0.5757	0.6485	0.6582	0.4959
DE_Banks	GR	0.0423**	0.1220	0.1223	0.0665*	0.1634	0.0516*

(*Continued*)

TABLE 4. (Continued)

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
C.							
AllCountries (Weighted)	AllBanks (Weighted)	0.0482**	0.1109	0.4805	0.9273	0.7479	0.6586
AllCountries (Unweighted)	AllBanks (Unweighted)	0.1422	0.2575	0.6659	0.2570	0.1737	0.1463
GR	AllBanks (Weighted)	0.3839	0.2478	0.5199	0.4172	0.8803	0.9754
GR	AllBanks (Unweighted)	0.1020	0.1571	0.5022	0.0836*	0.3023	0.2627
AllBanks (Weighted)	AllCountries (Weighted)	0.8245	0.6728	0.6681	0.2779	0.3566	0.2938
AllBanks (Unweighted)	AllCountries (Unweighted)	0.8727	0.6261	0.4150	0.3080	0.5724	0.5258
AllBanks (Weighted)	GR	0.1001	0.3051	0.5739	0.4780	0.2697	0.4896
AllBanks (Unweighted)	GR	0.1985	0.1035	0.0614*	0.0872*	0.2782	0.4853

(*Continued*)

TABLE 4. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
A.							
GR	GR_Banks	0.7368	0.8375	0.8616	0.8522	0.7907	0.8705
PT	PT_Banks	0.9395	0.9620	0.9757	0.7208	0.7757	0.8407
IT	IT_Banks	0.5885	0.1314	0.1873	0.3293	0.5756	0.8936
SP	SP_Banks	0.6726	0.4447	0.4925	0.5574	0.7794	0.7519
IR	IR_Banks	0.7880	0.6953	0.3753	0.5059	0.6006	0.7916
FR	FR_Banks	0.7200	0.4435	0.4211	0.6523	0.8592	0.8234
NL	NL_Banks	0.2153	0.4520	0.4833	0.8227	0.7066	0.7870
DE	DE_Banks	0.3779	0.0799***	0.0654*	0.2239	0.7844	0.7619
GR_Banks	GR	0.4248	0.2245	0.4811	0.5615	0.2911	0.5002
PT_Banks	PT	0.2320	0.4665	0.5260	0.6258	0.6468	0.6040
IT_Banks	IT	0.2878	0.2800	0.6609	0.9374	0.7012	0.7363
SP_Banks	SP	0.2323	0.2201	0.7894	0.9177	0.8413	0.8211
IR_Banks	IR	0.4150	0.5529	0.5651	0.2963	0.1785	0.3327
FR_Banks	FR	0.5462	0.3448	0.1673	0.0561*	0.3072	0.2838
NL_Banks	NL	0.2823	0.4399	0.1474	0.6361	0.6772	0.3651
DE_Banks	DE	0.0079*	0.2157	0.4494	0.5990	0.0997*	0.0300**

(Continued)

TABLE 4. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
B.							
GR	PT_Banks	0.0199**	0.0390**	0.1377	0.0764*	0.1443	0.3700
GR	IT_Banks	0.0521***	0.0819***	0.0788*	0.0316**	0.0302**	0.0721*
GR	SP_Banks	0.0812***	0.0643***	0.0109**	0.0495**	0.0625*	0.1622
GR	FR_Banks	0.0477**	0.0935***	0.1908	0.2846	0.1195	0.1510
GR	IR_Banks	0.7090	0.7320	0.3804	0.4771	0.5856	0.8183
GR	NL_Banks	0.5840	0.3326	0.2487	0.5743	0.4062	0.4718
GR	DE_Banks	0.3899	0.0188**	0.1190	0.2768	0.6405	0.8331
PT_Banks	GR	0.0739***	0.1976	0.2932	0.3215	0.1542	0.1280
IT_Banks	GR	0.2847	0.4354	0.2041	0.3590	0.7022	0.6334
SP_Banks	GR	0.3942	0.2569	0.0920*	0.0720*	0.0702*	0.3502
FR_Banks	GR	0.1115	0.3782	0.1179	0.2185	0.3942	0.3671
IR_Banks	GR	0.2542	0.5440	0.5566	0.3420	0.3131	0.5044
NL_Banks	GR	0.1372	0.1894	0.1109	0.1332	0.1436	0.1806
DE_Banks	GR	0.1840	0.2804	0.2731	0.7626	0.8636	0.8814

(*Continued*)

TABLE 4. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
C.							
AllCountries (Weighted)	AllBanks (Weighted)	0.1561	0.3071	0.1766	0.3196	0.3561	0.4502
AllCountries (Unweighted)	AllBanks (Unweighted)	0.7640	0.1499	0.2189	0.5706	0.6227	0.7688
GR	AllBanks (Weighted)	0.0901***	0.1326	0.1830	0.3980	0.3470	0.5038
GR	AllBanks (Unweighted)	0.2224	0.4393	0.5285	0.4971	0.6715	0.5230
AllBanks (Weighted)	AllCountries (Weighted)	0.3374	0.4986	0.1645	0.4045	0.2970	0.6556
AllBanks (Unweighted)	AllCountries (Unweighted)	0.7095	0.9348	0.0497**	0.0470**	0.0879*	0.0307**
AllBanks (Weighted)	GR	0.1016	0.3706	0.0835*	0.1087	0.1302	0.2704
AllBanks (Unweighted)	GR	0.3760	0.6330	0.2161	0.3342	0.5023	0.7713

(Continued)

TABLE 4. (Continued)

Note: The table reports p-values of the nonlinear D&P Granger causality test on the GARCH-BEKK filtered data for lags $l_X = l_Y = 1, 2, 3, 4, 5, 6$. We test the null hypothesis that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively. GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

volatility spillover effects.[42] Specifically, in the first subperiod, the results show persistent causal effects in the direction from Greek, Portuguese and German bank CDS to the corresponding sovereign CDS spreads. In addition, there are shorter duration unilateral causal relationships from Spanish and Dutch bank CDS spreads to the sovereign CDS of Spain and the Netherlands. There is also weak evidence of causality running from Greek sovereign CDS spreads to Greek, Portuguese, Spanish, German and unweighted bank CDS spreads.

In the second subperiod, there is evidence for the existence of bidirectional causal interlinkages between German sovereign and bank CDS spreads, Greek sovereign and Spanish and Portuguese bank CDS. There are also causal effects from French and German bank CDS to the sovereign CDS spreads of Greece at short lag, and more persistent causal effects from Italian bank CDS spreads to Greek sovereign CDS. The sovereign credit spreads of Greece have weak causal effects on the weighted bank CDS, while the unweighted sovereign CDS spreads have significant explanatory power for predicting the respective bank CDS.

Overall the results of table 4 show that volatility effects and spillovers are occurring mainly in Panel A, namely in the CDS spreads between banks and their sovereigns. On the other hand, the results in Panels B and C indicate that nonlinear causal effects persist after GARCH filtering in both periods, suggesting that volatility spillovers are less like to induce nonlinear causality.[43]

42. Some of the notable differences are as follows: There is no longer evidence of bidirectional causality between Spanish, French and German bank and sovereign CDS after GARCH-BEKK filtering in the first subperiod albeit unidirectional causality from German and Spanish bank CDS to their sovereign CDS is maintained. There is also no evidence of causality running from Italian bank to sovereign CDS, and from Greek sovereign CDS to German and Italian bank CDS. In the second subperiod, there is no evidence of unidirectional causality from Dutch and French bank CDS to their sovereign CDS, and from Greek and Italian sovereign CDS to the corresponding bank CDS, after GARCH-BEKK filtering.

43. We re-run the linear and nonlinear causality tests by using the aggregate European Monetary Union 5-year CDS-sovereign index published by Thomson Financial Datastream (Datastream code: DSESV5E) and the corresponding CDS-banking index (Datastream code: DSEBK5E). The results are generally in line with the previous findings supporting the robustness of our conclusions. These results are available upon request.

V. Conclusion

This paper provides evidence on the changing dynamics characterizing the nexus between sovereign and bank credit risk around an important event during the European sovereign debt crisis, specifically the period before and after the announcement of PSI. The results show that there were significant bidirectional causal interlinkages between sovereign and bank credit risk in the period before PSI, especially from sovereign credit spreads to the corresponding banking sector credit spreads. The dynamic interlinkages between banks and sovereigns in terms of magnitude and persistence weakened after PSI, and this result holds consistently across a step-by-step procedure involving linear causality and nonlinear causality tests both in terms of raw and filtered data. We surmise this evidence supports the view that PSI was successful in weakening the nexus between banks and sovereigns, and in this sense, it may be viewed as a positive outcome.

In the case of Greece, the results show bidirectional causality between banks and their sovereign in the first period but surprisingly little evidence of causality in the second period aside from some weak evidence of nonlinear causality at longer lags. We surmise this evidence is consistent with an important element in the PSI providing Greek banks full recovery through recapitalization for portfolio losses suffered as a result of the PSI haircut, thereby preventing country-specific risk turning into a systemic risk. Additionally, the results suggest that strong causal effects running from Greek sovereign CDS to bank CDS of other Eurozone countries in the period before PSI appears to have been greatly subdued in the following subperiod.

The extension of causality testing to a nonlinear framework captures more efficiently the unpredictable and abnormal variations in CDS markets that occurred under the crisis conditions. More specifically, the D&P (2006) Granger causality test provides significant evidence of nonlinear causal relationship between sovereign and bank CDS series. The D&P test results indicated additional Granger causal relationships that were not evident from linear causality tests, specifically for Portuguese banks on their sovereign in the first period, Italian banks on their sovereign and Greek sovereign on Greek banks in the second period. Additionally, whilst most linear causal relationships vanished after VAR/VEC filtering, nonlinear causal linkages were still present and more importantly persisted after multivariate GARCH filtering during both periods.

European banks had significant albeit varying exposures to Greek sovereign debt, with the effectiveness of the PSI program resting in its ability to balance these risks while delivering a positive outcome in terms of placing Greek sovereign debt on a more sustainable path. Hence, the success of the program rested on its ability to raise investor confidence allowing Greece to access again the international financial markets, while mitigating the transmission of the Greek sovereign crisis to the rest of the Eurozone. The findings of this study are important since widely held views at the time were very pessimistic about the outcome of the program. Greece was able to access capital markets again with small issues totaling euro 4.5 billion in 2014 paving the way for a return to the debt markets of its banks and corporates but such progress was short lived. With the benefit of hindsight, it can be said that the beneficial effects of the program did not prove to be long lasting but this was more a reflection of continuing economic depression driven by extreme fiscal austerity.

In Cyprus big banks attracted large overseas deposits, mainly from Russia, and invested heavily in Greek sovereign bonds. While exposure to Greece made Cyprus more vulnerable, the economy was already under pressure owing to a significant deterioration of public finances, damage to investor confidence, with the country losing access to international capital markets as early as May 2011. A promising avenue for future research is implementating our methodological approach to the analysis of credit risk interdependence between Greece and Cyprus using alternative proxy variables for bank credit risk. This analysis could shed more light on the dynamics of the risk transfer mechanism in the broader context of developments in Cyprus at the time. Lessons in turn from the experience of both Cyprus and Greece raise questions about what other initiatives may be undertaken by European regulatory authorities aiming at containing the strong nexus between sovereigns and banks, and what the appropriate response should be to a crisis. Part of the question is a broader assessment of the costs and benefits of capital controls or the bail-in of unsecured depositors within the parameters defining a multi-faceted response to a crisis.

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Appendix A

TABLE A1. Change of Causality based on Hsiao Causality Test

Response variable	Control variable	1st period FPE (k,0)-FPE (k, l)	2nd period FPE (k,0)-FPE (k, l)	Causality
A.				
FR	FR_Banks	0.00002691	0.00007301	↑
DE	DE_Banks	0.00002796	0.00000021	↓
PT_Banks	PT	0.00007541	0.00000959	↓
IT_Banks	IT	0.00005739	0.00000810	↓
SP_Banks	SP	0.00003345	0.00000654	↓
IR_Banks	IR	0.00002528	0.00000192	↓
FR_Banks	FR	0.00001503	0.00000962	↓
NL_Banks	NL	0.00001832	0.00000499	↓
B.				
GR	IT_Banks	0.00002362	0.00005000	↑
GR	SP_Banks	0.00002969	0.00000129	↓
GR	IR_Banks	0.00000499	0.00000216	↓
GR	FR_Banks	0.00000852	0.00008544	↑
GR	NL_Banks	0.00002291	0.00000682	↓
GR	DE_Banks	0.00002962	0.00004581	↑
PT_Banks	GR	0.00007095	0.00000304	↓
IT_Banks	GR	0.00007024	0.00000386	↓
SP_Banks	GR	0.00002901	0.00000152	↓
IR_Banks	GR	0.00001812	0.00000549	↓
FR_Banks	GR	0.00003259	0.00000906	↓
NL_Banks	GR	0.00002772	0.00000013	↓
DE_Banks	GR	0.00001860	0.00000151	↓
C.				
AllCountries (Weighted)	AllBanks (Weighted)	0.00000492	0.00001347	↑
AllCountries (Unweighted)	AllBanks (Unweighted)	0.00000303	0.00002522	↑
GR	AllBanks (Weighted)	0.00002391	0.00003406	↑
AllBanks (Weighted)	AllCountries (Weighted)	0.00001541	0.00000003	↓
AllBanks (Weighted)	GR	0.00002028	0.00000048	↓
AllBanks (Unweighted)	GR	0.00002647	0.00000085	↓

(*Continued*)

TABLE A1. (Continued)

Note: This table presents the changes in causality for the CDS time series, for which there is a causal relationship in both subperiods. Period 1 ranges from 1 Jan 2009 to 26 Oct 2011 and period 2 from 27 Oct 2011 to 30 May 2014. FPE is final prediction error. GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

TABLE A2. Difference-in-Difference Results

Response variable	Control variable	Coefficient of INT	Causality
A.			
GR	GR_Banks	–0.4523*** (p=0.0015)	↓
PT	PT_Banks	–0.4510*** (p=0.0000)	↓
IT	IT_Banks	**–0.0680 (p=0.2892)**	-
SP	SP_Banks	**–0.2451*** (p=0.0005)**	↓
IR	IR_Banks	–0.0991 (p=0.2318)	-
FR	FR_Banks	0.0022 (p=0.9706)	-
NL	NL_Banks	–0.1808*** (p=0.0040)	↓
DE	DE_Banks	–0.2196*** (p=0.0064)	↓
GR_Banks	GR	–0.1429*** (p=0.0000)	↓
PT_Banks	PT	–0.1781*** (p=0.0000)	↓
IT_Banks	IT	**–0.0079 (p=0.8077)**	-
SP_Banks	SP	**–0.0145 (p=0.6128)**	-
IR_Banks	IR	–0.2127*** (p=0.0000)	↓
FR_Banks	FR	–0.1517*** (p=0.0000)	↓
NL_Banks	NL	0.0305 (p=0.4818)	-
DE_Banks	DE	–0.1004*** (p=0.0008)	↓
B.			
GR	PT_Banks	0.6042*** (p=0.0000)	↑
GR	IT_Banks	–0.1901** (p=0.0384)	↓
GR	SP_Banks	–0.3738*** (p=0.0002)	↓

(*Continued*)

TABLE A2. (Continued)

Response variable	Control variable	Coefficient of INT	Causality
B.			
GR	IR_Banks	–0.3363*** (p=0.0054)	↓
GR	FR_Banks	–0.2330*** (p=0.0053)	↓
GR	NL_Banks	–0.2600** (p=0.0140)	↓
GR	DE_Banks	–0.266249*** (p=0.0032)	↓
PT_Banks	GR	–0.3977*** (p=0.0000)	↓
IT_Banks	GR	–0.3571*** (p=0.0000)	↓
SP_Banks	GR	–0.3060*** (p=0.0000)	↓
IR_Banks	GR	–0.2391*** (p=0.0000)	↓
FR_Banks	GR	–0.3164*** (p=0.0000)	↓
NL_Banks	GR	–0.1952*** (p=0.0000)	↓
DE_Banks	GR	–0.2742*** (p=0.0000)	↓
C.			
AllCountries (Weighted)	AllBanks (Weighted)	–0.2223*** (p=0.0035)	↓
AllCountries (Unweighted)	AllBanks (Unweighted)	–0.2899*** (p=0.3447)	↓
GR	AllBanks (Weighted)	–0.3330*** (p=0.0080)	↓
GR	AllBanks (Unweighted)	–0.3679** (p=0.0282)	↓
AllBanks (Weighted)	AllCountries (Weighted)	–0.2461*** (p=0.0000)	↓
AllBanks (Unweighted)	AllCountries (Unweighted)	–0.3728*** (p=0.0000)	↓
AllBanks (Weighted)	GR	–0.2777*** (p=0.0000)	↓
AllBanks (Unweighted)	GR	–0.2489*** (p=0.000)	↓

(*Continued*)

TABLE A2. (Continued)

Note: INT is the PSI interaction variable with the corresponding CDS. Bold values indicate the pairs of sovereign and bank CDS series in which a long-term relation is observed in the whole sample period. Numbers in parentheses are p-values. *, **, *** denote statistical significance at the 10%, 5%, and 1% level, respectively. GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

TABLE A3. Nonlinear D&P Granger Causality Results for VAR- or VECM- Filtered Data

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
A.							
GR	GR_Banks	0.0133**	0.0774*	0.0501*	0.0595*	0.0995*	0.2185
PT	PT_Banks	0.0023***	0.0027***	0.0397**	0.0329**	0.0564**	0.0236**
IT	IT_Banks	0.0717*	0.2767	0.1256	0.2473	0.3835	0.5603
SP	SP_Banks	0.0188**	0.0276**	0.0459**	0.0370**	0.2627	0.4068
IR	IR_Banks	0.9072	0.5604	0.9857	0.9710	0.9505	0.8234
FR	FR_Banks	0.1298	0.0102**	0.0415**	0.0280**	0.0502*	0.0700*
NL	NL_Banks	0.0498**	0.1378	0.0679*	0.1016	0.1547	0.1417
DE	DE_Banks	0.1008	0.0020***	0.0023***	0.0041***	0.0184**	0.0197**
GR_Banks	GR	0.0044***	0.0307**	0.2619	0.2977	0.7032	0.7334
PT_Banks	PT	0.1508	0.0257**	0.0075***	0.0100**	0.0089***	0.0270**
IT_Banks	IT	0.1458	0.2533	0.3331	0.4983	0.5709	0.6398
SP_Banks	SP	0.0880*	0.0517*	0.0772*	0.1125	0.0616*	0.1474
IR_Banks	IR	0.9372	0.7410	0.8580	0.7465	0.7805	0.6060
FR_Banks	FR	0.0533*	0.0180**	0.0558*	0.0665*	0.0692*	0.1907
NL_Banks	NL	0.3807	0.5188	0.2666	0.4885	0.4753	0.5732
DE_Banks	DE	0.0167**	0.0175**	0.0111**	0.1043	0.1209	0.4416

(*Continued*)

TABLE A3. (Continued)

		Period 1					
Dependent Variable	Independent Variable	*l* = 1	*l* = 2	*l* = 3	*l* = 4	*l* = 5	*l* = 6
B.							
GR	PT_Banks	0.0481**	0.1447	0.0871*	0.0689*	0.2091	0.2651
GR	IT_Banks	0.1977	0.0418**	0.0194**	0.0323**	0.0448**	0.0996*
GR	SP_Banks	0.1070	0.2423	0.4240	0.4637	0.5448	0.4467
GR	IR_Banks	0.7542	0.4839	0.8534	0.7551	0.1754	0.1380
GR	FR_Banks	0.1036	0.1636	0.1147	0.1511	0.1516	0.3387
GR	NL_Banks	0.2633	0.0518*	0.0480**	0.0372**	0.0595*	0.0296**
GR	DE_Banks	0.3086	0.2963	0.5439	0.4588	0.6540	0.5198
PT_Banks	GR	0.1558	0.2134	0.1264	0.1400	0.5492	0.6217
IT_Banks	GR	0.0524***	0.1137	0.1212	0.2187	0.3519	0.4351
SP_Banks	GR	0.0552***	0.1453	0.0810*	0.0537*	0.1163	0.1965
IR_Banks	GR	0.7518	0.8658	0.9271	0.9091	0.9273	0.9438
FR_Banks	GR	0.1110	0.6688	0.7689	0.7499	0.6023	0.5968
NL_Banks	GR	0.2966	0.1594	0.1631	0.2263	0.2625	0.4535
DE_Banks	GR	0.0594***	0.5836	0.6250	0.3290	0.3977	0.5200

(*Continued*)

TABLE A3. (Continued)

		Period 1					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
C.							
AllCountries (Weighted)	AllBanks (Weighted)	0.0516*	0.2312	0.3472	0.3401	0.3641	0.3332
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0756*	0.1900	0.5673	0.3521	0.3391	0.4534
GR	AllBanks (Weighted)	0.2629	0.2327	0.4885	0.3383	0.4922	0.6958
GR	AllBanks (Unweighted)	0.2305	0.2516	0.7355	0.3449	0.5216	0.5652
AllBanks (Weighted)	AllCountries (Weighted)	0.4606	0.0988*	0.2463	0.1858	0.2936	0.1652
AllBanks (Unweighted)	AllCountries (Unweighted)	0.9906	0.6573	0.5928	0.5402	0.9513	0.9373
AllBanks (Weighted)	GR	0.2608	0.2059	0.2541	0.2637	0.4249	0.5832
AllBanks (Unweighted)	GR	0.6577	0.3333	0.3593	0.3298	0.5815	0.7947

(*Continued*)

TABLE A3. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
A.							
GR	GR_Banks	0.3517	0.6854	0.7234	0.7906	0.6160	0.4128
PT	PT_Banks	0.9823	0.9619	0.9883	0.6673	0.6312	0.6513
IT	IT_Banks	0.9040	0.3638	0.1722	0.2600	0.6690	0.6989
SP	SP_Banks	0.6350	0.3385	0.2011	0.4946	0.6314	0.6465
IR	IR_Banks	0.7338	0.5019	0.2805	0.4128	0.4353	0.6344
FR	FR_Banks	0.2514	0.0840*	0.0837*	0.1674	0.2514	0.5194
NL	NL_Banks	0.0585*	0.1099	0.0971*	0.2161	0.2664	0.2887
DE	DE_Banks	0.0950*	0.0252**	0.0401**	0.2239	0.3248	0.4202
GR_Banks	GR	0.3379	0.1029	0.3996	0.6034	0.4054	0.2803
PT_Banks	PT	0.1193	0.4142	0.5811	0.5126	0.5559	0.5326
IT_Banks	IT	0.0759*	0.0888*	0.5691	0.8557	0.4934	0.3674
SP_Banks	SP	0.1359	0.1957	0.6809	0.7789	0.6319	0.7265
IR_Banks	IR	0.3496	0.5095	0.4398	0.2124	0.1333	0.3724
FR_Banks	FR	0.1477	0.2211	0.1773	0.1311	0.4735	0.6258
NL_Banks	NL	0.8168	0.6703	0.3510	0.9030	0.2887	0.8765
DE_Banks	DE	0.0189**	0.3881	0.5186	0.3153	0.0349**	0.0329**

(*Continued*)

TABLE A3. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
B.							
GR	PT_Banks	0.2614	0.4015	0.6433	0.4548	0.3481	0.5067
GR	IT_Banks	0.1244	0.0337**	0.0630*	0.0587*	0.0631*	0.1059
GR	SP_Banks	0.0084***	0.0056***	0.0021*	0.0306**	0.0405**	0.0828*
GR	IR_Banks	0.3682	0.2980	0.8725	0.8707	0.9074	0.8285
GR	FR_Banks	0.0064***	0.0052***	0.0444**	0.0222**	0.0537*	0.0705*
GR	NL_Banks	0.6809	0.4005	0.4931	0.7272	0.7037	0.7836
GR	DE_Banks	0.3085	0.1582	0.3244	0.5362	0.6466	0.8356
PT_Banks	GR	0.2575	0.6007	0.8187	0.7370	0.5711	0.3477
IT_Banks	GR	0.3042	0.5735	0.4720	0.7243	0.8939	0.9577
SP_Banks	GR	0.1886	0.0385**	0.0237**	0.0847	0.1104	0.2806
IR_Banks	GR	0.5338	0.3651	0.5530	0.2168	0.0635*	0.1741
FR_Banks	GR	0.0044*	0.0603*	0.0222**	0.0884*	0.0997*	0.0930*
NL_Banks	GR	0.4715	0.3901	0.2253	0.2659	0.2664	0.3390
DE_Banks	GR	0.0563*	0.2063	0.3244	0.5786	0.5489	0.6003

(*Continued*)

TABLE A3. (Continued)

		Period 2					
Dependent Variable	Independent Variable	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
C.							
AllCountries (Weighted)	AllBanks (Weighted)	0.0896*	0.1528	0.0727*	0.3103	0.7967	0.8444
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0842*	0.1561	0.2226	0.6124	0.6271	0.7546
GR	AllBanks (Weighted)	0.1065	0.0695*	0.0709*	0.2277	0.4290	0.7511
GR	AllBanks (Unweighted)	0.2879	0.3759	0.4483	0.6091	0.5312	0.4653
AllBanks (Weighted)	AllCountries (Weighted)	0.1665	0.2344	0.1168	0.1993	0.4200	0.7035
AllBanks (Unweighted)	AllCountries (Unweighted)	0.0555*	0.0621*	0.0417**	0.0377**	0.0515*	0.0275**
AllBanks (Weighted)	GR	0.1393	0.6991	0.2408	0.3469	0.4074	0.3462
AllBanks (Unweighted)	GR	0.7278	0.9130	0.6020	0.5879	0.5342	0.6079

(*Continued*)

TABLE A3. (Continued)

Note: The table reports p-values of the nonlinear D&P Granger causality test on the VAR- or VECM- filtered data for lags $l_X = l_Y = 1, 2, 3, 4, 5, 6$. We test the null hypothesis that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively. GR, PT, IT, SP, IR, FR, NL, DE denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily sovereign CDS premia, respectively and GR_Banks, PT_Banks, IT_Banks, SP_Banks, IR_Banks, FR_Banks, NL_Banks, DE_Banks denote Greek, Portuguese, Italian, Spanish, Irish, French, Dutch and German 5-year senior unsecured daily bank CDS premia, respectively. AllCountries (Weighted) denotes the weighted sovereign CDS spreads based on the annual gross domestic product for each country. AllBanks (Weighted) denotes the weighted bank CDS spreads based on the annual total liabilities of each banking institution for each country. AllCountries (Unweighted) and AllBanks (Unweighted) denote the unweighted sovereign and bank aggregate CDS series, respectively.

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