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THE DYNAMICS OF SPILLOVER EFFECTS DURING THE EUROPEAN SOVEREIGN DEBT TURMOIL

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MACROPRUDENTIAL RESEARCH NETWORK

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ABSTRACT

In this paper we develop empirical measures for the strength of spillover effects. Modifying and extending the framework by Diebold and Yilmaz (2011), we quantify spillovers between sovereign credit markets and banks in the euro area. Spillovers are estimated recursively from a vector autoregressive model of daily CDS spread changes, with exogenous common factors. We account for interdependencies between sovereign and bank CDS spreads and we derive generalised impulse response functions. Specifically, we assess the systemic effect of an unexpected shock to the creditworthiness of a particular sovereign or country-specific bank index to other sovereign or bank CDSs between October 2009 and July 2012. Channels of transmission from or to sovereigns and banks are aggregated as a Contagion index (CI). This index is disentangled into four components, the average potential spillover: i) amongst sovereigns, ii) amongst banks, iii) from sovereigns to banks, and iv) vice-versa. We highlight the impact of policy-related events along the different components of the contagion index. The systemic contribution of each sovereign or banking group is quantified as the net spillover weight in the total net-spillover measure. Finally, the captured time-varying interdependence between banks and sovereigns emphasises the evolution of their strong nexus.

Keywords: CDS; contagion; sovereign debt; systemic risk; impulse responses

JEL-Classification: C58; G01; G18; G21

NON-TECHNICAL SUMMARY

The recent financial crisis that developed from a global banking crisis in the summer of 2007 to a European sovereign debt crisis since 2010 is one of the most challenging episodes for policy makers both at governments and central banks since the introduction of the euro.

An issue that has attracted widespread attention by academia, policy makers and market participants is the phenomenon of contagion. Constâncio (2012) refers to contagion as "one of the mechanisms by which financial instability becomes so widespread that a crisis reaches systemic dimensions.[…]As a consequence, crisis management by all competent authorities should also focus on policy measures that are able to contain and mitigate contagion."

In a seminal paper, Allen and Gale (2000) explain "contagion" as a consequence of excess spillover effects. In their example, a banking crisis in one region may spill over to other regions. Contagion in their view is hence the phenomenon of extreme amplification of spillover effects. Therefore spillover effects are a necessary - but not a sufficient - condition for contagion. In this paper we intend to answer a few policy relevant questions: When are spillovers "extreme"? When would they trigger financial contagion? How can they be distinguished from those that occur within "normal" i.e. "non-dangerous" magnitudes? Who are the main contributors to total spillovers in the system?

Extending the framework by Diebold and Yilmaz (2011), we propose an analytical and empirical framework for measuring spillover effects. We illustrate our method by providing an empirical application to the interlinkages between sovereigns and banks in the euro area. By analysing daily data of CDS spreads we quantify those spillover effects based on an 80-days rolling regression window. We combine together the information from sovereign and bank CDS markets in a vector autoregressive framework, augmented by several control variables. In our model we focus on 11 sovereigns and nine country-specific banking groups from the euro area, over the period October 2009 - July 2012. Furthermore, we rely on generalised impulse responses approach in order to assess the systemic effect of an unexpected shock to the creditworthiness of a particular sovereign or country-specific bank index. We aggregate this information into a Contagion Index. Our measure internalises interdependencies of the variables in our system. This index has four main components: average potential spillover i) amongst sovereigns, ii) amongst banks, iii) from sovereigns to banks and iv) vice-versa.

Our measure can be used in a static or dynamic context, by showing the state of potential contagion at a certain point in time or a time dependent contagion index. Features of this toolbox allow us to identify systemically relevant entities (i.e. country specific banking sectors and sovereigns) from the proposed set of sovereigns and banks in our system. We have proposed in this paper a simple method to compute thresholds for “excessive” spillovers, based on empirical distributions of CDS changes in combination with subjective preferences. Excessive spillovers are a characteristic of dysfunctional markets and can lead to financial instability. They can be associated with a regime change (usually characterized by “non-linearity”) that is characterized by “excess” interdependencies, excluding the common shocks that affect all variables simultaneously. “Abnormal” spillovers are a source of contagion and systemic risk. The relationships that exist between financial variables (e.g. markets, participants, intermediaries) are characterized by an extreme dependence, different than the one that is observed during tranquil times excluding the common shocks.

Our results show a clear upward pattern of growing interdependencies between banks and sovereigns, that represents a potential source of systemic risk. Euro area sovereign creditworthiness carries a growing weight in the overall financial market picture, with a sub-set of sovereigns that can potentially produce negative externalities to the financial system. We find that several previous policy interventions had a mitigating impact on spillover risks. In our application we find that a shock in Spanish sovereign CDS reveals an elevated impact on both euro area sovereigns and banks during the first half of 2012, compared to 2011. Moreover, spillover effects from a shock to Spanish sovereign CDS to euro zone core countries and to non-core countries become more similar in magnitude during 2012. We also found strong evidence that the nexus between sovereigns and banks amplified strongly until the end of June 2012. However, systemic contributions of Greece, Portugal and Ireland decrease remarkably after the implementation of IMF/EU programs. Nevertheless, Ireland regains its positive net spillover status since the beginning of 2012. The setup of the EFSF and the decision of the two LTROs in December 2012 have a mitigating impact on all four contagion index components. By contrast, nationalization of Bankia in Spain had a further impact on all four contagion index components, reinforcing spillover effects.

The paper presents a macro-prudential toolbox for measuring the potential contagion in the euro area using market data. It can be adapted to the needs of policymakers by integrating other banks or sovereigns or extending it to real economy variables. Furthermore, we attempt to show its usefulness in quantifying the potential effects of different policy measures in containing spillovers across the system. Finally we provide critical spillover thresholds that can be interpreted as “alarming” levels which could lead to contagion.

I INTRODUCTION

The recent financial crisis, which developed from a global banking crisis in the summer of 2007 to a European sovereign debt crisis since 2010, is one of the most challenging episodes for policy makers both at governments and central banks since the introduction of the euro. After the collapse of "Lehman Brothers" in autumn 2008, the fear of contagion is one of the most prominent issues on the agenda both for financial research and policy making. Clearly, the fear of contagion has and still does put pressure on policy makers and influences policy decisions in particular within the Eurozone. Being able to gauge the potential risk of contagion is therefore of paramount interest for policymakers and agents in financial markets. In the existing empirical and theoretical literature there is a broad range of definitions for contagion, see e.g. Forbes (2012). By the same token, a variety of approaches and methods on how to measure contagion has been proposed. Dornbusch *et al.* (2000) or Forbes and Rigobon (2002), among others, describe contagion as a significant increase in cross-market interdependencies after a "large" shock hits one country or a group of countries. Contagion viewed from that perspective is hence determined by the portion of interdependency that exceeds any fundamental relationship among countries and that is not attributable to the magnitude of common shocks. More generally, contagion can also be associated with a *negative externality* triggered by institution(s) or market participant(s) in distress that might affect other players. Furthermore, Hartmann *et al.* (2005) summarize the main five criteria to identify contagion as: i) an idiosyncratic negative shock that affects a financial institution and spreads to other parts of the financial system or an idiosyncratic negative shock that affects an asset and triggers declines in other asset prices; ii) the interdependencies between asset prices or defaults are different than in tranquil times; iii) the excess dependencies cannot be explained by common shocks; iv) events associated with extreme left tail returns; v) interdependencies evolve sequentially. Constâncio (2012) extends the identification of contagion in two directions: the existence of an initial trigger-event and the abnormal speed, strength or scope that accompanies financial instability.

For the purpose of this paper we borrow as benchmark the approach put forward by Allen and Gale (2000) who explain contagion as a consequence of spillover effects. In their example, a banking crisis in one region may spill over to other regions. Contagion in their view is hence the phenomenon of extreme amplification of spillover effects. Spillover effects are therefore a necessary - but not a sufficient - condition for contagion. But when are spillovers "extreme" and when would they trigger contagion? How can they be distinguished from those that occur within "normal" i.e. "non-dangerous" magnitudes? In this paper we present a method and an index that can answer these questions in quasi real time. We propose an analytical and empirical framework for measuring spillover effects and we illustrate our method by providing an empirical application to the inter-linkages between sovereign credit markets and systemically relevant banks. By analysing daily data of CDS spreads we quantify those spillover effects based on a 80-days rolling regression window. Our measure internalises interdependencies of the variables in our system. We aggregate this information into a *Contagion Index.* This index has four main components: average potential spillover i) amongst sovereigns, ii) amongst banks, iii) from sovereigns to banks and iv) vice-versa.

There are several mechanisms that could explain the transmission of spillover effects within these four channels. As regards spillover amongst Eurozone sovereign bonds they are at least indirectly linked by the joint monetary policy transmission mechanism, the Eurosystem's collateral framework and by a shared default risk of Eurozone member countries via the EFSF and future ESM.[1] Spillover effects between (domestic) sovereign creditworthiness and (domestic) banks are induced by a feedback mechanism that intensified during the financial crisis. The dynamics of such a sovereign-and-banks feedback loop are driven by systemic financial externalities that have a negative impact on the real economy and consequently on public finances, see e.g. Acharya *et al.* (2011), Alter and Schüler (2012), Bicu and Candelon (2012), De Bruyckere *et al.* (2012), Merler and Pisani-Ferry (2012) or Gross and Kok (2012). Sovereign debt amplification feeds back into the financial sector by affecting balance sheets of financial institutions and thereby having a negative impact on domestic banks' ratings that pushes up their funding costs, see e.g. BIS (2011). With a domestic financial sector in distress government guarantees for the financial sector lose credibility when sovereign creditworthiness deteriorates as well and thereby yielding further amplification of spillovers. If government liabilities increase, this causes a higher debt burden and hence increased pressure for sovereigns. Finally, there are several channels that transmit contagion risks within the banking sector alone, such as common credit exposures, interbank lending or trade of derivatives. Apart from the "fundamental-based contagion" channels, portfolio rebalancing theory and information asymmetries among market participants might induce spillover effects as well.

Our empirical framework is based on a medium-size vector autoregressive model with exogenous variables (VARX). These exogenous variables account for common global and regional trends that allow us to identify and to measure the systemic contribution of sovereigns and banks. We fit the model recursively based on daily log-returns of sovereign and bank CDS series over the period October 2009 until July 2012. The use of CDS data was partly motivated by recent studies which show that past CDS spreads improve the forecast quality of bond yield spreads, see e.g., Palladini and Portes (2011) or Fontana and Scheicher (2010) who provide a

[1] The EFSF was created on 9 May 2010 as a temporary facility and will be merged with the European Stability Mechanism (ESM hereafter). The ESM was set up on 24 June 2011 as a permanent crisis mechanism. The share of the countries guaranteeing the EFSF's debt is in proportion to each country's capital share in the European Central Bank (ECB) adjusted to exclude countries with EU/IMF supported programs.

detailed discussion on the relationship between euro area sovereign CDSs and government bond yields. We derive generalised impulse response functions (GIRF) as functions of residuals together with the interdependence coefficients. The GIRFs serve as input for inference and detection of spillovers in the euro area. Based on recent work by Diebold and Yilmaz (2011), we extend their methodology that accounts for spillover and contagion in several directions. Instead of using the forecast error variance decomposition, we use the framework of generalized impulse responses. In this setup, we analyse the normalised potential spillover effects of an unexpected shock in each variable on others. We determine an optimal rolling window size for our VARX model (80 days). The "optimal" size is characterised by a trade-off between robustness and reliability of estimated coefficients on the one hand (the longer the sample the better the quality) and gaining information about a build-up of spillover effects over time on the other hand (by aiming for many windows of shorter samples).

Our main results reflect increasing spillover measures and therefore a high level of potential contagion before key financial market events or policy interventions during the sovereign debt crisis. While the contagion index amongst banks remains stable during the analysed period, both the contagion index of sovereigns and the overall contagion index (for both banks and sovereigns) trend upward. The individual net contribution of the IMF/EU program countries is highly elevated during the periods that precedes their respective bailout, but declines considerably afterwards. Spillover effects from banks to sovereigns and vice-versa trend upward in periods of stress, reflecting the evidence of a tightening nexus between banks and sovereigns in the Eurozone.

The remainder of this paper is organized as follows. In Section 2 we discuss studies related to our research. Section 3 presents the data and the methodology utilised. Section 4 presents our results, Section 5 provides some empirical robustness checks, and Section 6 concludes.

2 RELATED LITERATURE

The main strand of literature related to our paper focuses on contagion in financial markets. As defined by Forbes and Rigobon (2002), contagion refers to a significant increase in cross-market correlation compared to the one measured during tranquil periods. They find that the estimated correlation increases during stress times but tends to be biased upwards. If tests are not adjusted for heteroskedasticity bias they result in misleading evidence of contagion. They conclude that a stable and elevated co-movement during both tranquil and stress times should be referred to as interdependence. Allen and Gale (2000) provide an analysis of contagion caused by linkages between banks. When one region suffers a banking crisis, banks from other regions that hold claims against the affected region devalue these assets and their capital is eroded. Spillover effects from the affected region can trigger an infection of other adjacent regions. The extreme amplification of spillover effects is referred to as "contagion". This mechanism could also be explained by self-fulfilling expectations: if shocks from a region serve as signals that improve the prediction of shocks in another region then a crisis in the former creates the expectation of a crisis in the latter.

In this paper, we propose a new methodology that complements contagion methodologies developed by Caceres *et al.* (2010), Caporin *et al.* (2012), Claeys and Vašíček (2012), De Santis (2012), Donati (2011) and Zhang *et al.* (2011). Dungey et al. (2004), ECB (2005), and ECB (2009) review the main empirical and theoretical methods that deal with financial contagion. Analysing bond spreads of the euro area countries, De Santis (2012) finds that global, country-specific and contagion risks are the main factors that drive sovereign credit spreads. Based on a multivariate model with time-varying correlations and volatilities, Zhang *et al.* (2011) use CDS spreads to infer joint and conditional probabilities of default of the euro-area countries. Furthermore, Caceres *et al.* (2010) use the methodology developed by Segoviano (2006) and estimate the spillover coefficients for each country in the euro area. Their findings suggest that the gravity center of contagion source shifted from countries that were at the beginning more affected by the financial crisis (i.e. Ireland, Netherlands, and Austria) to those euro area countries with weak long-term sustainability and high short-term refinancing risk (i.e. Greece, Portugal and Spain). Caporin *et al.* (2012) study sovereign risk contagion within the euro area countries. They find that contagion in Europe remained subdued in the period they analyse. They conclude that the common shift observed in CDS spreads is the outcome of the usual interdependence and that the strength in propagation mechanisms has not changed during the recent crisis. Similar to Favero and Giavazzi (2002), our model is embedded into a vector autoregressive framework that is able to capture interdependencies between variables in the system, taking into account their lagged dynamics. Bekaert *et al.* (2005) analyse contagion across international equity markets. They use a two-factor asset pricing model and provide evidence for global and regional market integration. Furthermore, they decompose sources of volatility into global, regional and local and measure their weights.

Financial contagion is one form of systemic risk. As conceptualized by De Bandt et al. (2009), systemic risk is usually associated with the banking system but may have strong negative consequences to other sectors of the real economy and may affect economic welfare. In this paper we introduce a new measure to assess the systemic contributions and we apply it to both sovereigns and financial institutions. ECB (2010) summarizes the main tools and concepts for the detection and measurement of systemic risk. Since central banks are interested in measuring and monitoring contagion in order to preserve financial stability under the macro-prudential dimension, our contribution is primarily focused on policy instruments. Our systemic risk measure complements the well-established work by Acharya *et al.* (2010), Adrian and Brunnermeier (2009) or Huang *et al.* (2009), among others.

Since financial contagion refers to excess interdependencies besides the common factors, a critical issue that has to be solved before pursuing any econometric inference is how to account for common shocks and to obtain idiosyncratic residuals. Our model is inspired by the Arbitrage Pricing Theory (APT), where asset returns are determined by a set of common factors and several characteristics related to idiosyncratic (non-diversifiable) risk. The second strand of literature associated with our paper is related to common factors in asset returns. Berndt and Obreja (2010) study the determinants of European corporate CDS returns and identify as one of the main common factors the super-senior tranche of the iTraxx Europe index, referred to as "the economic catastrophe risk". Longstaff *et al.* (2011) analyse the determinants of sovereign credit risk and divide them into local economic variables, global financial market variables, global risk premium, and net investment flows into global funds. They find evidence that sovereign credit risk is driven mainly by global financial market variables or a global risk premium and to a lesser extent by local macroeconomic variables. Similar, by analysing sovereign CDS spreads in the US and Europe, Ang and Longstaff (2011) show that systemic sovereign risk is more related to financial markets than to country-specific macro-characteristics. Beirne and Fratzscher (2012) find evidence for "wake-up call" contagion, suggesting that global financial markets are more influenced by economic fundamentals during periods of stress than in tranquil times. In contrast, regional contagion is less able to explain sovereign risks. Ejsing and Lemke (2011) investigate the co-movements of CDS spreads of euro area countries and banks with a common risk factor and find that sovereign CDS series became more sensitive to the common risk factor than banks' CDS spreads. These findings motivate our choice for using several global and regional common factors, in order to "filter" the CDS returns.

Kalbaska and Gatwoski (2012) study contagion among several European sovereigns using CDS data. They employ a correlation analysis and find that countries under stress (such as Greece, Ireland, Portugal, Spain and Italy) tend to trigger very little or no contagion among the core countries during their analysed period. Our results show that the potential spillovers from Spain and Italy, especially during the developments until July 2012, might be a "game-changer" from this perspective. We find that after the establishment of the EFSF in 2010 core countries are highly sensitive to shocks from periphery countries. Diebold and Yilmaz (2009, 2011 and 2012) introduce and develop a framework based on forecast error variance decomposition for vector autoregressive (VAR) models. They implement their framework to equity markets and across different asset classes, building both on total and on "directional" volatility spillover measures. Among other results, they find that equity markets had an important contribution in transmitting spillovers to international markets and other asset classes. Claeys and Vašíček (2012) use a similar econometric framework as Diebold and Yilmaz (2011) and apply it to EU sovereign bond spreads relative to the German Bund. Their results show that spillover among sovereign yields increased considerably since 2007 but its importance is different across countries. They find that spillover effects dominate the domestic fundamental factors for EMU countries. Finally, Alter and Schüler (2012) find evidence for contagion from banks to sovereign CDS before public rescue programs for the financial sector were launched whereas sovereign CDS spreads do spill over to bank CDS series thereafter.

3 ECONOMETRIC METHODOLOGY AND DATA DESCRIPTION

In order to capture potential spillovers that could trigger financial contagion across the euro area, we apply an econometric framework based on daily sovereign and bank CDS spreads, see Appendix A1 for details about the data. In addition we use a number of exogenous control variables. The CDS data series considered refer to senior five year spreads denominated in USD (for sovereigns) and in EUR (for banks). Our sample starts in October 2009 and ends on 3 July 2012.[2] Tests for unit roots suggest that the series are difference-stationary. Table A1.2 summarizes the main statistical characteristics of the data in log-levels and in first differences. In order to obtain time-varying parameters we decide to use a rolling-window estimation approach similar to that by Diebold and Yilmaz (2011). Since in our framework the rolling window size is 80 days, the first estimation point refers to end of January 2010.

3.1 VECTOR AUTOREGRESSIVE MODEL WITH EXOGENOUS VARIABLES (VARX)

We write a vector autoregressive model amended by several exogenous variables as:

$$\begin{bmatrix}\Delta y_{1,t}\\ \vdots \\ \Delta y_{n,t}\end{bmatrix} = \begin{bmatrix}\alpha_{1,0}\\ \vdots \\ \alpha_{n,0}\end{bmatrix} + \sum_{i=1}^{p}\begin{bmatrix}\gamma_{11,i} & \cdots & \gamma_{1n,i}\\ \vdots & \ddots & \vdots \\ \gamma_{n1,i} & \cdots & \gamma_{nn,i}\end{bmatrix}\begin{bmatrix}\Delta y_{1,t-i}\\ \vdots \\ \Delta y_{n,t-i}\end{bmatrix} + \sum_{j=0}^{q}\begin{bmatrix}\beta_{11,j} & \cdots & \beta_{1k,j}\\ \vdots & \ddots & \vdots \\ \beta_{n1,j} & \cdots & \beta_{nk,j}\end{bmatrix}\begin{bmatrix}Exo_{1,t-j}\\ \vdots \\ Exo_{k,t-j}\end{bmatrix} + \begin{bmatrix}u_{1,t}\\ \vdots \\ u_{n,t}\end{bmatrix}, \; u_t \sim id(0, \Sigma_u) \qquad (1)$$

In our case, we estimate a VARX model with two lags (p=2) for the endogenous variables and contemporaneous exogenous variables (q=0).[3] The vector of endogenous (*y*) variables consists of first log-differences of daily CDS spreads from eleven euro-area countries: Austria (AT), Belgium (BE), Finland (FI), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), the Netherlands (NL), Portugal (PT), and Spain (ES). Together with the sovereign CDS spreads we use in each of the above mentioned countries an aggregated index for the domestic banks.[4] As a vector of exogenous variables (i.e. Exo_t) we utilise several control factors in first differences: the *iTraxx WE SovX* index (as the main common factor of the Eurozone sovereign CDS spreads), the *iTraxx Senior Financials Europe* index (as the main common factor of the

[2] The starting point was influenced by the availability of exogenous variables (i.e. *iTRAXX SovX Western Europe* index). This period also coincides with the first signs of sovereign debt problems related to Greece.

[3] We choose two lags based on several constraints: should be consistent across variables and across time and more lags translates into a larger estimation window size.

[4] With the exception of Finland and Ireland. For these two countries CDS data for banks is not available over a meaningful sample length. Bank variables together with exogenous variables are described in Table A1.1 in Appendix A1. Bank country-specific indices are weighted by assets of the component banks.

European bank CDS spreads), the *iTraxx Europe index* (that refers to 125 European investment grade companies across all sectors, including financials, that incorporates the overall credit performance of the Eurozone's real economy), the *iTraxx Crossover* (that refers to 50 European companies with high yields/sub-investment grade, that refers to lower quality credit instrument for the real economy), the spread between *3 month Euribor and EONIA* swap (a common measure of the interbank risk premium), the *EuroStoxx 50* index (the representative European stock index), the *US* and the *UK sovereign CDS* series and the *VIX index* (that is based on S&P 500 option prices and it is regarded as a common measure of investors' risk aversion).[5] As discussed in the previous section, by including the exogenous variables, we attempt to account for common/systematic factors, both regional and global, that affect at the same time all sovereign and bank CDS spreads. After accounting for all explanatory variables (the lagged endogenous variables and the exogenous control variables), the remaining residuals ***u*** from eq. (1) represent the isolated idiosyncratic part. The explicit model with bank and sovereign variables is presented in Appendix A2.A.[6]

3.2 GENERALIZED IMPULSE RESPONSE FUNCTIONS (GIRF)

Impulse response analysis provides a dynamic perspective of the interactions between the endogenous variables of the VARX process. It takes into account both the variance-covariance matrix if the residuals and the estimated γ-coefficients from the VARX model in eq. (1).[7]

Using the framework proposed by Koop *et al.* (1996) and Pesaran and Shin (1998), we specify the generalized impulse responses function (GIRF).[8] The generalized impulse response function can be written as:

$$\begin{pmatrix} \psi_{y_1}^{y_1}(n) \\ \vdots \\ \psi_{y_n}^{y_1}(n) \end{pmatrix} = \underbrace{\sigma_{(y_1,y_1)}^{-\frac{1}{2}}}_{normalization} * \underbrace{\Phi_n}_{\substack{MA\ coefficients \\ matrix}} * \overbrace{\Sigma_u}^{\substack{Var-covariance \\ matrix\ of\ residuals}} * \underbrace{\begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{pmatrix}}_{\substack{Selection \\ vector}} \qquad (2)$$

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[5] The spread between 3m Euribor and 3m Eonia swap is the EUR funding equivalent of the spread between 3m LIBOR and 3m USD OIS, for the USD funding. "Eonia swap" (the variable used in our analysis) is an overnight index swap (OIS) on Eonia, which is a weighted average of all overnight unsecured lending interbank transactions, executed by a panel of banks. The Bloomberg ticker of this instrument is "EUSWEC CMPN Curncy". Since our focus is centred on euro area banks and sovereigns this market indicator should better reflect interbank risk premium, (see e.g. De Socio (2011).

[6] As a robustness check, we have also estimated our analysis in a two-step setup: first regressing the CDS returns on the common factors and control variables and second estimating a simple VAR model between the residuals from the first step. There are no significant differences in our results.

[7] In the context of financial markets, it is difficult to assume a certain identification structure (like in the case of the monetary policy) and to use either Choleski decomposition or the non-factorized impulse responses.

[8] Following Lütkepohl (2007), we present in Appendix A2.B the steps towards a moving average (MA) representation of the VAR model.

where $\boldsymbol{\phi}_n$ represents the matrix of moving average coefficients at lag n, which can be calculated in a recursive way from the VARX coefficient matrices (see Appendix A2.B); $\boldsymbol{\Sigma_u}$ denotes the variance-covariance matrix of the residuals; $\boldsymbol{\sigma}_{(y_1,y_1)}^{-\frac{1}{2}}$ is the standard deviation related to the error of shock variable. The selection vector chooses the first variable as the impulse variable. The interpretation of the impulse responses is analogue to the interpretation of *semi-elasticities*. For instance, an impulse or a shock in variable ES (in period t=0) means a unit increase in the structural error that leads to an increase of the respective CDS series by $\boldsymbol{\sigma}_{(y_1,y_1)}^{\frac{1}{2}}$ per cent (see e.g. Alter and Schüler (2012)).

The quantitative measure of potential spillover effects is computed as the average cumulated response of a variable in the following week, as percentage of the initial shock to the impulse variable (i.e. we normalise by the standard deviation of the impulse variable at day t=0).[9] The average cumulated response of variable y_2 to a shock in the impulse variable y_1 is computed as the mean of the cumulated responses at day t=0, day t=1 and day t=5:

$$IR_{y_1 \to y_2} = \frac{\psi_{y_1}^{y_2}(0) + \sum_{h=0}^{1} \psi_{y_1}^{y_2}(h) + \sum_{h=0}^{5} \psi_{y_1}^{y_2}(h)}{3} \qquad (3)$$

The weighted average of responses from these three days (over the following week) does incorporate *feedback effects* from the two lags of the impulse variable and by including the temporary or persistent *long-run effect* of a potential shock.

3.3 THE SPILLOVER MATRIX

Similar as in the framework described by Diebold and Yilmaz (2011) for the forecast error variance decomposition, we derive the impulse responses (IRs) from each variable to all other variables in the system and define *the spillover matrix*. Notice that substituting the forecast error variance decomposition with the impulse responses from the GIRF framework would not change the basic economic implications of the results. In other words, we construct a matrix of potential spillover effects from each variable in the system (i.e. each variable is ordered first). These possible spillover effects answer the question "How would variable y_2 (column variable) evolve in the following week if variable y_1 increases by one standard deviation?" On each line

[9] By using this normalisation, changes in volatility have no impact on our potential contagion measures and we can compare our results across variables and across time.

of this matrix we write the responses of the other variables from a shock in the variable on the main diagonal (values on the main diagonal are set to zero).[10]

Table 1: The Spillover Matrix

Response \ Shock	y_1	y_2	..	y_n	To Others
y_1	$-$	$IR_{y_1 \to y_2}$	..	$IR_{y_1 \to y_n}$	$\sum_{j=1}^{N} IR_{y_1 \to y_j}, \quad j \neq 1$
y_2	$IR_{y_2 \to y_1}$	$-$	..	$IR_{y_2 \to y_n}$	$\sum_{j=1}^{N} IR_{y_2 \to y_j}, \quad j \neq 2$
⋮	⋮	⋮	⋱	⋮	⋮
y_n	$IR_{y_n \to y_1}$	$IR_{y_n \to y_2}$	..	$-$	$\sum_{j=1}^{N} IR_{y_n \to y_j}, \quad j \neq n$
From Others	$\sum_{j=2}^{N} IR_{y_j \to y_1}$	$\sum_{j=1, j \neq 2}^{N} IR_{y_j \to y_2}$	..	$\sum_{j=1}^{N-1} IR_{y_j \to y_n}$	$\boldsymbol{CI = \frac{100}{N(N-1)} \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} IR_{y_i \to y_j}}$

Note: Row variables are the origin of the unexpected shock. Column variables are the respondents or spillover receivers. CI represents the contagion index, calculated as the average response in the spillover matrix.

The potential spillover effects are aggregated on each line and column and represent the total OUT and the total IN as potential contributions to contagion from and to each variable.

Furthermore, based on the spillover matrix, we define several measures that allow for inference of the systemic contribution of each variable or the total spillover in the system.

Let us first define the *individual OUT spillover effects* as the average sum of the impulse responses to others:

$$SE_{OUT, y_i \to *} = \sum_{\substack{j=1 \\ j \neq i}}^{N} IR_{y_i \to y_j} \qquad (4)$$

Second we define the *individual spillover IN effects* as the average sum of the impulse responses from others:

$$SE_{IN, * \to y_i} = \sum_{\substack{j=1 \\ j \neq i}}^{N} IR_{y_j \to y_i} \qquad (5)$$

Similar to net exports from the international trade, we define the *bilateral net spillover effect* as the difference between the impulse responses sent and received from/to another variable:

$$SE_{NET, y_i \to y_j} = IR_{y_i \to y_j} - IR_{y_j \to y_i} \qquad (6)$$

[10] We will not take into account the main diagonal values in computing the average potential spillover (i.e. the Contagion Index and its components).

The net measure in eq. (6) enables us to distinguish between pure covariance spillovers and feedback effects. The net spillover effects represent the amplification contribution of the first two lags of the impulse variable to the response variable. In this way, we are able to capture the sequential feature associated with systemic events (see for example de Bandt *et al.* (2009)). Furthermore, this is also in line with the concept of systemic risk defined as the negative externality that one (financial) institution poses to the rest of the (financial) system. The net spillover effects help us to construct our new measure of systemic contribution, as defined below in eq (9).

Bilateral net spillover effects for a pair of sovereigns can either be negative or positive and have the property that $SE_{NET,y_i \to y_j} + SE_{NET,y_j \to y_i} = 0$. Using $SE_{NET,y_i \to y_j}$ for each variable, we can set up a *net spillover matrix* that has the property of being *anti-symmetric*. This matrix shows *the net potential spillover* from $y_i \to y_j$ and vice-versa.

The *total bilateral net spillover effects* for variable y_i is the sum of its bilateral net effects:

$$TSE_{NET,y_\mathrm{i}} = \sum_{\substack{j=1 \\ j \neq i}}^{N} (IR_{y_i \to y_j} - IR_{y_j \to y_i}) = \sum_{j \neq i}^{N} SE_{NET,y_i \to y_j} \qquad (7)$$

The sum of all TSE_{NET,y_i} in the system is equal to zero. In order to get the systemic contribution of each variable, we define the *total net positive (TNP) spillover* of the system. TNP spillover is the sum across all variables of their total net spillover effects (eq (7)) if TSE_{NET,y_i} is positive:

$$TNP_{Spillover} = \sum_{\substack{i=1, \\ TSE_{NET,y_\mathrm{i}}>0}}^{N} TSE_{NET,y_\mathrm{i}} \qquad (8)$$

Now we can introduce *the systemic contribution* of each variable y_i in our system as the ratio between the individual total net contagion effects and the total net positive spillover of the system.

$$SC_{y_i} = \frac{TSE_{NET,y_\mathrm{i}}}{TNP_{Spillover}} \qquad (9)$$

3.4 CONTAGION INDICES

Next, we introduce *the contagion index* of the system (here for sovereigns and banks) as:

$$CI = \frac{100}{N(N-1)} \sum_{i=1}^{N} \sum_{j \neq i} IR_{y_\mathrm{i} \to y_\mathrm{j}} \qquad (10)$$

If we restrict the cumulative impulse responses in the interval [0, 1], our index will be bound between 0 and 100.[11] It shows the average potential spillover effects in our system, based on the previous 80-days interdependencies. When we relate to the total Contagion Index, we use the term "Contagion Index of sovereigns and banks" (i.e. CI sovs and banks). This index can be further decomposed into four main averaged components: *CI-sovs* (for the spillover among sovereigns), *CI-banks* (for the spillover among banks), *CI from banks to sovs* (for the spillover from banks to sovereigns) and *CI from sovs to banks* (for the spillover from sovereigns to banks). Let *M* be the number of sovereigns and *P* the number of banks (where $M+P=N$, the total number of endogenous variables), and sovereigns ordered first, then:

$$CI_{sovs} \equiv \frac{100}{M(M-1)} \sum_{i=1}^{M} \sum_{j\neq i}^{M} IR_{y_i \to y_j} \; ; \qquad (11)$$

$$CI_{bks} \equiv \frac{100}{P(P-1)} \sum_{i=M+1}^{N} \sum_{j\neq i}^{N} IR_{y_i \to y_j} \; ; \qquad (12)$$

$$CI_{sovs \to bks} \equiv \frac{100}{M*P} \sum_{i=1}^{M} \sum_{j=M+1}^{N} IR_{y_i \to y_j} \; ; \qquad (13)$$

$$CI_{bks \to sovs} \equiv \frac{100}{P*M} \sum_{i=M+1}^{N} \sum_{j=1}^{M} IR_{y_i \to y_j} \, . \qquad (14)$$

Finally, *CI of sovereigns and banks* can be re-written as the weighted average of its four components (see eq (19) in Appendix A3).

[11] We relax this condition below in section 5.3 and discuss some implications. Results remain qualitatively very similar.

4 RESULTS

This section presents our main empirical results along two dimensions: dealing with simultaneity i.e. interaction between sectors and their entities; and addressing dynamics of time-varying parameters of the underlying rolling window models. First we show the spillover index "in action" by looking for example at the effects from Spanish sovereign CDS to all other variables in the system at two single points in time, i.e. focusing on a single sample window as a "snapshot". Next we extend the static dimension to a dynamic analysis. We present empirical results for the contagion index for each point in time over the entire sample. Moreover we discuss systemic contributions of individual sovereign CDS to the total contagion index and we demonstrate how the indicators are evolving before and after key market and policy events. Finally we suggest a method to identify and determine thresholds for "excessive spillover" i.e. the threshold beyond which we identify acute risks of contagion.

4.1 A STATIC PERSPECTIVE

We start our empirical analysis with the framework introduced in the previous section, by estimating spillover effects for individual points in time.

4.1.1 AN ILLUSTRATIVE EXAMPLE: THE CASE OF SPANISH SOVEREIGN CDS

Focusing on Spanish sovereign CDS as impulse variable we present the results of isolated sample windows. The responses of other variables are compared over two static periods: at 13 January 2012 (based on the estimation period end of July 2011 - January 2012 i.e. 2011H2) and 15 June 2012 (based on the estimation period January 2012 until beginning of June 2012 i.e. 2012H1).

The quantitative measure of a potential spillover effect is the cumulated response of a variable as percentage of the shock to the impulse variable. Two aspects are analysed: the impact of a shock in Spanish sovereign CDS on other sovereign CDS spreads; and the impact on CDS of bank groups in various countries.

Figure 1 shows the potential cumulative impact on sovereign CDS spreads in response to a shock in Spanish CDS. The magnitude of spillover effects to Italian sovereign CDS decreased in the first half of 2012, from 83% to 68%. An unexpected shock of 100 bps to Spanish sovereign CDS would, therefore, translate into a 68 bps increase in Italian sovereign CDS over the following week (compared to nearly 83 bps in 2011H2). The potential spillover to other sovereign CDS has, however, increased dramatically during 2012H1. The biggest relative increase from 2011 to 2012 is the spillover to German CDS, which has grown by factor 22, from 2% to 44%. In absolute terms, the potential spillover is the highest in the case of French CDS (85%, up from 26%) and Austrian CDS (76%, up from 30%). Similar in the case of Italy, we notice that spillovers to Ireland and Greece have decreased. We therefore conclude that the potential impact on "Non-Core" countries decreased (with the exception of Portugal) at the expense of a higher potential impact on "Core" countries. Figure 2 shows the expected cumulated impact of a shock in other countries' CDS to Spanish sovereign CDS, again for both periods. As can be seen, the reverse spillover effects to Spanish sovereign CDS are different, in most cases (sometimes even qualitatively when comparing over the two periods, see e.g. Portugal). In other words, these results translate into a positive *net potential spillover* from Spanish sovereign CDS to the other sovereign CDS spreads, showing the increased *systemic relevance* of the Spanish CDS spread in 2012H1.

Figure 1: Potential impact of a Spanish CDS shock on other sovereign CDS changes

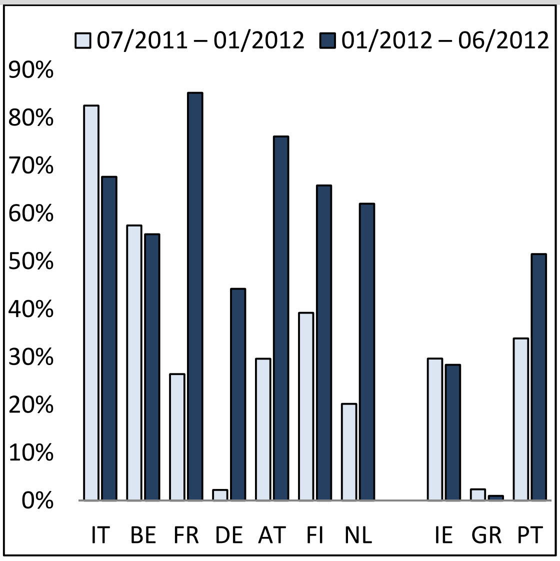
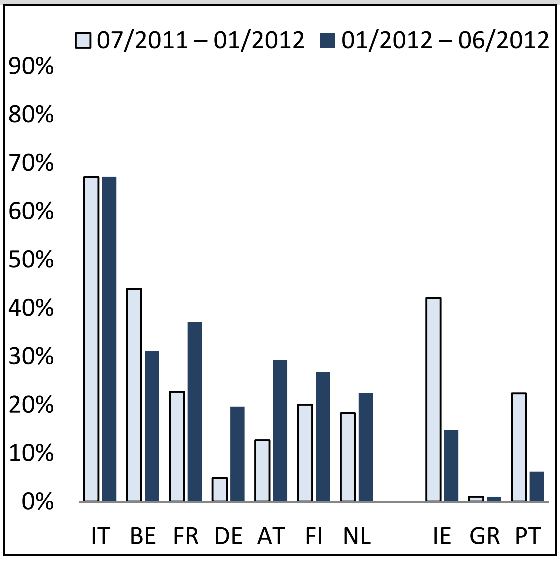


Figure 2: Potential impact on Spanish sovereign CDS from a shock in the other sovereign CDS



Note: The results can be read as follows: (left-panel) for example a 100 bps unexpected shock in the Spanish CDS would increase the French CDS by almost 30 bps (in the first period) and 85bps (in the second one); (right-panel) for example a 100 bps unexpected shock in the French CDS would increase the Spanish CDS by almost 20 bps (in the first period) and 40 bps (in the second one). Impact refers to the average cumulated impulse responses in the following week.

The potential spillover effects from Italian to Spanish CDS (see Figure 2) did not change and remained at around 67% in both periods. Hence, the results in Figure 2 can be interpreted as a successful robustness check for the validity of the economic interpretations of the estimated spillover measures. The potential impact of a shock in Irish, Greek or Portuguese sovereign CDS decreased in 2012H1 compared to 2011H2.

Turning to the potential spillover effects from Spanish sovereign CDS to bank CDSs, the development since 2011 is even more dramatic as can be seen in Figure 3. Here we split into two categories of Spanish banks by distinguishing the two large and complex banking groups from the others.[12] Apart from the Spanish banks, the impact of a shock to Spanish sovereign CDS is largest for Italian banks, which increased from 14% in 2011 to 48% over the second period. The impact on German bank CDS has increased by more than factor six, from 5% up to 34%. In the recent debt crisis a fundamental problem is the feedback loop between domestic banks and their sovereign. Our analysis shows strong evidence this mechanism. The potential spillover effects from a shock in the Spanish sovereign CDS to Spanish G1 banks have increased dramatically: 51% in 2012H1 compared to 17% in the 2011H2. Similarly, but slightly less, the impact of a shock to Spanish G2 banks has increased to 26%, compared to 11% in 2011. With regard to the robustness check, the same applies as with the effects of sovereigns on Spanish CDS. Results in Figure 4 show that the potential effects from individual bank CDSs on Spanish sovereign CDS are much less pronounced than vice versa, but they nevertheless increased as well in 2012H1 from close to zero (in 2011H2), in nearly all cases.

Figure 3: Potential impact of a shock in Spanish sovereign CDS on bank CDSs

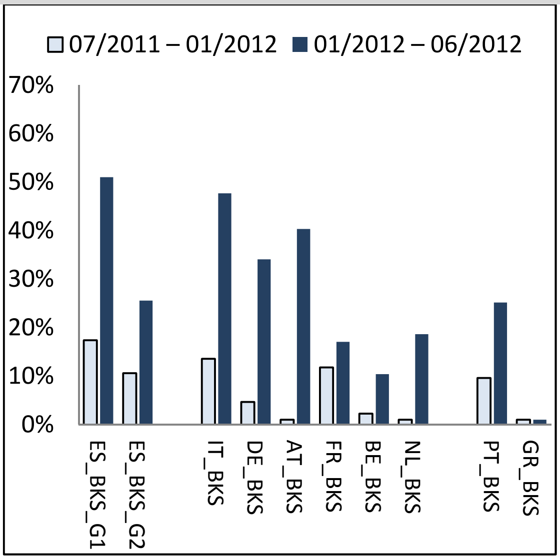
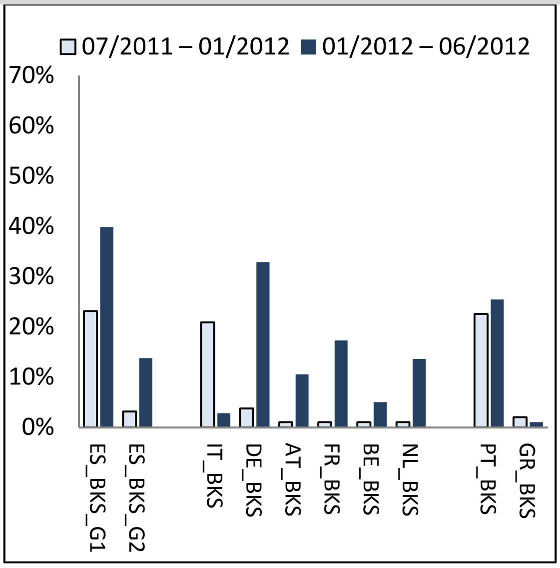


Figure 4: Potential impact of a shock from banks on Spanish sovereign CDS



Note: Potential impact refers to the average cumulated impulse responses in the following week.

[12] Group 1 (ES_bks_G1) consists of Banco Santander and BBVA, and the banks in Group 2 (ES_bks_G2) are Banco Pastor, Banco Popolar Español, Caja de Ahorros, and Banco Sabadell. See Appendix A1 for a complete list of the country-specific bank CDS groups used.

4.1.2 A SNAPSHOT OF SPILLOVER MATRICES- THE USE OF HEAT-MAPS

Table 2 and Table 3 present the entire picture on 21 June 2012, for all variables in the system.[13] In Table 2 shocks feed from row variables to column variables. Each row shows the spillover effects of an impulse to the variable in the first column. The responding variables are highlighted on the top row. In the last column (Sum OUT) we aggregate the total potential spillover sent ($SE_{OUT,y_i \to *}$), see eq (4) by each row variable and on the bottom row (Sum IN) we aggregate the total spillover received ($SE_{IN,* \to y_i}$), see eq (6) by each column variable.

The four quadrants represent potential spillover effects: among sovereigns (top-left), among banks (bottom-right), from sovereigns to banks (top-right) and from banks to sovereigns (bottom-left). Greece and Greek banks have almost no impact on the rest of the variables, while they receive substantial spillover.

Table 3 presents the net spillover effects for each pair of variables i.e. the difference between the spillovers sent and received by the row variable to the column variable. Looking at the net spillover matrix on 21 June 2012, Spain ranks first, based on the total net spillover TSE_{NET,y_i}, see eq. (7), (the sum of net spillover effects to all variables in the "Sum NET" column). Among banking groups, German banks (DE_bks, ranked second) have an important influence on the rest of the system, with a net spillover of 4.34. Although French banks (FR_bks) have a negative total net spillover and therefore being net receivers of potential spillovers, they intermediate the largest potential spillover flow (the sum of $SE_{OUT,y_i \to *}$ and $SE_{IN,* \to y_i}$ in Table 2), corresponding to eq. (4) and (5).

[13] In order to be consistent across all countries, Spanish banks are merged in a single group. A similar snapshot is available in Appendix A4 (Table A4.1 and Table A4.2) at the end of July 2011. A detailed description of the inference based on the two types of matrices and a comparison between the two periods is provided in subsection 5.3.3.

Table 2: The spillover matrix of EA sovereigns and banks (on 21 June 2012)

Impulse \ Response	AT	BE	FI	FR	GR	DE	IE	IT	NL	PT	ES	AT_bks	BE_bks	FR_bks	GR_bks	DE_bks	IT_bks	NL_bks	PT_bks	ES_bks	Sum OUT
AT	.	0.83	0.82	0.99	0.00	0.74	0.51	0.87	0.75	0.64	0.52	0.24	0.18	0.57	0.00	0.16	0.33	0.23	0.09	0.21	8.68
BE	0.74	.	0.81	0.85	0.30	0.80	0.26	0.79	0.90	0.09	0.37	0.23	0.04	0.62	0.80	0.32	0.44	0.31	0.30	0.55	9.52
FI	0.54	0.58	.	0.78	0.00	0.57	0.18	0.54	0.77	0.23	0.23	0.15	0.12	0.46	0.00	0.13	0.53	0.18	0.17	0.36	6.52
FR	0.71	0.58	0.55	.	0.03	0.69	0.09	0.58	0.39	0.50	0.33	0.10	0.00	0.32	0.00	0.22	0.16	0.19	0.03	0.10	5.57
GR	0.00	0.01	0.00	0.00	.	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.13
DE	0.45	0.52	0.65	0.79	0.45	.	0.02	0.44	0.45	0.21	0.08	0.00	0.00	0.31	0.20	0.23	0.25	0.08	0.05	0.00	5.18
IE	0.51	0.54	0.19	0.32	0.40	0.00	.	0.33	0.00	1.00	0.20	0.33	0.43	0.76	0.68	0.30	0.47	0.12	0.73	0.44	7.75
IT	0.87	0.92	0.78	0.85	0.41	0.76	0.36	.	0.87	0.62	0.68	0.38	0.07	0.71	0.00	0.41	0.46	0.31	0.32	0.32	10.10
NL	0.20	0.23	0.35	0.11	0.00	0.15	0.00	0.21	.	0.00	0.16	0.14	0.00	0.30	0.43	0.13	0.28	0.36	0.07	0.31	3.43
PT	0.21	0.14	0.15	0.31	0.17	0.21	0.54	0.20	0.00	.	0.04	0.15	0.17	0.52	0.37	0.24	0.22	0.08	0.36	0.10	4.20
ES	0.68	0.67	0.40	0.54	0.00	0.20	0.05	0.87	1.00	0.16	.	0.44	0.00	0.75	0.00	0.60	0.54	0.84	0.12	0.64	8.50
AT_bks	0.19	0.17	0.00	0.02	0.00	0.00	0.54	0.27	0.13	0.60	0.29	.	0.09	0.28	0.77	0.16	0.10	0.15	0.32	0.06	4.16
BE_bks	0.14	0.00	0.18	0.11	0.18	0.06	0.35	0.07	0.00	0.43	0.02	0.09	.	0.26	0.33	0.10	0.10	0.08	0.17	0.00	2.66
FR_bks	0.37	0.37	0.37	0.36	0.16	0.29	0.54	0.34	0.34	0.91	0.13	0.35	0.15	.	0.60	0.60	0.68	0.65	0.47	0.35	8.05
GR_bks	0.00	0.01	0.01	0.00	0.34	0.02	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	.	0.00	0.00	0.05	0.00	0.07	0.59
DE_bks	0.36	0.39	0.22	0.50	0.02	0.44	0.72	0.49	0.37	1.00	0.40	0.57	0.13	1.00	0.56	.	0.88	0.70	0.77	0.32	9.83
IT_bks	0.21	0.27	0.44	0.28	0.00	0.26	0.71	0.30	0.27	0.94	0.16	0.39	0.23	1.00	0.56	0.74	.	0.67	0.76	0.42	8.62
NL_bks	0.19	0.12	0.23	0.19	0.00	0.06	0.18	0.11	0.29	0.61	0.15	0.38	0.16	0.91	1.00	0.54	0.63	.	0.22	0.46	6.43
PT_bks	0.00	0.27	0.09	0.00	0.76	0.03	0.68	0.16	0.06	0.70	0.04	0.28	0.05	0.56	0.67	0.45	0.55	0.06	.	0.35	5.76
ES_bks	0.15	0.33	0.28	0.10	0.00	0.01	0.26	0.08	0.73	0.33	0.07	0.18	0.02	0.40	1.00	0.16	0.33	0.31	0.28	.	5.01
Sum IN	6.52	6.97	6.53	7.08	3.23	5.28	6.00	6.65	7.41	8.99	3.87	4.40	1.87	9.72	8.01	5.50	6.95	5.38	5.27	5.06	**120.68**

Note: Variables in the first column are the impulse origin. Variables on the top row are the respondents to the shock. Values in the matrix represent the average cumulated spillover effect over the first 5 days. The intensity of a shock on a respondent is marked by different levels of colour (*white* means no impact and intense *red* means very strong impact). The cumulative impact is bound between 0 and 1. A value of 0.5 means that the response variable would be impacted in the same direction with an intensity of 50% the initial unexpected shock in the impulse variable. If the initial shock has a magnitude of 10 bps then the response variable is expected to increase by 5 bps in the following week. In the last column we have the aggregated impact sent (*Sum OUT*) by each row variable and on the bottom row the aggregated spillover received (*Sum IN*) by each column variable. The bottom-right cell (in bold) shows *total spillover* in the system (by dividing this value to the total number of non-diagonal cells i.e. 20x19 we obtain *the contagion index* of EA sovereigns and banks, as introduced in eq. (10)). The results for GR and GR_bks should be interpreted with caution since the CDS spreads reached implausible traded quotes during this period.

Table 3: Net Spillover matrix (on 21 June 2012)

Net Matrix	AT	BE	FI	FR	GR	DE	IE	IT	NL	PT	ES	AT_bks	BE_bks	FR_bks	GR_bks	DE_bks	IT_bks	NL_bks	PT_bks	ES_bks	Sum NET
AT	0.00	0.10	0.28	0.27	0.00	0.29	0.00	-0.01	0.55	0.43	-0.16	0.04	0.04	0.19	0.00	-0.20	0.12	0.04	0.09	0.06	**2.16**
BE	-0.10	0.00	0.23	0.27	0.29	0.28	-0.29	-0.14	0.68	-0.05	-0.30	0.06	0.04	0.25	0.79	-0.07	0.17	0.19	0.03	0.22	**2.55**
FI	-0.28	-0.23	0.00	0.22	0.00	-0.08	-0.01	-0.24	0.42	0.08	-0.17	0.15	-0.06	0.09	-0.01	-0.09	0.08	-0.06	0.08	0.07	**-0.01**
FR	-0.27	-0.27	-0.22	0.00	0.03	-0.10	-0.23	-0.27	0.29	0.20	-0.22	0.08	-0.11	-0.04	0.00	-0.28	-0.12	0.00	0.03	0.00	**-1.52**
GR	0.00	-0.29	0.00	-0.03	0.00	-0.44	-0.39	-0.39	0.00	-0.17	0.00	0.00	-0.16	-0.16	-0.31	-0.01	0.00	0.00	-0.75	0.00	**-3.09**
DE	-0.29	-0.28	0.08	0.10	0.44	0.00	0.02	-0.31	0.29	0.00	-0.12	0.00	-0.06	0.03	0.18	-0.21	-0.01	0.03	0.02	-0.01	**-0.10**
IE	0.00	0.29	0.01	0.23	0.39	-0.02	0.00	-0.04	0.00	0.45	0.15	-0.21	0.08	0.22	0.68	-0.42	-0.24	-0.05	0.05	0.18	**1.75**
IT	0.01	0.14	0.24	0.27	0.39	0.31	0.04	0.00	0.66	0.42	-0.18	0.11	0.00	0.37	0.00	-0.08	0.17	0.20	0.17	0.23	**3.45**
NL	-0.55	-0.68	-0.42	-0.29	0.00	-0.29	0.00	-0.66	0.00	0.00	-0.84	0.01	0.00	-0.05	0.35	-0.24	0.01	0.07	0.02	-0.42	**-3.99**
PT	-0.43	0.05	-0.08	-0.20	0.17	0.00	-0.45	-0.42	0.00	0.00	-0.12	-0.46	-0.25	-0.39	0.37	-0.76	-0.72	-0.53	-0.34	-0.23	**-4.79**
ES	0.16	0.30	0.17	0.22	0.00	0.12	-0.15	0.18	0.84	0.12	0.00	0.15	-0.02	0.62	0.00	0.21	0.38	0.69	0.07	0.57	4.63
AT_bks	-0.04	-0.06	-0.15	-0.08	0.00	0.00	0.21	-0.11	-0.01	0.46	-0.15	0.00	0.00	-0.07	0.77	-0.41	-0.29	-0.23	0.04	-0.12	-0.24
BE_bks	-0.04	-0.04	0.06	0.11	0.16	0.06	-0.08	0.00	0.00	0.25	0.02	0.00	0.00	0.11	0.33	-0.03	-0.14	-0.08	0.12	-0.02	0.79
FR_bks	-0.19	-0.25	-0.09	0.04	0.16	-0.03	-0.22	-0.37	0.05	0.39	-0.62	0.07	-0.11	0.00	0.60	-0.40	-0.31	-0.25	-0.10	-0.05	-1.68
GR_bks	0.00	-0.79	0.01	0.00	0.31	-0.18	-0.68	0.00	-0.35	-0.37	0.00	-0.77	-0.33	-0.60	0.00	-0.56	-0.56	-0.95	-0.66	-0.93	-7.42
DE_bks	0.20	0.07	0.09	0.28	0.01	0.21	0.42	0.08	0.24	0.76	-0.21	0.41	0.03	0.40	0.56	0.00	0.14	0.16	0.32	0.17	4.34
IT_bks	-0.12	-0.17	-0.08	0.12	0.00	0.01	0.24	-0.17	-0.01	0.72	-0.38	0.29	0.14	0.31	0.56	-0.14	0.00	0.05	0.21	0.09	1.67
NL_bks	-0.04	-0.19	0.06	0.00	0.00	-0.03	0.05	-0.20	-0.07	0.53	-0.69	0.23	0.08	0.25	0.95	-0.16	-0.05	0.00	0.16	0.15	1.05
PT_bks	-0.09	-0.03	-0.08	-0.03	0.75	-0.02	-0.05	-0.17	-0.02	0.34	-0.07	-0.04	-0.12	0.10	0.66	-0.32	-0.21	-0.16	0.00	0.07	0.49
ES_bks	-0.06	-0.22	-0.07	0.00	0.00	0.01	-0.18	-0.23	0.42	0.23	-0.57	0.12	0.02	0.05	0.93	-0.17	-0.09	-0.15	-0.07	0.00	-0.05

Note: If the value in the cell is negative (blue horizontal bar) it means that the row variable is the net receiver and the column variable is the net sender. If the value is positive (red horizontal bar) the column variable is net receiver and the row variable is net sender. The last column shows the sum of net spillover effects of the row variable. In case the NET sum spillover is positive (bold values) then the variable is a *net sender* of the system.

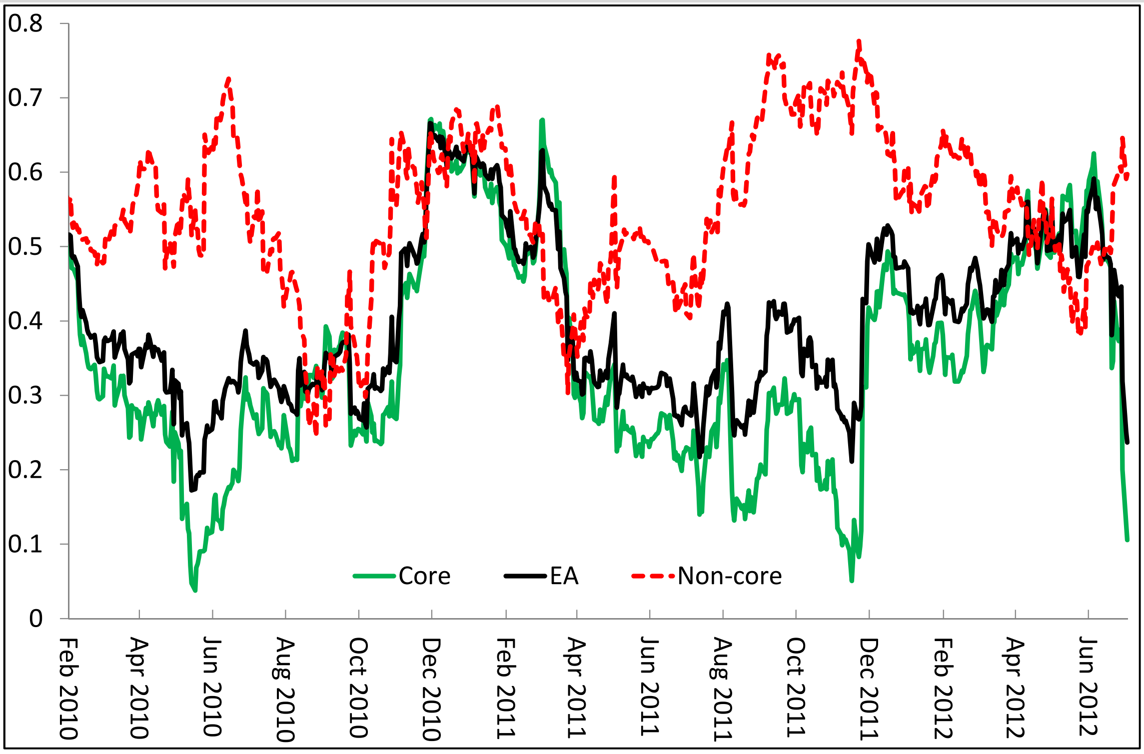
4.2 THE DYNAMICS OF POTENTIAL SPILLOVER EFFECTS

In this sub-section we extend the snapshot perspective from Section 4.1 to a dynamic analysis. We analyse the responses from a shock in Spanish sovereign CDS based on a 80-day rolling-window. First, we start with a model that consists only of sovereign CDS changes. Second, we estimate a model with both sovereigns and banks, similar to eq *(15)* presented in Appendix A2.

4.2.1 TIME-VARYING IMPACT ON EURO AREA SOVEREIGNS – THE CASE OF SPAIN

Using a 80-day rolling window, we estimate the VARX coefficients and the residuals recursively. We further obtain the dynamics of the cumulated impact on euro-area sovereigns. In *Figure 5* we present our results of the impulse response analysis from a shock in ES sovereign CDS. We aggregate the impact on three different groups: "Non-core" (GR, IE, IT, and PT), Euro-area (AT, BE, FI, FR, DE, GR, IE, IT, NL and PT) and "Core" countries (AT, BE, FI, FR, DE, and NL). Each group index is a GDP weighted average of the individual responses. Static analysis has already signalled an increase in the interdependence between Spain and "Core" countries and an untightening the relationships within the "Non-core" countries in 2012H1. This trend reverses at the end of June 2012, after the G20 meeting and EU summit.

Figure 5: The dynamics of the cumulated potential impact on CDS spreads of "Non-core" countries group (red), euro-area (black) and "Core" countries group (green) from a shock in the Spanish sovereign CDS



Note*:* "Core" refers to the average impact on AT, BE, FI, FR, DE, and NL weighted by GDP; "EA**"** refers to the average impact on the entire sample of Eurozone countries: AT, BE, FI, FR, GR, DE, IE, IT, NL, and PT weighted by GDP; "Non-core" refers to the average impact on GR, IE, IT and PT weighted by GDP.

There is clear evidence that the "Non-core" countries are more sensitive to a shock in the Spanish CDS than "Core" countries. An interesting result of our analysis is that during times of "distress" the gap between the two groups narrows while during tranquil episodes the gap widens. The amplification of potential contagion can be seen as a result of increased interdependences between sovereign CDS spreads.

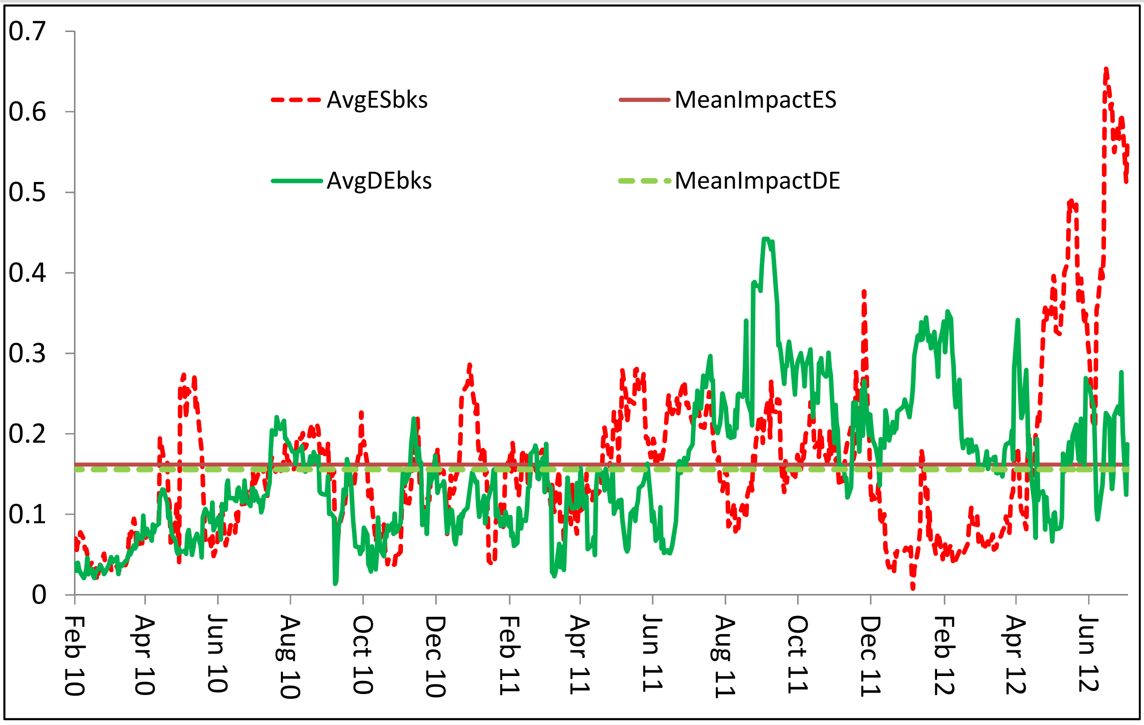
4.2.2 TIME-VARYING IMPACT ON EUROPEAN BANKS

The average time-varying potential spillover to European banks is depicted in Figure 6. There we show the differences between the effects from a shock in Spanish sovereign CDS and from a shock in German sovereign CDS.[14] During the entire data sample the mean impact from DE is slightly below the mean impact from ES (15.6% compared with 16.7%).

[14] We merge Spanish banks (ES_bks_G1 and ES_bks_G2) in this analysis in order not to have biased results towards Spanish banks i.e. to have a uniform framework across all countries.

The average potential spillover effect on banks is the mean of a shock from the respective country (here e.g. ES and DE) at the end of each rolling window.[15] As can be seen in Figure 6, at the beginning of April 2012, the average impact from a shock in Spanish sovereign CDS exceeds the mean impact (over the entire period) and exceeds the previous peak that was reached at the end of November 2011. By mid-May 2012 the average potential spillover effects from a Spanish shock reaches the level of 65%. In other words, the entire European banking system reacted strongly to the Spanish sovereign debt crisis during the April-June 2012 period. After the G20 and EU summits, the potential contagion pressure to the European banking system mitigates. This analysis highlights the advantage of monitoring the time-varying potential impact from each variable of the system.

Figure 6: Average cumulated impact on European banks from a shock in the Spanish sovereign CDS ("AvgESbks", red) and from a shock in the German government CDS ("AvgDEbks", green)



Note: "AvgESbks" and "AvgDEbks" refer to the average potential impact on European banks from a shock in the Spanish sovereign CDS, and German sovereign CDS respectively; "MeanImpactES" and "MeanImpactDE" are the mean impact over the entire sample from a shock in Spanish sovereign CDS, and German sovereign CDS respectively.

[15] This can be refined with weights from the BIS foreign claims exposures as in eq (25) of Appendix A3.

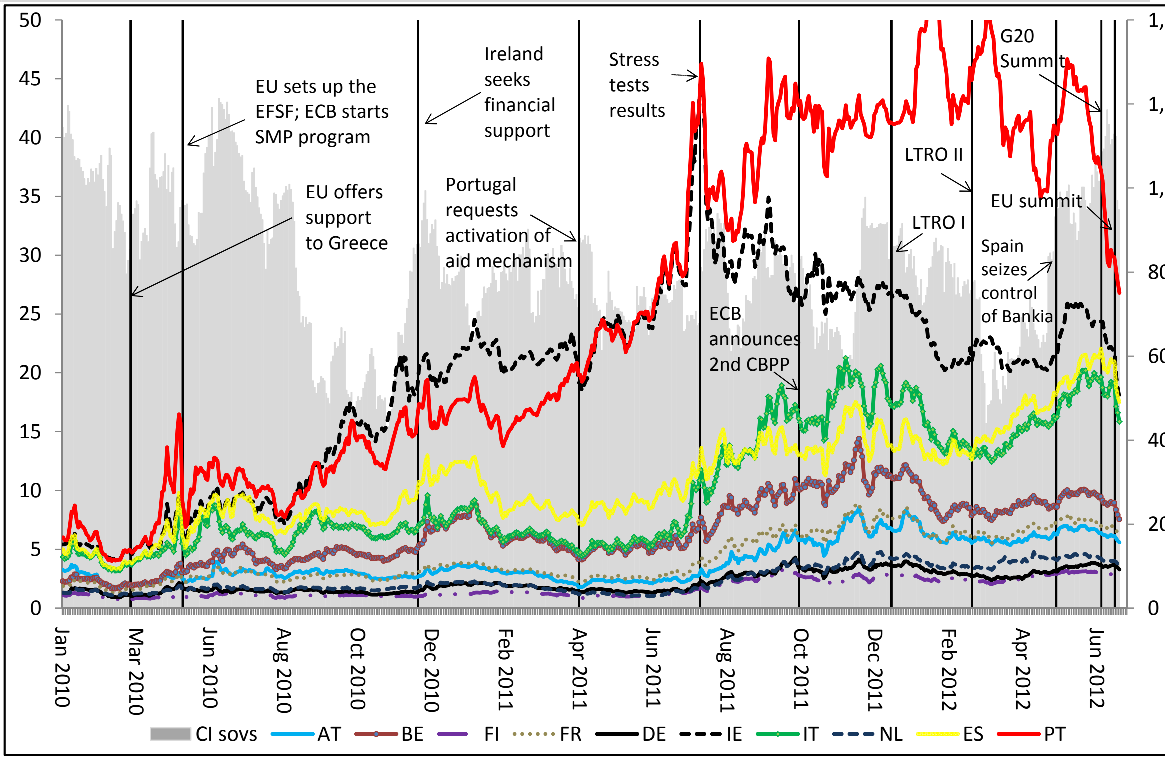
4.3 THE EURO AREA CONTAGION INDEX

4.3.1 THE EURO AREA CONTAGION INDEX OF SOVEREIGNS

In this sub-section we analyse the dynamics of the Contagion Index for all sovereigns (CI-sovs) as introduced in eq (11) and shown in *Figure 7*. We highlight several important events in the Eurozone that preceded changes in the CI-sovs.[16] We also present the sovereign CDS series in levels from all analysed countries (right axis, with the exception of the Greek sovereign CDS).

During the analysed period, CI-sovs takes values between a minimum value of 15.34 (on 28 October 2010) and a maximum level of 43.33 (on 09 June 2010). As can be seen in Figure 7, several news/events (e.g. policy related actions) had a decreasing impact on the index. This aspect will be developed in detail in *sub-section 4.6*. During the period related to the Spanish banking/sovereign debt crisis the sovereign contagion index reached a peak on 22 June 2012 (42.36**)** very close to the 2010 peak. After the G20 and EU summit, the index drops to around 34 (on 3 July 2012).

Figure 7: Sovereign CDS series (right axis; in basis points) and the EA Contagion Index (only for sovereigns; left axis; the purple-grey area)



Note*:* "CI sovs" (grey shaded area) is the component of the Contagion Index for sovereigns, as introduced in eq (11). It takes values between 0 and 100. It is calculated as the average potential spillover effect from each sovereign to the others. GR CDS exceeds the scale of the other sovereign CDSs and could not be plotted. The list of events marked by vertical lines is presented in Appendix, Table A1.4.

[16] The description of selected events and the exact dates are presented in Table A1.4 (in the Appendix).

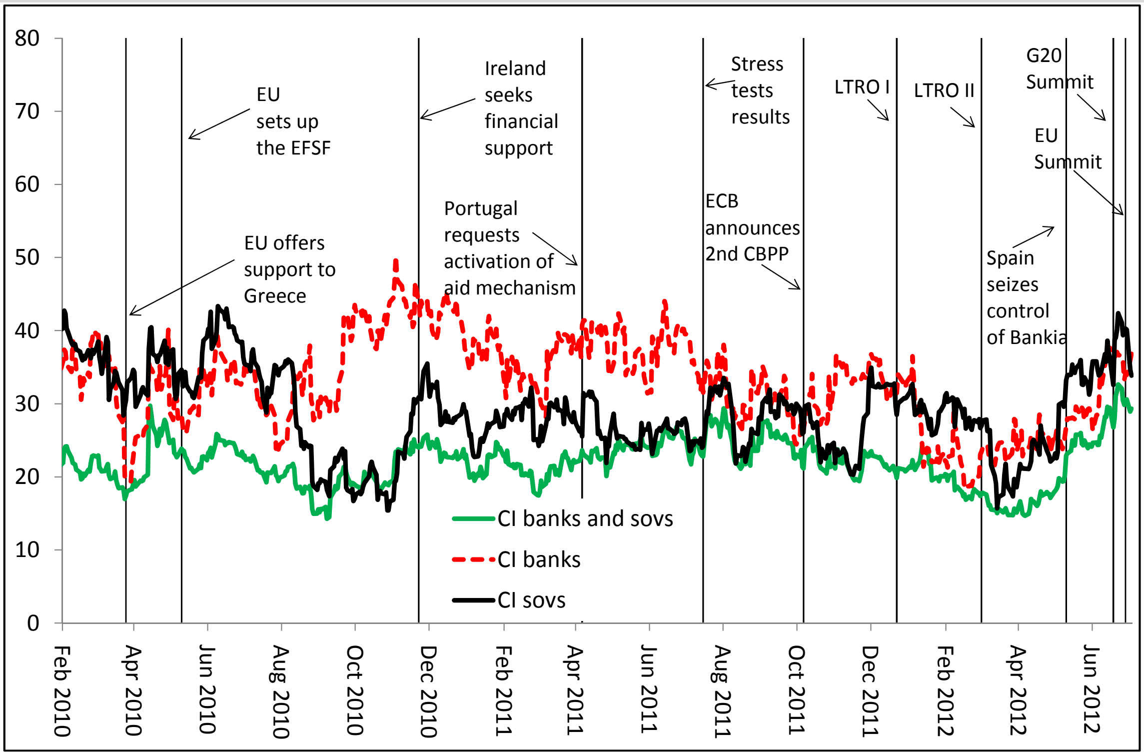
4.3.2 THE EURO-AREA CONTAGION INDEX OF SOVEREIGNS AND BANKS

In this sub-section, we focus on the results from our joint analysis of banks and sovereigns. To exemplify our results we provide the contagion matrices (both in absolute and in net terms) for some particular dates. As previously mentioned, in this analysis, the two Spanish banking groups (ES_bks_G1 and ES_bks_G2) are merged into a single group (ES_bks) in order to be consistent across all countries.[17]

In the sample period under scrutiny, the Contagion Index for banks (CI-banks) takes values between a minimum level of 18.4 (reached on 16/02/2012, between the two LTROs) and a maximum level of 50.2 (on 3 Nov. 2010 around time when Ireland has seek a bailout). At the beginning and towards the end of our sample, CI-banks and CI-sovs are characterized by a tighter co-movement. During most of that period, the average potential spillovers among banks exceed those between sovereigns. This characteristic is reversed in the first half of 2010 and in 2012. The spillover index for the entire system (both banks and sovereigns) has a slight upward trend. We conclude in the following section that this provides evidence for an increasing interconnectedness between banks and sovereigns, i.e. a tightening of the nexus between these two sectors.

[17] Similar, the new single group of Spanish banks (ES_bks) is weighted by banks' total assets. See Table A2.

Figure 8: EA Contagion Indices: only sovereigns (CI-sovs; black), only banks (CI-banks; red) and the entire system (the average potential spillover effect from the Contagion matrix; CI banks and sovs; green)

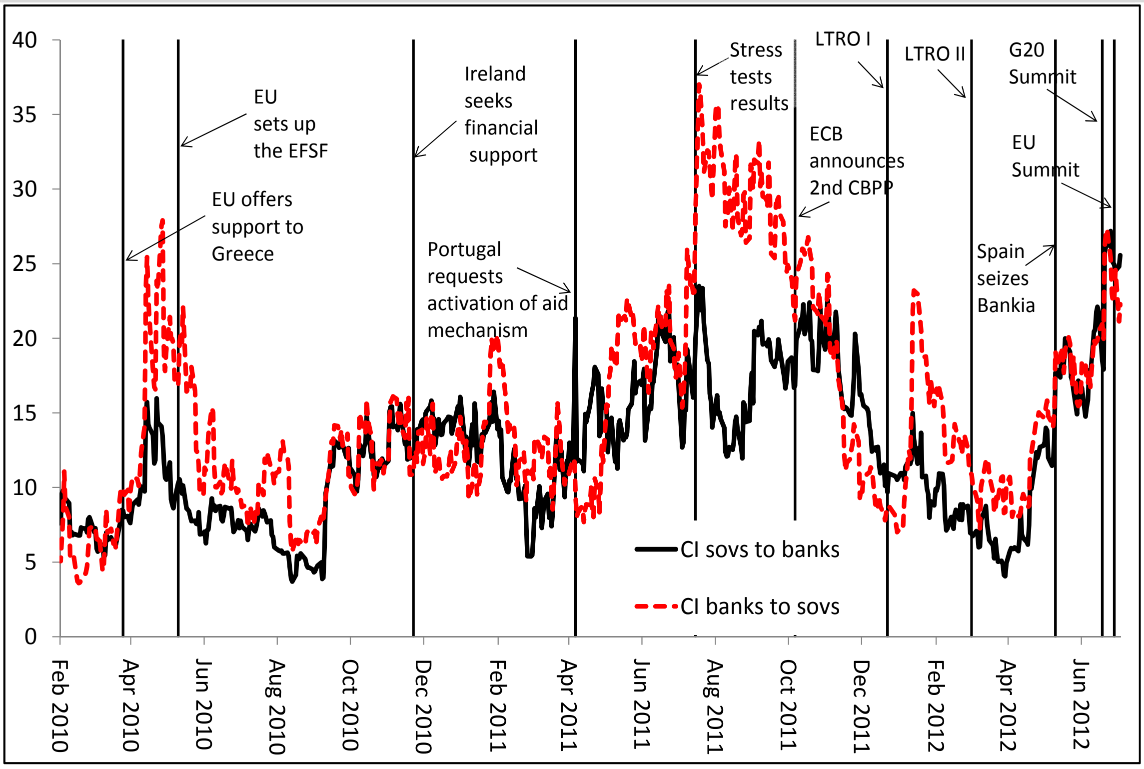


Note: "CI banks and sovs", as introduced in eq (10), is not the average of "CI-banks" and "CI-sovs". It summarizes the information from all four sub-components i.e. the entire system of banks and sovereigns, including the potential spillover effects from banks to sovereigns and vice-versa.

4.3.3 THE FEEDBACK LOOP BETWEEN SOVEREIGNS AND BANKS

We now turn to the indices related to spillover effects on banks from a shock in sovereign CDSs and vice-versa, see Figure 9 and eq (13) and (14). These two indices capture the average interdependence between the sovereign and the banking sector. After the collapse of Lehman Brothers in 2008, governments in many countries have contributed to bailing out financial institutions. This has implied at least a partial credit risk transfer from banks to sovereigns. Over the last two years, both indices increased more than twice their initial values in February 2010. At the beginning of the sample, the contagion index from banks to sovereigns takes a value of around eight. It reaches the peak level of 37, after the publication of the stress test results for the European banking industry. This period reflects also a widening of the gap between the two indices. On the other side, the contagion index from sovereigns to banks takes a value of around five at the beginning, and peaks during the Spanish sovereign debt crisis in June 2012, at a value of 26.9, more than five times higher than at the beginning of the sample.

Figure 9: Average potential spillover from banks to sovereigns (red) and from sovereigns to banks (black)



Note: "CI banks to sovs" refers to the average spillover effects sent by banks to sovereigns as introduced in eq (14). "CI sovs to banks" refers to the average spillover effects sent by sovereigns to banks as introduced in eq (13).

4.4 THE SPILLOVER AND NET SPILLOVER MATRICES

In this sub-section, we present both spillover and net spillover matrices of sovereigns and banks together with several measures of systemic relevance of our variables in the system derived from these matrices. For illustration we present two snapshots: first on 18 July 2011 (after bank stress tests results are published) and second on 21 June 2012 (after the G20 summit). At each point in time, both spillover matrices are based as before on an information set of past 80 days.

Table A4.1 and Table A4.2 (in Appendix A4) show the spillover and the net spillover matrices on 18 July 2011. The four quadrants reflect the flow of different components of the index: interactions between sovereigns (top-left), spillover effects from sovereigns to banks (top-right), interactions between banks (bottom-right) and spillover effects from banks to sovereigns. The overall picture shows that stress in the banking sector impacts severely on euro-area sovereigns. The information related to the sent and received spillover effects together with the total flow is summarized in Table 4.

Table 2 and Table 3 (presented in sub-section 4.1) present the contagion and the net spillover matrices on 21 June 2012. Compared with the two matrices from July 2011, this period is characterised by an overall elevated spillover level in all four quadrants. Both sovereigns and banks strongly impact on each other. Focusing on the net spillover matrix, we can identify the main drivers of potential contagion in our system. This information is presented in Tables 4 and 5.

Table 4: Ranking of NET senders and receivers of spillover effects on the 18 July 2011

Rank	Variable		Sum NET	Sum OUT	Sum IN	Total FLOW
1	DE_bks	NET SENDERS	4.75	10.30	5.55	**15.85**
2	IT_bks		3.29	8.12	4.83	12.95
3	AT_bks		3.09	5.79	2.71	8.50
4	AT		1.51	8.95	7.45	**16.40**
5	BE_bks		1.01	5.16	4.15	9.32
6	NL_bks		0.90	4.40	3.50	7.90
7	PT_bks		0.83	8.02	7.19	**15.21**
8	ES_bks		0.41	7.32	6.91	**14.22**
9	PT		0.23	3.70	3.47	7.17
10	DE		0.10	5.01	4.91	9.92
11	BE	NET RECEIVERS	-0.38	4.64	5.01	9.65
12	NL		-0.61	4.60	5.21	9.81
13	FR		-0.69	6.71	7.40	**14.11**
14	FR_bks		-0.74	6.15	6.89	13.04
15	FI		-0.91	1.53	2.44	3.97
16	IE		-0.95	4.68	5.63	10.30
17	GR_bks		-2.01	0.82	2.82	3.64
18	ES		-2.33	5.04	7.37	12.41
19	IT		-2.94	3.73	6.67	10.39
20	GR		-4.58	2.00	6.58	8.57

Table 5: Ranking of NET senders and receivers of spillover effects on the 21 June 2012

Rank	Variable		Sum NET	Sum OUT	Sum IN	Total FLOW
1	ES	NET SENDERS	4.63	8.50	3.87	12.38
2	DE_bks		4.34	9.83	5.50	**15.33**
3	IT		3.45	10.10	6.65	**16.75**
4	BE		2.55	9.52	6.97	**16.49**
5	AT		2.16	8.68	6.52	15.20
6	IE		1.75	7.75	6.00	13.75
7	IT_bks		1.67	8.62	6.95	**15.57**
8	NL_bks		1.05	6.43	5.38	11.81
9	BE_bks		0.79	2.66	1.87	4.53
10	PT_bks		0.49	5.76	5.27	11.03
11	FI	NET RECEIVERS	-0.01	6.52	6.53	13.04
12	ES_bks		-0.05	5.01	5.06	10.07
13	DE		-0.10	5.18	5.28	10.46
14	AT_bks		-0.24	4.16	4.40	8.55
15	FR		-1.52	5.57	7.08	12.65
16	FR_bks		-1.68	8.05	9.72	**17.77**
17	GR		-3.09	0.13	3.23	3.36
18	NL		-3.99	3.43	7.41	10.84
19	PT		-4.79	4.20	8.99	13.19
20	GR_bks		-7.42	0.59	8.01	8.60

Note: Variables are ordered from the highest to lowest net spillover effect in the system (column "Rank"). In bold are the highest five values of Total Flow. Sum NET is the difference between Sum OUT and Sum IN and Total Flow is the sum of the two terms.

Tables 4 and 5 rank our variables according to the net spillover contribution to the system in July 2011 and at the end of June 2012. The ranking of net senders for the first period that ends on 18 July 2011 (i.e. after the publication of the results from the EBA bank stress-testing exercise) is clearly dominated by banking groups. German, Italian and Austrian banks are the biggest net senders of spillover effects. Biggest net spillover receivers (at the bottom of the table) are sovereign CDS of Spain, Italy and Greece. The period (ending on 21 June 2012 after the G20 summit) is qualitatively remarkably different. Sorting by the net spillover effects, the top five is dominated by sovereign CDS spreads: Spain, Italy, Belgium, and Austria. German, Italian and Dutch banks remain in the first 10 most important net spillover senders, but on lower positions than in the first period. At the bottom part, Greece, French and Greek banks seem to be the most vulnerable to potential contagion in both periods. This is also consistent with the peak in our Contagion Index around that period. Moreover, Italy, Spain and Ireland that are highly receptive to spillover effects in the first period, become top net senders in the second period. French and German banks seem to be among of the important nodes by total flow in both periods, reflecting their systemic relevance in the euro area sovereign-banking system.

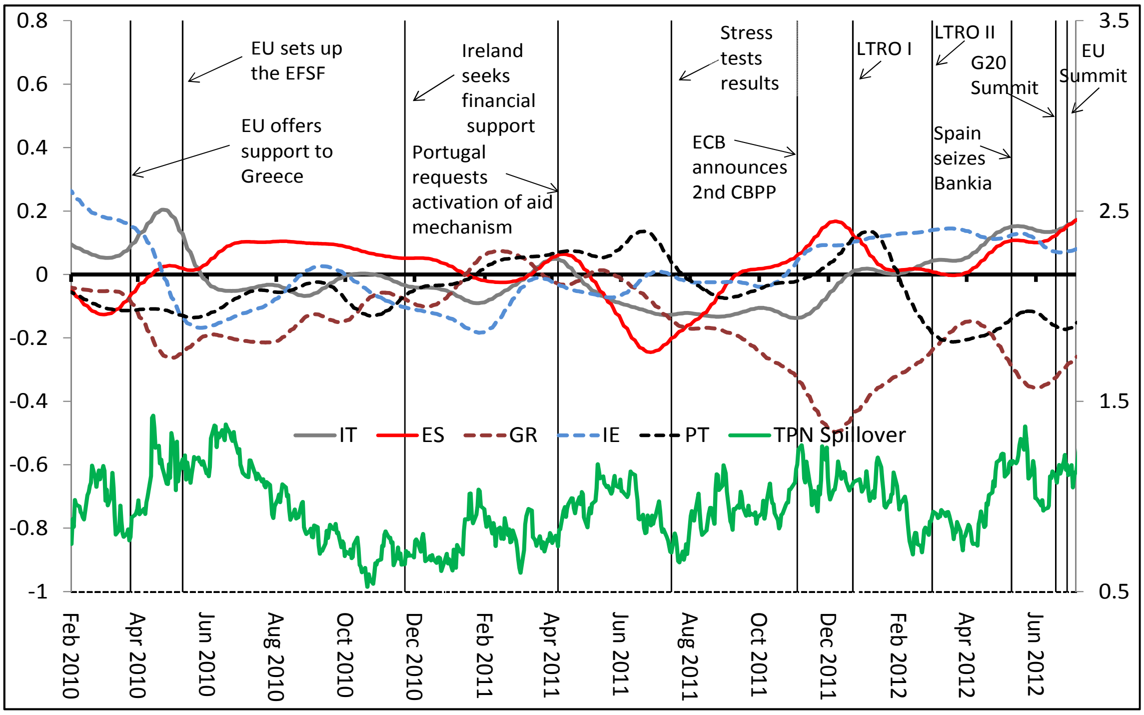
4.5 THE SYSTEMIC CONTRIBUTION OF SOVEREIGNS

Next we focus more closely on the total net positive (TNP) spillover, as defined in eq (8), which captures the sum of net positive spillovers from all banks and sovereigns. In Figure 10 we plot the time-varying systemic contributions (i.e. the weight of individual net spillover in the TNP spillover, eq. (9)) of the IMF/EU program countries (Greece, Ireland, and Portugal; dotted lines; left-hand scale) together with other countries being currently under stress, namely Spain and Italy (grey and red lines; left-hand scale).

As introduced in eq. (9), the systemic contribution (SC) of each variable y_i from our system is the ratio between the individual total net potential spillovers to each other variables and TNP spillover of the system. The SC of Greece (blue dotted line) shows most of the time negative values, meaning that it receives net potential spillover from the others. The SC of Ireland decreases after the implementation of EFSF. Furthermore, the SC of Portugal becomes negative after the implementation of LTRO I. The SC of Italy, Spain and Ireland fluctuate between -0.2 and 0.25. From summer 2011 onwards, their weights have a clear upward trend. Since March 2012, Italy and Spain have a positive and significant SC. The main observation is that after countries receive aid from EU/IMF the overall systemic risk significantly decreases. This can be interpreted as a partial transfer of (tail-) risk from the program countries to the EFSF after the latter was established. Finally, the evolution of the TNP spillover follows a similar pattern compared with the contagion indices described in previous sections.

To sum up, this analysis highlights in Figure 10 time-varying systemic contributions of several euro area countries from our system of banks and sovereigns together with the impact of some relevant events presented in Table A1.4.

Figure 10: The systemic contributions of GR, IE, IT, ES, and PT (left axis) and the Total Net Positive (TNP) Spillover (right axis)



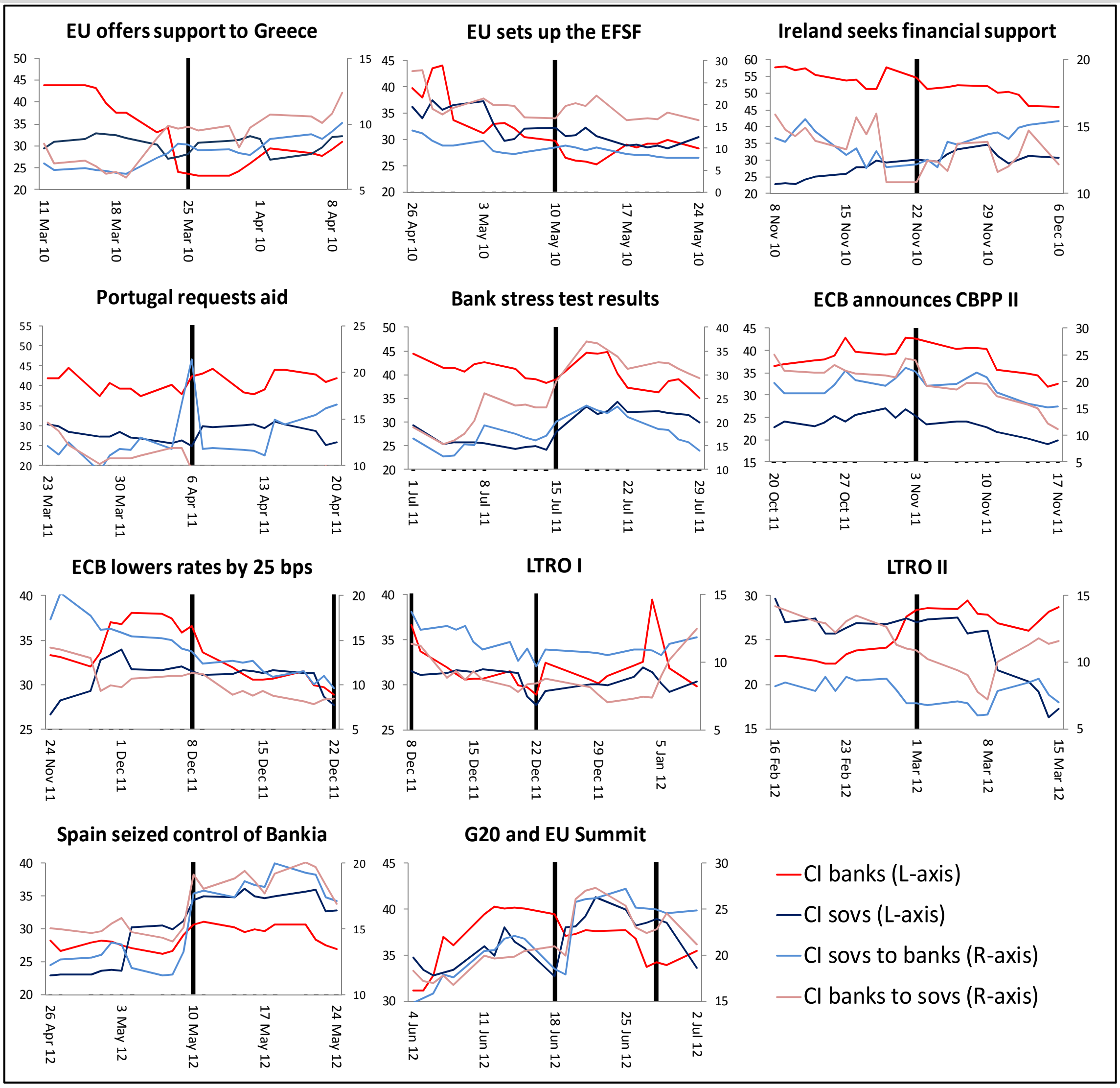
Note: "TNP Spillover" (right axis) is the Total Positive Net Spillover in our system of banks and sovereigns. In this figure we have normalized it. Time-varying systemic contributions of each sovereign are smoothed with the HP filter (smoothing parameter = 5000).

4.6 THE IMPACT OF DIFFERENT ECONOMIC/POLICY EVENTS ON THE CONTAGION INDEX

An important qualitative robustness check for any empirical approach is in-sample consistency (or "fit of the data") with historical events. Here, we analyse both qualitatively and quantitatively the short-term impact of different events on our proposed contagion indices. Together with the cumulated returns of components of the contagion index, the events are summarized in Table A1.4. Several events had a positive effect on all four components: the establishment of the EFSF (Event 2), the announcement of the second CBPP (Event 6) and the 25bps rate-cut by the ECB (Event 7; with the exception of the CI sovereigns that do not have a negative return over both +10-days interval and ±10-days interval).

The nationalization of BANKIA (Event 10) is the event that is related to the most adverse impact on all contagion components. There are two events that suggest evidence for a clear risk transfer from banks to sovereigns: when EU offers support to Greece (Event 1) and after Ireland seeks financial support (Event 3). We find that there are also three events in which we observe afterwards lower potential contagion among sovereigns and likewise from sovereigns to banks. However, at the same time this analysis shows an increase of the interdependency amongst banks themselves: LTRO II (Event 9) and Event 4, when Portugal requests activation of the aid mechanism.

Figure 11: The impact on spillover indices (sovereigns, banks, from banks to sovereigns, and from sovereigns to banks) at some specific news/policy events



Note: Each window refers to 10 days before and after the event. A list of the complete description of events and the cumulative returns over the 20 days window interval are presented in Table A1.4 (in the Appendix A1).

4.7 CRITICAL SPILLOVER THRESHOLDS FOR CONTAGION

To provide a stylised example suppose financial variable X is identified as a net spillover sending variable. Assume further that from an observed empirical distribution it is known how often that variable has increased at least *n* basis points over a given time unit. Finally assume, that risk of contagion from X to Y is a function of the magnitude with which Y reacts to a shock induced by X. Then there exists a threshold beyond which reactions in responses of Y are considered to be "excessive" and hence trigger contagion. In Table 6 we show how to apply this idea to our model. We first derive the empirical distribution of daily changes in CDS from a sample of more than 700 observations and from there we take the critical magnitudes of spillover thresholds from characteristic percentiles. This is presented in the left panel of Table 6 where for illustrative purposes we restrict ourselves to four shock-inducing variables: sovereign CDS and bank CDS (both from ES and IT).

Obtaining a threshold spillover for contagion follows along a two-step algorithm. First, one has to choose a tail probability (from the left panel in Table 6) according to a subjective risk aversion. Second pick a *subjectively* tolerable increase of basis points for a shock-response variable. Table 6 accounts for levels from 15 to 50 basis points (right hand panel). Consider, as example, first a 0.1% subjective tail risk probability for a Spanish government CDS (the probability of a day-to-day increase of more than 54 basis points). Second, assume that a tolerable magnitude for a (here day-to-day) increase in any response variable as a response to a shock in a Spanish sovereign CDS is 20 basis points. The critical threshold level would then be a 37% spillover effect in eq (4) from Spanish sovereign CDS to any chosen variable. For a less risk averse player who chooses a subjective tail probability of 5% and who picks as well 20 basis points as tolerable response, the subjective threshold of contagion is higher, i.e. 87%. These are two extreme examples. However, the "snapshot" taken in June 2012 (see Figure 1) shows that even an extreme non-risk-averse player would perceive the spillover effect from Spanish to French sovereign CDS (bigger than 90%) as risk of contagion. Risk-averse players who fear contagion at much lower spillover levels would conclude to observe strong evidence for contagion in June 2012 as the threshold of 37% is passed for almost all variables.[18]

[18] In a more sophisticated way we will simulate critical values based on Monte Carlo techniques. We leave this for future research.

Table 6: Critical spillover levels for contagion of an unexpected shock in the impulse variable: A. Spanish (ES) sovereign CDS; B. Italian (IT) sovereign CDS; C. Spanish banks (ES_bks) CDS; and D. Italian banks (IT_bks) CDS

Historical probability of events	Shock variable: observed lower bound increase of bps	Response variable: Critical level (in bps) 15	20	30	40	50
	Tail event (daily change)	**Spillover thresholds** cumulative increase (over one week)				
A.	**ES sovereign CDS**					
0.1%	54	28%	37%	56%	74%	93%
0.5%	47	32%	43%	64%	85%	106%
1%	36	42%	56%	83%	111%	139%
2%	29	52%	69%	103%	138%	172%
5%	23	65%	87%	130%	174%	-
B.	**IT sovereign CDS**					
0.1%	72	21%	28%	42%	56%	69%
0.5%	52	29%	38%	58%	77%	96%
1%	41	37%	49%	73%	98%	122%
2%	32	47%	63%	94%	125%	156%
5%	22	68%	91%	136%	182%	-
C.	**ES banks CDS**					
0.1%	47	32%	43%	64%	85%	106%
0.5%	35	43%	57%	86%	114%	143%
1%	30	50%	67%	100%	133%	167%
2%	27	56%	74%	111%	148%	185%
5%	20	75%	100%	150%	200%	-
D.	**IT banks CDS**					
0.1%	55	27%	36%	55%	73%	91%
0.5%	46	33%	43%	65%	87%	109%
1%	37	41%	54%	81%	108%	135%
2%	30	50%	67%	100%	133%	167%
5%	20	75%	100%	150%	200%	-

Note: Historical probabilities of events refer to our analysed period: October 2009 – July 2012, 717 observations in total. We do not report any spillover thresholds of the response variable above 200%.

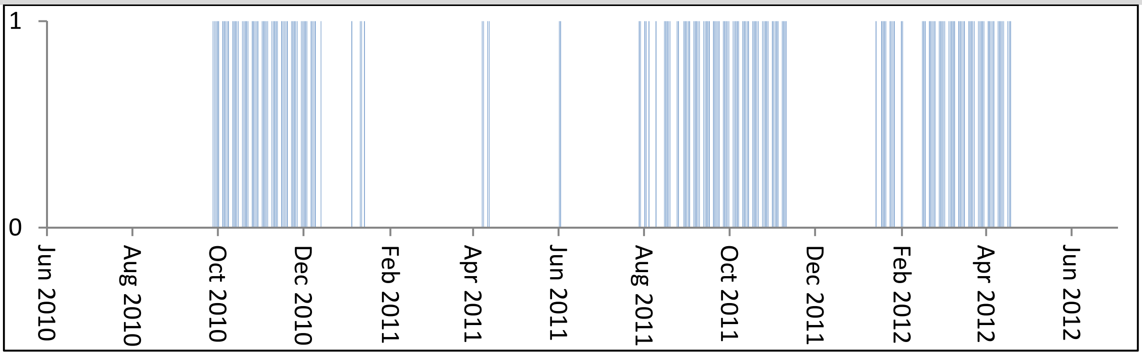
5 ROBUSTNESS AND MOTIVATION OF SETUP PARAMETERS

To assess the sensitivity of choices and assumptions with respect to the specification of our model we apply several robustness checks. We discuss the potentially time-varying distributions of residuals from the estimated VARX system and some model constraints. The choice of the window size is presented in the Appendix A5.

5.1 DIFFERENCES IN DISTRIBUTIONS OF RESIDUALS

Furthermore, we show the results for the residuals' distributions over time. In order to check whether these distributions change, we employ the two-sample Kolmogorov-Smirnov (KS test)[19] test to compare whether the distribution at any time=*t* is different from the distribution 80 days before. Figure 13 presents the results and persistence of the test rejection in the analysed sample. The first test refers to the observation in June 2010 that is compared with our first distribution at the end of January 2010.

Figure 13: Rejection of the Null hypothesis of the Kolmogorov-Smirnov (KS) test

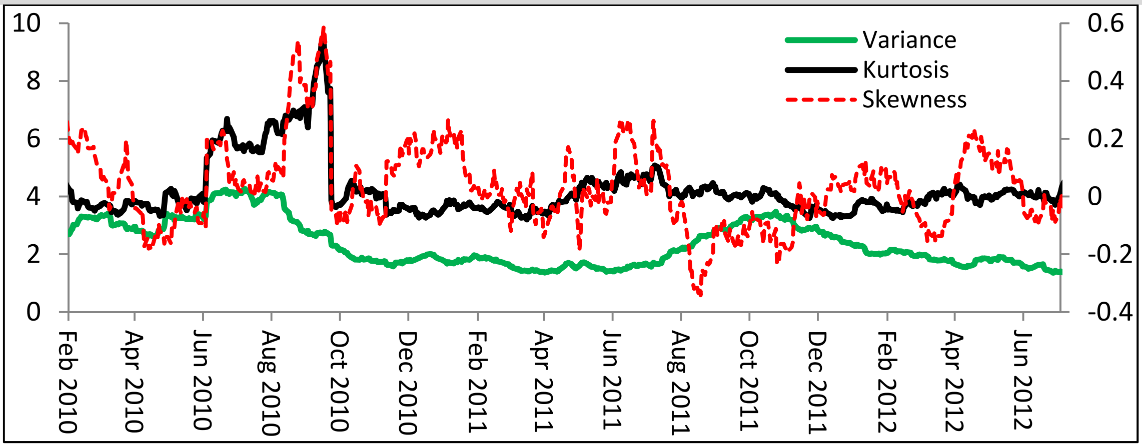


Note*:* The test compares the sample of the VAR residuals at time *t* with the sample of the residuals from the VAR estimated 80days before. Values of 1(blue bars) refer to the rejection of the null hypothesis (i.e. same distribution for the two samples) at 1% confidence level.

There are at least three different regimes in our sample. In order to get a more detailed picture about the time-varying distributions we present in Figure 14 the second, third and fourth moment of the empirical distribution of the residuals. These results motivate our choice of a VAR with time-varying parameters, since there is clear evidence of structural breaks.

[19] KS test compares the distributions of two data samples. The null hypothesis is that **both samples** are from the same continuous distribution. The alternative hypothesis is that they are from different continuous distributions. If the result is **1** the test rejects the null hypothesis at the 1% significance level; and if is **0** the null hypothesis cannot be rejected.

Figure 14: Moments of the sample distributions of residuals from the VAR model estimated at time *t*

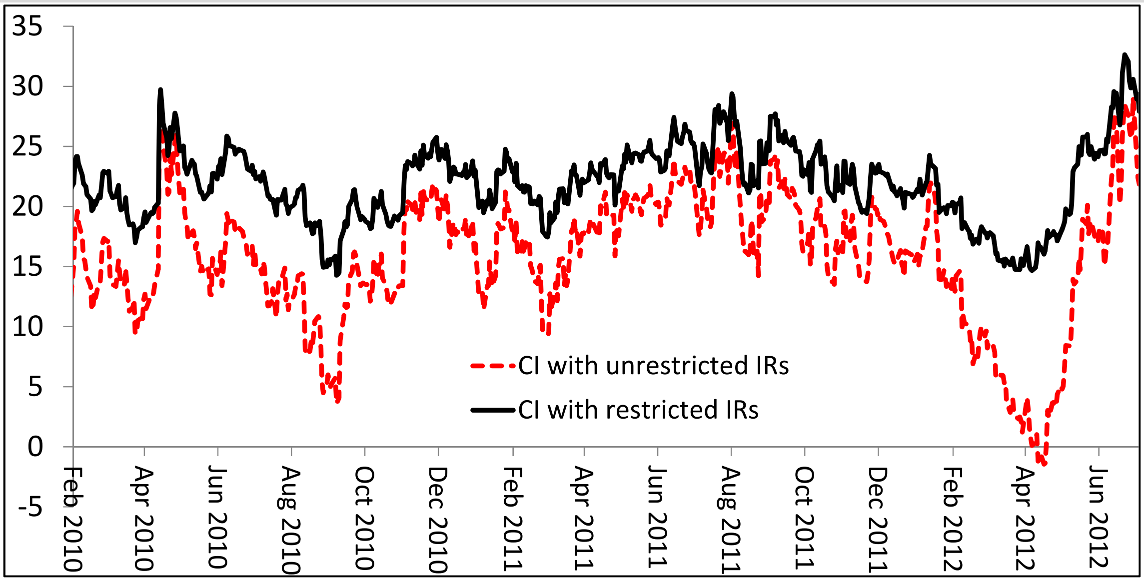


Note*:* Variance and kurtosis (Left-axis) and skewness (Right-axis).

5.2 RELAXING RESTRICTIONS IMPOSED ON IMPULSE RESPONSES

In the analysis above, when estimating the Contagion Index and its components we restricted the IRs to take values in the [0, 1] interval. We relax the restriction imposed on the impulse response functions and Figure 15 shows that results do not change dramatically. In particular, in stress periods the differences are very small, while in calm periods the [0,1] restriction yields a higher contagion index.

Figure 15: The Contagion Index with restricted and unrestricted IRs



Note: The restriction imposed on the cumulative impulse responses is to be bounded by the [0,1] interval.

6 CONCLUSION AND OUTLOOK

During the recent sovereign debt crisis a prominent theme discussed by academics, policy makers and market participants is that of contagion. There is an urgent need for tools and instruments to provide reliable information - in particular for policy makers - to take effective and efficient policy measures. New tools for the measurement of contagion and spillover effects will have the potential for playing an important role in monitoring and identifying systemic risks.

In this paper we present an empirical framework that is able to quantify spillover effects. Based on standard VAR techniques we use generalised impulse response functions to calculate spillover indices. Following the definition of contagion by Allen and Gale (2000) who interpret contagion as a consequence of excess spillover, we propose a method to construct contagion indices based on measures for aggregated spillover effects. We define spillover as the transmission of an unexpected but identified shock from one variable to receiving or responding variables in the system. Aggregation of net spillover effects at each point in time yields then a contagion index. We apply our method to investigate interactions between banks and sovereigns and use their CDS spreads as market-based asset prices from a typically liquid market. The contagion index proposed in this paper can be disentangled into four components which signal excess spillover i) amongst sovereigns, ii) amongst banks, iii) from sovereigns to banks, iv) vice-versa. By using a rolling-window estimation technique we are able to capture changes of interdependencies over time, in quasi-real time, which allows us to gauge the effectiveness of policy interventions.

Our measure can be used in a static or dynamic context, by showing the state of potential contagion at a certain point in time or a time dependent contagion index. Presenting interdependent spillover magnitudes in a system e.g. by attaching different intensities of colour corresponding to the magnitude of a particular spillover effect generates a so called "heat map". By looking at consecutive points in time those heat maps change colour and illustrate the build-up or diminishing of potential contagion. Features of this toolbox allow us to identify systemically relevant entities (i.e. country specific banking sectors and sovereigns) from the proposed set of sovereigns and banks in our system. In this paper we have proposed a simple method to compute thresholds for "excessive" spillovers, based on empirical distributions of CDS changes in combination with subjective preferences.

Our results show clear growing interdependencies between banks and sovereigns, that represents a potential source of systemic risk. Euro area sovereign creditworthiness carries a growing weight in the overall financial market picture, with a sub-set of sovereigns that can potentially produce negative externalities to the financial system. We find that several previous policy interventions had a mitigating impact on spillover risks. In our application we find that a shock in Spanish sovereign CDS reveals an elevated impact on both euro area sovereigns and banks during the first half of 2012, compared to 2011. Moreover, spillover effects from a shock to Spanish sovereign CDS to Eurozone core countries and to non-core countries become more similar in magnitude during 2012. We also found strong evidence that the nexus between sovereigns and banks amplified strongly until the end of June 2012. However, systemic contributions of Greece, Portugal and Ireland decrease remarkably after the implementation of IMF/EU programs. Nevertheless, Ireland regains its positive net spillover status since the beginning of 2012. The setup of the EFSF and the decision of the two LTROs in December 2011 have a mitigating impact on all four contagion index components. By contrast, nationalization of Bankia in Spain had a further growing impact on all four contagion index components.

For future research, we plan to extend our approach along various avenues. We will extend our tool by incorporating extreme realisations and capturing the dynamics using extreme-value-theory as well as Monte Carlo simulations. We will further improve the statistical and econometric framework tool and derive statistical distributions of impulse response functions. With regard to economic applications the next steps will be to extend the model to real economy entities and capture potential spillovers to different sectors in order to shed light on macro-financial interlinkages.

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APPENDIX

A1 DESCRIPTION OF VARIABLES AND EVENTS

Table A1.1: Composition and description of bank-specific and exogenous variables

Name of the Variable	Composition or description
Endogenous variables	
AT_bks	Erste Group Bank, Raiffeisen Zentralbank Österreich
BE_bks	DEXIA Group, KBC Group
FR_bks	BNP Paribas, Credit Agricole, Societe Generale
DE_bks	Deutsche Bank, Commerzbank, DZ Bank, Landesbank Baden-Württemberg, Landesbank Hessen-Thüringen, HSH Nordbank, WestLB
GR_bks	EFG Eurobank Ergas, National Bank Of Greece
IT_bks	Unicredito, Intesa Sanpaolo, Banca Montepaschi Di Siena, Unione Di Banche Italiene (UBI), Banca Popolare Italiana
NL_bks	ING Bank, Rabobank, SNS Bank
ES_bks	Banco Santander, Banco Bilbao Vizcaya Argentaria (BBVA), Banco Pastor, Banco Popular Español, La Caixa, Banco Sabadell
ES_bks_G1	Banco Santander , Banco Bilbao Vizcaya Argentaria (BBVA)
ES_bks_G2	Banco Pastor, Banco Popular Español, La Caixa, Banco Sabadell
PT_bks	Banco Comercial Portugues , Banco BPI, Banco Espirito Santo, Caixa General De Depositos
Exogenous variables	
SOVXWE	iTraxx SovX Western Europe[20]
SNRFIN	iTraxx Europe Senior Financials
ITRXEUR	iTraxx Europe index (125 investment grade companies, all sectors)
XOVER	iTraxx Crossover index (50 sub-investment grade companies, all sectors)
EUREON	The spread between 3 month EURIBOR and EONIA swap
VIX	The volatility index of S&P 500
EUROSTOXX	The EURO STOXX 50 Index
US	The 5 year senior CDS of United States of America
UK	The 5 year senior CDS of United Kingdom
UK_bks	Royal Bank of Scotland Group, HSBC Holdings, Barclays Bank, Lloyds TSB Bank

Note: All endogenous bank variables are computed as asset-weighted averages. All bank components are 5 year senior CDS spreads denominated in EUR. Source: CMA (via Datastream) and Bloomberg.

[20] For the constituents of these indices please refer to:
http://www.markit.com/assets/en/docs/products/data/indices/credit-index-annexes/iTraxx_SovX%20WE_Series%207.pdf
http://www.markit.com/assets/en/docs/products/data/indices/credit-index-annexes/iTraxx%20Europe%20annex_Series%2017.pdf

Table A1.2: Descriptive Statistics

Type		Variable Name	Variable in levels											Δ(ln(variable))										
			No Obs	Mean	Median	Min	Max	Std Dev	Skew	Kurtosis	JB Test	ADFv1 pValue	ADFv2 pValue	No Obs	Mean	Median	Min	Max	Std Dev	Skew	Kurtosis	JB Test	ADFv1 pValue	ADFv2 pValue
Endogenous	CDS Sovereigns	AT	718	107	86	49	239	47.80	0.85	2.33	101	0.618	0.269	717	0.227	0.252	-30.75	21.03	3.76	-1.01	15.92	5,109	0.001	0.001
		BE	718	167	150	32	403	85.90	0.23	2.05	34	0.551	0.118	717	0.143	0.051	-32.52	21.36	4.10	-0.47	9.31	1,214	0.001	0.001
		FI	718	44	33	16	90	21.36	0.71	1.94	95	0.740	0.268	717	0.124	0.081	-19.61	32.93	4.22	0.53	9.92	1,466	0.001	0.001
		FR	718	109	84	21	247	61.20	0.51	1.94	65	0.671	0.172	717	0.241	0.187	-22.05	18.12	4.35	-0.09	5.36	167	0.001	0.001
		GR	718	3,680	1,010	122	25,961	5512	2.57	9.84	2,189	0.391	0.336	717	0.172	0.026	-15.44	17.98	4.02	0.33	4.74	104	0.001	0.001
		DE	718	57	46	19	121	25.95	0.57	2.04	66	0.724	0.135	717	0.268	0.089	-17.36	19.59	4.15	0.09	4.68	85	0.001	0.001
		IR	718	505	582	115	1,287	254.48	-0.10	2.03	29	0.526	0.695	717	0.665	0.220	-104.45	50.10	8.05	-2.84	50.00	66,951	0.001	0.001
		IT	718	259	191	68	596	150.19	0.66	1.99	83	0.652	0.157	717	0.191	0.014	-18.33	22.22	4.10	0.18	5.63	211	0.001	0.001
		NL	718	64	49	25	136	32.55	0.73	2.01	93	0.723	0.344	717	0.179	0.112	-35.24	22.11	4.04	-0.63	14.16	3,771	0.001	0.001
		ES	718	282	256	68	618	130.45	0.34	2.50	21	0.721	0.002	717	0.253	0.219	-40.43	21.54	4.84	-0.40	11.45	2,154	0.001	0.001
		PT	718	639	495	53	1,762	431.89	0.30	1.67	64	0.523	0.317	717	0.168	0.000	-18.64	17.49	3.92	0.24	5.12	141	0.001	0.001
	CDS Banks	At_bks	718	192	167	121	374	62.78	1.05	2.97	131	0.611	0.516	717	0.048	0.008	-20.06	12.04	3.27	-0.34	5.93	270	0.001	0.001
		BE_bks	718	338	255	141	744	180.00	0.80	2.18	97	0.915	0.494	717	0.094	0.000	-18.54	20.64	3.49	0.68	8.20	864	0.001	0.001
		FR_bks	718	167	131	56	380	83.47	0.74	2.22	83	0.522	0.021	717	0.063	0.000	-25.19	15.07	3.01	-0.11	11.89	2,361	0.001	0.001
		GR_bks	718	1,166	966	139	3,634	693.84	0.51	2.49	40	0.381	0.001	717	0.188	0.072	-17.22	11.34	2.72	-0.13	6.79	432	0.001	0.001
		DE_bks	718	145	131	76	319	50.29	0.77	2.74	72	0.530	0.055	717	0.160	0.005	-40.79	19.15	4.77	-0.61	11.03	1,973	0.001	0.001
		IT_bks	718	253	188	64	690	160.96	0.79	2.35	88	0.748	0.203	717	0.324	-0.034	-50.70	45.86	6.15	0.54	24.77	14,191	0.001	0.001
		NL_bks	718	132	116	57	251	50.08	0.62	2.18	67	0.702	0.099	717	0.090	0.000	-20.28	15.12	3.57	0.06	5.48	184	0.001	0.001
		ES_bks	718	356	327	124	712	153.85	0.42	2.25	38	0.805	0.288	717	0.200	0.051	-30.70	16.57	3.85	-0.48	9.60	1,522	0.001	0.001
		ES_bks_G1	718	234	228	66	484	101.60	0.38	2.42	27	0.695	0.002	717	0.272	0.114	-37.53	19.37	4.27	-0.57	12.14	2,535	0.001	0.001
		ES_bks_G2	718	478	426	181	940	206.10	0.45	2.08	50	0.916	0.560	717	0.128	-0.011	-23.88	13.77	3.42	-0.39	7.05	509	0.001	0.001
		PT_bks	718	644	635	74	1,378	372.74	0.08	1.83	42	0.703	0.839	717	0.207	0.050	-43.57	19.18	4.68	-1.01	14.72	4,224	0.001	0.001
Exogenous	CDS Indices	SOVXWE	718	202	183	47	386	97.30	0.17	1.79	47	0.666	0.106	717	0.105	0.000	-25.94	16.60	3.52	-0.14	8.32	847	0.001	0.001
		SNRFIN	718	172	160	64	355	69.27	0.44	2.21	42	0.630	0.027	717	0.068	-0.112	-14.40	29.07	4.25	0.74	7.32	623	0.001	0.001
		ITRX EUR	718	120	109	65	208	34.66	0.75	2.45	76	0.656	0.174	717	0.065	0.029	-25.98	15.28	3.24	-0.42	9.77	1,389	0.001	0.001
		XOVER	718	534	502	352	874	129.20	0.64	2.28	64	0.516	0.280	717	0.004	-0.053	-20.59	12.65	2.94	-0.04	7.14	512	0.001	0.001
	Other	EUREON	718	0.61	0.49	0.22	1.35	0.29	0.96	2.87	111	0.447	0.987	717	-0.076	-0.627	-35.06	40.55	7.28	0.85	6.94	550	0.001	0.001
		EURSTOXX	718	257	263	201	297	23.75	-0.50	2.09	54	0.476	0.252	717	-0.080	0.079	-17.41	17.78	3.03	-0.19	9.63	1,318	0.001	0.001
		US CDS	718	43	43	20	64	7.75	-0.53	3.35	38	0.631	0.052	717	0.094	0.000	-18.54	20.64	3.49	0.68	8.20	864	0.001	0.001
		UK CDS	718	72	71	44	103	12.76	0.24	2.56	13	0.551	0.089	717	0.048	0.008	-20.06	12.04	3.27	-0.34	5.93	270	0.001	0.001
		UK_bks	718	159	143	82	291	51.34	0.60	2.16	65	0.589	0.024	717	0.213	0.002	-17.53	10.69	2.97	-0.57	8.40	910	0.001	0.001
		VIX	718	23	21	14	48	6.24	1.31	4.35	259	0.212	0.020	717	-0.016	0.000	-5.54	8.67	1.46	0.02	5.82	238	0.001	0.001

Note: "JB test" refers to the Jarque–Bera test for normality. The JB test statistic is χ^2distributed. The null hypothesis is rejected in all cases, for both CDS levels and log first-differences. "ADFv1" and "ADFv2" refer to the augmented Dickey–Fuller test for unit-roots. "ADFv1" has an "autoregressive" model and "ADFv2" refers to the "trend stationary" model. The null-hypothesis of existence of a unit root cannot be rejected for levels, but can be rejected in the case of log first-differences.

Table A1.3: Country-specific bank assets and the weight in the country bank index

No.	Country	Bank name	Assets*	Weight
1	Austria	Erste Group	216,709	0.59
2	Austria	Raiffeisen Zentralbank	148,798	0.41
3	Belgium	Dexia Group	412,759	0.59
4	Belgium	KBC Group	290,635	0.41
5	France	BNP Paribas	1,965,283	0.40
6	France	Crédit Agricole	1,723,608	0.35
7	France	Société Générale	1,181,372	0.24
8	Germany	Deutsche Bank	2,103,295	0.51
9	Germany	Commerzbank	691,014	0.17
10	Germany	DZ Bank	388,525	0.09
11	Germany	Landesbank Baden-Württemberg	373,059	0.09
12	Germany	Landesbank Hessen-Thüringen	163,985	0.04
13	Germany	HSH Nordbank	150,930	0.04
14	Germany	WestLB	220,179	0.05
15	Greece	EFG Eurobank Ergas	73,587	0.41
16	Greece	National Bank Of Greece	104,095	0.59
17	Italy	Unicredito	926,769	0.44
18	Italy	Intesa Sanpaolo	652,630	0.31
19	Italy	Banca Montepaschi Di Siena	244,300	0.12
20	Italy	Unione Di Banche Italiene	131,511	0.06
21	Italy	Banca Popolare Italiana	134,942	0.06
22	Netherlands	ING Group	1,241,729	0.72
23	Netherlands	Rabobank	404,682	0.23
24	Netherlands	SNS Bank	78,918	0.05
25	Portugal	Banco Comercial Portugues	92,029	0.27
26	Portugal	Banco BPI	44,754	0.13
27	Portugal	Banco Espirito Santo	81,265	0.24
28	Portugal	Caixa General De Depositos	118,637	0.35
29	Spain	Banco Santander**	1,283,349	0.57
30	Spain	BBVA**	600,477	0.27
31	Spain	Banco Popular Español	158,207	0.07
32	Spain	Banco Sabadell	105,321	0.05
33	Spain	La Caixa	70,667	0.03
34	Spain	Banco Pastor	30,376	0.01
35	UK	Royal Bank of Scotland	1,506,867	0.23
36	UK	HSBC	2,555,579	0.38
37	UK	Barclays	1,563,527	0.24
38	UK	Lloyds TSB Bank	970,546	0.15

Note: * assets are in thousand euros, Q1 2011. ** In section 4.1, the two Spanish banks (Banco Santander, BBVA) are considered as being part of ES_Bks_G1, and the rest four Spanish banks (Banco Popular Español, Banco Sabadell, La Caixa, Banco Pastor) are part of ES_Bks_G2.

Table A1.4: Selected events during the Euro-area sovereign/banking crisis and the cumulative returns of contagion indices

No	Date	Event	10D cumulative return after the event				±10D cumulative return around the event			
			CI bks	CI sovs	CI from sovs to bks	CI from bks to sovs	CI bks	CI sovs	CI from sovs to bks	CI from bks to sovs
1	25/03/2010	EU offers support to Greece	31%	14%	19%	26%	-30%	9%	44%	45%
2	10/05/2010	EU sets up the EFSF; ECB starts SMP	-5%	-5%	-24%	-2%	-29%	-16%	-45%	-40%
3	22/11/2010	Ireland seeks financial support	-16%	2%	27%	12%	-21%	34%	9%	-23%
4	06/04/2011	Portugal requests activation of the aid mechanism	-1%	4%	-22%	-15%	0%	-15%	37%	-44%
5	15/07/2011	EBA bank stress test results are published	-10%	7%	-30%	3%	-21%	2%	-16%	54%
6	06/10/2011	ECB announces second covered bond purchase programme	-24%	-22%	-30%	-54%	-11%	-14%	-22%	-56%
7	08/12/2011	ECB lowers interest rates by 25 bps	-21%	-12%	-29%	-26%	-13%	4%	-44%	-41%
8	22/12/2011	LTRO I	3%	9%	22%	48%	-19%	-4%	-14%	10%
9	01/03/2012	LTRO II	1%	-36%	1%	6%	24%	-42%	-15%	-19%
10	10/05/2012	Spain seizes control of Bankia	-12%	-4%	-3%	-11%	-5%	43%	39%	13%
11	18/06/2012	G20 Summit	-10%	3%	34%	1%	14%	-3%	68%	16%
12	28/06/2012	EU Summit*	8%	-16%	3%	-2%	-8%	-10%	16%	12%

Note: * Since our analysis ends on 3 July 2012, the cumulative return around/after the EU Summit is computed only for the next 5 days. ±10D around the event refers to the cumulative return between the values of the index 10 days after the event and 10 days before the event, such that the event is centred.

A2 THE EXPLICIT VAR MODEL WITH EXOGENOUS COMMON FACTORS

A. Our VAR model with sovereigns, banks, and exogenous variables can be represented as:

$$\begin{bmatrix} \Delta y_{AT,t} \\ \vdots \\ \Delta y_{ES,t} \\ \Delta y_{AT\_bks,t} \\ \vdots \\ \Delta y_{ES\_bks,t} \end{bmatrix} = \begin{bmatrix} \alpha_{1,0} \\ \vdots \\ \alpha_{n,0} \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} \gamma_{11,i} & \cdots & \gamma_{1n,i} \\ \vdots & \ddots & \vdots \\ \gamma_{n1,i} & \cdots & \gamma_{nn,i} \end{bmatrix} \begin{bmatrix} \Delta y_{AT,t-i} \\ \vdots \\ \Delta y_{ES,t-i} \\ \Delta y_{AT_{bks},t-i} \\ \vdots \\ \Delta y_{ES\_bks,t-i} \end{bmatrix} + \sum_{i=0}^{q} B_i \, Exo_{t-i} + \begin{bmatrix} u_{AT,t} \\ \vdots \\ u_{ES,t} \\ u_{AT\_bks,t} \\ \vdots \\ u_{ES\_bks,t} \end{bmatrix}, \quad (1)$$

where $u_{j,t} \sim wn\,(0, \Sigma_u)$

B. The moving average (MA) representation of the VAR model:

A VAR (p) model can be represented as:

$$Y_t = \nu + \sum_i^p A^i \, Y_{t-i} + U_t \quad (2)$$

Furthermore, a stable VAR process can be rewritten as:

$$Y_t = \mu + \sum_{i=0}^{\infty} \phi_i U_{t-i} \quad (3)$$

where ϕ_i are the Moving Average (MA) coefficient matrices. And

$$\phi_0 = I_k \tag{4}$$

A3 OTHER VERSIONS OF THE CONTAGION INDICES AND SYSTEMIC CONTRIBUTION OF SOVEREIGNS

The four components of contagion index, as defined in eqs (11) – (14), can be weighted and summed as:

$$CI = \frac{100}{N(N-1)}[M(M-1) * CI_{sovs} + P(P-1) * CI_{bks} + M * P * (CI_{sovs \to bks} + CI_{bks \to sovs})] \tag{5}$$

The second version of the Contagion Index of sovereigns that we propose is to weight the sum of "IN" spillover effects (received) by the euro-area GDP. In this sense we give a higher importance to whom is affected by the spillover effects coming from other variables:

$$CI_{wIN} = 100 * \sum_{i=1}^{N} w_i \sum_{j \neq i}^{N} y_{i \to j} \tag{6}$$

Where w_i is the GDP weight of sovereign *i* in the Eurozone.[21]

The third version of the CI sovereigns is to weight the sum of "OUT" spillover effects (sent) by the euro-area GDP. In this sense we give a higher importance to who affects the others:

$$CI_{wOUT} = 100 * \sum_{i=1}^{N} w_i \sum_{j \neq i}^{N} IR_{y_{i \to j}} \tag{7}$$

Similarly, w_i is the GDP-adjusted weight of sovereign *i* in the Eurozone's total GDP.

After we have introduced all these measures that derive from the Contagion Matrix, we can re-define our *systemic contribution* of a sovereign measure:

Version 2 $$SC_{Sov_i} = \frac{SE_{OUT,\ y_{i \to *}}}{CI_{wOUT}} + \frac{SE_{IN,\ y_{* \to i}}}{CI_{wIN}} \tag{8}$$

Version 3 $$SC_{Sov_i} = \frac{TSE_{NET,\ y_i}}{\sum_i^N TSE_{NET,\ y_i} * I_{TCE_{NET,\ y_i} > 0}} \tag{9}$$

where $I_{TCE_{NET,\ y_i} > 0}$ is an indicator function that allows only positive net total contagion effects to be summed (since the sum of $TCE_{NET,\ y_i}$ equals zero).

Extension 1 – Residuals and IRs from the VARX(2) model with sovereign CDS changes. The aggregation of the impulse responses from a system only with sovereigns, calculated as the expected shock impact in $\boldsymbol{Sov_i}$:

$$\boldsymbol{SCIS_{Sov_i}} = EDF_{Sov_i} * \frac{GDP_{Sov_i}}{GDP_{EA}} * \frac{\sum_j wTrade_{\ ij}\, \boldsymbol{SovereignResponse_{j,i}}}{wTrade_i} \tag{10}$$

[21] Since we are not considering in our analysis all euro area countries we adjust these weights, such that they sum up to 1.

Where:

- EDF_{Sov_i} is the expected default frequency of Sov_i (as calculated by Moody's)
- $SovereignResponse_{j,i}$ is the (average) cumulated response of $Sovereign_j$ to a shock in $Sovereign_i$
- $wTrade_{\ j,i}$ is the Trade weight of $Sovereign_j$ in Total Exports of $Sovereign_i$
- $wBIS_{ij}$ is the weight of total holdings of $Sovereign_j$'s Banking System towards $Sovereign_i$ as reported in the BIS Foreign Claims (ultimate risk basis) database
- $LevG_i$ is the ratio Total Governmental Debt/GDP of $Sovereign_i$
- $LevF_i$ is the ratio Total Assets of Banks/GDP of $Sovereign_i$
- $DomesticBanksAvgResponse$, $IntBanksAvgResponse$ are the average responses of financial institutions, domestic and foreign.

Extension 2 – Residuals and impulse responses from the VARX(2) model with sovereign and bank CDS changes. The aggregation of IRs from a system **with banks and sovereigns:**

$$\boldsymbol{SCIS_{Sov_i}} = \frac{GDP_{Sov_i}}{GDP_{EA}}\ x\ \frac{\sum_j wTrade_{\ ij} * \boldsymbol{SovereignResponse_{j,i}}}{wTrade_i} + \frac{External\ Debt_i}{TotalForeignClaims_i}\sum_j wBIS_{\ ij} * \boldsymbol{IntBanksAvgResponse} + \frac{Domestic\ Debt_i}{Domestic\ GDP_i}\ x\ LevF_i\ x\ \boldsymbol{DomesticBanksAvgResponse} \quad (11)$$

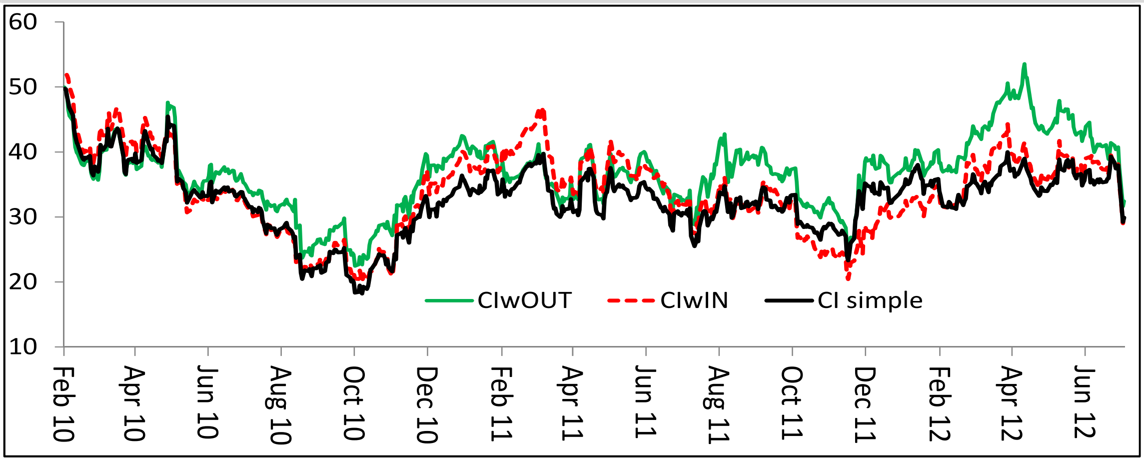
Where:

- $LevF_i$ is the ratio Total Assets of Banks/GDP of $Sovereign_i$
- $DomesticBanksAvgResponse, IntBanksAvgResponse$ are the average responses of financial institutions (domestic and foreign).

Different versions of the Contagion Index and systemic contributions of sovereigns (a comparison)

We calibrate differently our contagion index for euro-area sovereigns and show that there are no significant differences when we use *eqs (20)* and *(21)* instead of *(10)*. In this analysis, we show that when we put more weight on countries with higher GDP, that are being influenced by spillover effects from other countries, the contagion index (CIwOUT, blue line) tops the preceding highest level during the Spanish debt developments (on 10th April 2012). This index version has the role of highlighting a higher interdependence between big countries and small countries. If the former ones are affected by contagion, it can be considered a red flag for the entire stability of the system.

Figure A3.1: Different versions of the EA Contagion Index (in percentage points) of sovereigns



A4 SPILLOVER AND NET SPILLOVER MATRICES

Table A4.1: The spillover matrix of EA sovereigns and banks (on 18 July 2011)

Impulse \ Response	AT	BE	FI	FR	GR	DE	IE	IT	NL	PT	ES	AT_bks	BE_bks	FR_bks	GR_bks	DE_bks	IT_bks	NL_bks	PT_bks	ES_bks	Sum OUT
AT	.	0.51	0.00	0.91	0.62	0.52	0.48	0.85	0.43	0.33	0.82	0.12	0.03	0.71	0.00	0.58	0.20	0.21	0.85	0.78	8.95
BE	0.36	.	0.00	0.37	0.22	0.01	0.47	0.73	0.05	0.37	0.83	0.12	0.08	0.16	0.00	0.12	0.02	0.13	0.29	0.31	4.64
FI	0.00	0.00	.	0.00	0.00	0.00	0.19	0.03	0.07	0.04	0.00	0.12	0.08	0.00	0.58	0.00	0.27	0.00	0.12	0.02	1.53
FR	0.81	0.44	0.00	.	0.47	0.38	0.37	0.61	0.37	0.03	0.70	0.25	0.06	0.44	0.00	0.39	0.18	0.01	0.52	0.67	6.71
GR	0.25	0.11	0.06	0.17	.	0.09	0.23	0.05	0.26	0.20	0.16	0.00	0.14	0.11	0.00	0.02	0.01	0.04	0.07	0.02	2.00
DE	0.54	0.05	0.00	0.45	0.36	.	0.41	0.09	0.37	0.30	0.16	0.01	0.40	0.43	0.04	0.26	0.27	0.28	0.39	0.21	5.01
IE	0.30	0.34	0.18	0.32	0.34	0.22	.	0.31	0.00	0.71	0.39	0.06	0.41	0.15	0.00	0.10	0.03	0.14	0.43	0.24	4.68
IT	0.25	0.63	0.00	0.38	0.05	0.09	0.21	.	0.17	0.21	0.56	0.04	0.02	0.16	0.03	0.10	0.16	0.10	0.29	0.28	3.73
NL	0.22	0.22	0.37	0.39	0.19	0.38	0.04	0.61	.	0.07	0.12	0.02	0.20	0.14	0.58	0.15	0.33	0.21	0.21	0.17	4.60
PT	0.11	0.26	0.03	0.08	0.24	0.35	0.91	0.34	0.00	.	0.26	0.00	0.26	0.10	0.00	0.00	0.10	0.25	0.39	0.02	3.70
ES	0.45	0.63	0.00	0.35	0.35	0.06	0.36	0.64	0.04	0.41	.	0.14	0.00	0.28	0.00	0.24	0.07	0.20	0.38	0.43	5.04
AT_bks	0.36	0.09	0.49	0.47	0.44	0.00	0.01	0.00	0.39	0.00	0.37	.	0.00	0.34	0.97	0.56	0.23	0.14	0.26	0.67	5.79
BE_bks	0.28	0.27	0.28	0.20	0.69	0.44	0.36	0.09	0.40	0.19	0.05	0.00	.	0.47	0.12	0.28	0.39	0.29	0.30	0.06	5.16
FR_bks	0.63	0.08	0.14	0.55	0.78	0.39	0.25	0.07	0.37	0.06	0.25	0.12	0.49	.	0.19	0.50	0.26	0.21	0.43	0.37	6.15
GR_bks	0.02	0.08	0.11	0.04	0.04	0.06	0.00	0.03	0.12	0.00	0.02	0.07	0.08	0.05	.	0.02	0.06	0.00	0.00	0.01	0.82
DE_bks	0.83	0.34	0.17	0.76	0.64	0.49	0.37	0.46	0.49	0.09	0.65	0.45	0.55	0.95	0.00	.	0.80	0.49	0.81	0.93	10.30
IT_bks	0.50	0.22	0.26	0.49	0.33	0.55	0.13	0.42	0.61	0.06	0.47	0.22	0.64	0.75	0.08	0.67	.	0.38	0.63	0.69	8.12
NL_bks	0.03	0.00	0.21	0.03	0.45	0.19	0.16	0.00	0.44	0.13	0.12	0.31	0.53	0.45	0.24	0.36	0.43	.	0.07	0.25	4.40
PT_bks	0.75	0.37	0.06	0.74	0.23	0.50	0.42	0.65	0.23	0.20	0.68	0.29	0.19	0.64	0.00	0.55	0.56	0.20	.	0.77	8.02
ES_bks	0.75	0.36	0.07	0.69	0.15	0.20	0.27	0.67	0.38	0.04	0.75	0.36	0.00	0.55	0.00	0.66	0.46	0.22	0.75	.	7.32
Sum IN	7.45	5.01	2.44	7.40	6.58	4.91	5.63	6.67	5.21	3.47	7.37	2.71	4.15	6.89	2.82	5.55	4.83	3.50	7.19	6.91	**106.66**

Note: Variables in the first column are the impulse origin. Variables on the top row are the respondents to the shock. Values in the matrix represent the average cumulated spillover effect over the first 5 days. The intensity of a shock on a respondent is marked by different levels of colour (*light* means no impact and *dark* means very strong impact). The cumulative impact is bound between 0 and 1. A value of 0.5 means that the response variable will be impacted in the same direction with an intensity of 50% the initial unexpected shock in the impulse variable. If the initial shock has a magnitude of 10 bps then the response variable is expected to increase by 5 bps in the following week. In the last column we have the aggregated impact sent (*Sum OUT*) by each row variable and on the bottom row the aggregated spillover received (*Sum IN*) by each column variable. The bottom-right cell (in bold) shows *total spillover* in the system (by dividing this value to the total number of non-diagonal cells i.e. 20x19 we obtain *the contagion index* of EA sovereigns and banks, as introduced in eq (10)).

Table A4.2: Net spillover matrix (on 18 July 2011)

Net Matrix	AT	BE	FI	FR	GR	DE	IE	IT	NL	PT	ES	AT_bks	BE_bks	FR_bks	GR_bks	DE_bks	IT_bks	NL_bks	PT_bks	ES_bks	Sum NET
AT	0.00	0.15	0.00	0.10	0.37	-0.02	0.17	0.60	0.22	0.23	0.37	-0.25	-0.25	0.09	-0.02	-0.25	-0.31	0.18	0.10	0.03	**1.51**
BE	-0.15	0.00	0.00	-0.07	0.11	-0.04	0.13	0.10	-0.17	0.11	0.19	0.03	-0.20	0.09	-0.08	-0.21	-0.20	0.12	-0.09	-0.05	-0.38
FI	0.00	0.00	0.00	0.00	-0.06	0.00	0.01	0.03	-0.29	0.01	0.00	-0.37	-0.20	-0.14	0.46	-0.17	0.01	-0.21	0.06	-0.04	-0.91
FR	-0.10	0.07	0.00	0.00	0.30	-0.07	0.06	0.23	-0.02	-0.05	0.36	-0.22	-0.14	-0.11	-0.04	-0.37	-0.31	-0.03	-0.22	-0.02	-0.69
GR	-0.37	-0.11	0.06	-0.30	0.00	-0.26	-0.11	0.00	0.07	-0.04	-0.19	-0.44	-0.55	-0.68	-0.04	-0.62	-0.32	-0.40	-0.16	-0.14	-4.58
DE	0.02	0.04	0.00	0.07	0.26	0.00	0.20	0.00	-0.01	-0.05	0.10	0.01	-0.03	0.03	-0.02	-0.22	-0.28	0.09	-0.11	0.00	**0.10**
IE	-0.17	-0.13	-0.01	-0.06	0.11	-0.20	0.00	0.11	-0.04	-0.20	0.03	0.05	0.05	-0.10	0.00	-0.27	-0.09	-0.02	0.01	-0.02	-0.95
IT	-0.60	-0.10	-0.03	-0.23	0.00	0.00	-0.11	0.00	-0.44	-0.13	-0.08	0.04	-0.07	0.09	0.00	-0.37	-0.26	0.10	-0.36	-0.39	-2.94
NL	-0.22	0.17	0.29	0.02	-0.07	0.01	0.04	0.44	0.00	0.07	0.08	-0.37	-0.21	-0.23	0.46	-0.35	-0.29	-0.23	-0.02	-0.21	-0.61
PT	-0.23	-0.11	-0.01	0.05	0.04	0.05	0.20	0.13	-0.07	0.00	-0.15	0.00	0.07	0.04	0.00	-0.09	0.03	0.12	0.19	-0.02	**0.23**
ES	-0.37	-0.19	0.00	-0.36	0.19	-0.10	-0.03	0.08	-0.08	0.15	0.00	-0.23	-0.05	0.03	-0.02	-0.41	-0.40	0.08	-0.30	-0.31	-2.33
AT_bks	0.25	-0.03	0.37	0.22	0.44	-0.01	-0.05	-0.04	0.37	0.00	0.23	0.00	0.00	0.22	0.90	0.10	0.01	-0.17	-0.03	0.31	**3.09**
BE_bks	0.25	0.20	0.20	0.14	0.55	0.03	-0.05	0.07	0.21	-0.07	0.05	0.00	0.00	-0.02	0.05	-0.27	-0.25	-0.25	0.10	0.06	**1.01**
FR_bks	-0.09	-0.09	0.14	0.11	0.68	-0.03	0.10	-0.09	0.23	-0.04	-0.03	-0.22	0.02	0.00	0.15	-0.46	-0.49	-0.24	-0.21	-0.18	-0.74
GR_bks	0.02	0.08	-0.46	0.04	0.04	0.02	0.00	0.00	-0.46	0.00	0.02	-0.90	-0.05	-0.15	0.00	0.02	-0.01	-0.23	0.00	0.01	-2.01
DE_bks	0.25	0.21	0.17	0.37	0.62	0.22	0.27	0.37	0.35	0.09	0.41	-0.10	0.27	0.46	-0.02	0.00	0.13	0.13	0.27	0.27	**4.75**
IT_bks	0.31	0.20	-0.01	0.31	0.32	0.28	0.09	0.26	0.29	-0.03	0.40	-0.01	0.25	0.49	0.01	-0.13	0.00	-0.05	0.07	0.23	**3.29**
NL_bks	-0.18	-0.12	0.21	0.03	0.40	-0.09	0.02	-0.10	0.23	-0.12	-0.08	0.17	0.25	0.24	0.23	-0.13	0.05	0.00	-0.13	0.03	**0.90**
PT_bks	-0.10	0.09	-0.06	0.22	0.16	0.11	-0.01	0.36	0.02	-0.19	0.30	0.03	-0.10	0.21	0.00	-0.27	-0.07	0.13	0.00	0.03	**0.83**
ES_bks	-0.03	0.05	0.04	0.02	0.14	0.00	0.02	0.39	0.21	0.02	0.31	-0.31	-0.06	0.18	-0.01	-0.27	-0.23	-0.03	-0.03	0.00	**0.41**

Note: If the value in the cell is negative (blue horizontal bar) it means that the row variable is the net receiver and the column variable is the net sender. If the value is positive (red horizontal bar) the column variable is net receiver and the row variable is net sender. The last column shows the sum of net spillover effects of the row variable. In case the NET sum spillover is positive (bold values) then the variable is a net sender of the system

A5 OPTIMAL ROLLING WINDOW SIZE

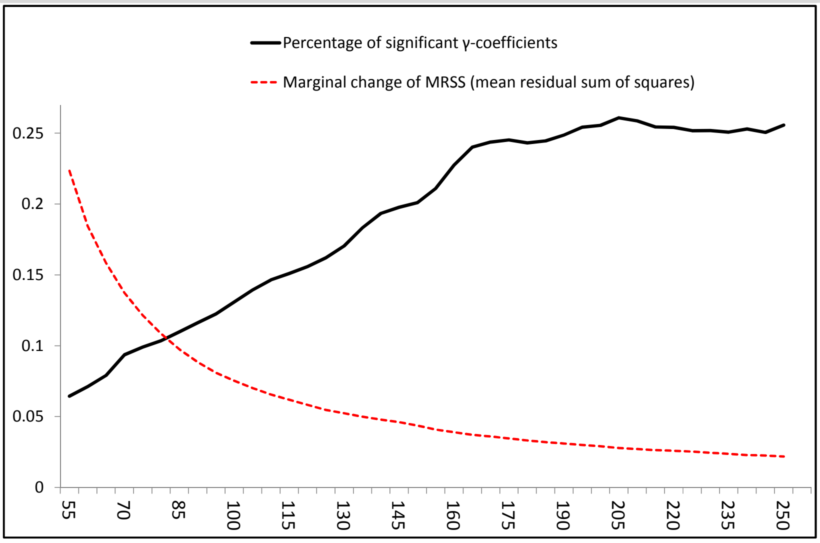
In this appendix section we provide an ad-hoc procedure to determine the appropriate window size for the rolling regressions of the empirical model presented in Section 3. Furthermore, we have implemented the contagion index for window sizes varying from 60 days to 120 days. These results show either a higher variance in VAR coefficients or lack to incorporate the developments in the CDS market in a timely manner. These robustness checks are available upon request.

The minimum sample size of any estimation period is dependent on the number of variables in the system including the order of lags. For the identification of an "optimal" rolling window size there is a trade-off between robustness and reliability of estimated VAR coefficients (the longer the sample the better the quality) on the one hand, and gaining information about a build-up of spillover effects over time (the shorter the sample window the larger the weight on more recent information) on the other hand. Against this trade-off we combine the results of the following functions. First, in the estimated VAR in eq. (1) at least one of the two γ-coefficients (corresponding to a lag length of two) of a shock variable has to be significant. Since we are interested in the percentage of significant γ-coefficients of the shock variable in the equations of response variables, we apply a joint test under the null hypothesis that γ_1 and γ_2 are simultaneously zero. In Figure 12 we present the percentage of tests that reject the null hypothesis of the joint test as a function of the window sample size.

Second, our aim is that measured spillover effects integrate potentially adverse developments for financial stability. As the sample size of the window increases the weight of new information decreases and spillover effects reflect new developments with a lag effect. We account for this aspect by computing the mean of residual sum of squares (MRSS). Since this function increases with the rolling window size, we are interested in the marginal change of the MRSS.

By finding the intersection of these two functions, we obtain an optimal rolling window size between 80 and 85 days. An illustrative representation of the two criteria is presented in Figure 12.

Figure 12: Optimal size of the rolling window



Note: On X-axis: rolling window size in number of days.