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Research Paper

Systemic risk and the sovereign-bank default nexus: a network vector autoregression approach

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ABSTRACT

Using the generalized value-at-risk method of Diebold and Yilmaz in their 2009 paper "Measuring financial asset return and volatility spillovers, with application to global equity markets" to measure the degree of spillover, we propose a metric for the systemic risk of a market. The metric considers the distribution of the impact to and from a market. This coskewness measure identifies key markets that play a central role in transmission across the market as a whole. We apply this method to detail the linkages between European Union (EU) sovereign bond markets and twenty major EU banks over time since 2000. We show that fiscal problems in Spain are transmitted via its internationally developed banking sector to the rest of Europe. This spillover has increased substantially since the outbreak of the crisis in the eurozone in May 2010. European Economic and Monetary Union-wide solutions have looked to stem the effects of ailing banking sectors and bad public finances as well as break the doom loop between banks and sovereigns. The creation of the European Financial Stability Facility and the European Stability Mechanism, in addition to European Central Bank

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action, has helped to decouple the situation of Spanish public finances from those of EU banks.

Keywords: spillover; contagion; sovereign bond spreads; fiscal policy; eurozone; financial crisis.

1 INTRODUCTION

The financial crisis started with losses on subprime loans in some US banks. However, it had global consequences, as uncovered debt positions triggered the collapse of major financial institutions both in the United States and Europe. This banking crisis called for policy intervention, not just by central banks, but also from the deep pockets of the taxpayer. Massive public sector aid was fired back at the financial sector as increased sovereign risk undermined bank balances. Once fiscal positions worsened considerably in several countries, excess holdings of sovereign debt left international banks exposed. Financial intermediaries further suffered the consequences of a slow economic recovery that resulted from rising credit risk and fiscal consolidation. The combined financial and fiscal crisis has been characterized by the speed of transmission and the strength of the feedback linkages across borders and financial markets.

The reason for the virulency of the crisis is a mixture of growing financial imbalances that have also distorted economic balances. The high degree of credit leverage in an increasingly global banking sector (Schoenmaker and Wagner 2013) has played a catalyzing role in transmitting economic and financial shocks. The microprudential type of regulation of individual financial institutions domestically became obsolete when financial markets became more integrated. Governments and central banks are therefore looking to strengthen macroprudential oversight in the banking system. In addition to spotting the negative externality problems that might result from a shock to a single financial institution, this oversight should perceive the risks building up in the macroeconomic environment that make the financial system more susceptible to collapse.

Control by newly set up institutions in the United States and the European Union (EU) requires new tools to measure the susceptibility of markets to systemic events (European Central Bank 2011). Systemic events, as opposed to idiosyncratic ones, spread from one market to another such that the overall stability of the system is impaired. If markets cannot withstand the collapse of a single market player or a few market players, systemic risk is high.

A measure of systemic risk should gauge the potential degree of instability in financial sectors, identify its origin and assess its scope for inflicting system-wide damages with high social cost. The aim is to highlight the fragility of the economic system to events that might result in a breakdown of the financial system, as well as assist governments and central banks in preventing an economic meltdown. Identifying the systemic players and the scope for them to amplify the effects of even small shocks is fraught with difficulties. First, the idiosyncratic or common shocks that hit the system may be exogenous, as, for example, with an economic downturn, or endogenous if they occur, for example, following a bank default or the burst of a bubble in credit and asset markets. Second, market structure determines the degree of contagion in a sequential fashion. In a random network in which all markets are connected to each other, containing the spread of a shock is more complicated, given the susceptibility of many players to contagion (Haldane 2009). By contrast, in a tiered network with a clear core-periphery pattern, central players become systematically more important and either "too big to fail" or "too interconnected to fail", amplifying the size of the shock to the market as a whole.[1] A set of quantitative indicators has been developed to measure systemic interactions in financial systems (Bougheas and Kirman 2015). Many studies use standard econometric tools to measure behavioral reactions based on some restrictions on the functioning of the banking system, or they use tail events to identify banks' reactions in crisis moments. Using the former approach, studies construct portfolio measures of the expected losses banks can suffer from their mutual links. The contingent claims analysis by Gray *et al* (2008), or the probability of default by Segoviano and Goodhart (2009), are examples of this approach. Some papers measure the systemic position of banks using concepts of cooperative game theory, such as the Shapley value (Tarashev *et al* 2010). Under the latter approach, extreme shocks to a market are isolated in order to see the consequences for all players. Acharya *et al* (2010), who compute the marginal system expected shortfall of capital in a bank; Adrian and Brunnermeier (2011), who use the conditional value-at-risk (CoVaR) measure of multiple banks; Chan-Lau (2010), who looks at co-risk; and Huang *et al* (2010), who study the distress insurance premium (DIP), all compute the marginal risk that a bank contributes to the overall risk of a financial system.

Most measures use day-to-day information from a specific segment of the financial market to analyze the direct interaction between market players. These measures can then be combined to indicate the overall stress in financial markets or linked to macroeconomic indicators to forewarn about more general instability in the economy (European Central Bank 2011). Early contributions developed early warning systems using univariate or multivariate logit/probit models (Berg *et al* 2005). These models are useful for signalling risks, but they do not capture idiosyncratic or systematic factors, nor do they evaluate the importance of exogenous or endogenous shocks to financial systems. Later studies therefore include macrofinancial data in order to measure the impact of common systemic events on the financial sector. Some studies

[1] For a complete survey on systemic risk, see Berger *et al* (2009).

that look at systemic crises in the banking sector have used event studies, but these have come to mixed conclusions, mostly because direct contagion is hard to distinguish from aggregate shocks.[2] Schwaab *et al* (2011), for example, compute the coincident and early warning indicators of the individual and simultaneous failure of financial institutions. They also measure how macroeconomic events affect this credit risk. Alessi and Detken (2011) include forward-looking measures of credit market activity in order to detect emerging instabilities.

A second group of studies applies network theory to analyze the entire interconnected system (Haldane 2009; Allen and Babus 2009). In contrast to the previous set of studies, which measure risk by statistical correlations in order to estimate the interconnections, network models look at the bilateral linkages directly. This holistic view of the system allows us to detect linkages between financial institutions so that the underlying structure of the market becomes clear; in addition, it takes into account the distribution of market positions across the system. Some have started building multi-agent networks with simple behavioral rules that simulate the microbehavior in networks (for an overview, see Acemoglu *et al* 2013). Others have focused on the simulation of shocks in different types of networks. While some papers do this at bank level, as in Mistrulli (2011) or Degryse and Nguyen (2007), others aggregate data at the sectoral level in order to analyze cross-border contagion (Degryse *et al* 2010; Castrén and Kavonius 2009). These measures look at counterparty risk from the bilateral flow of funds between institutions, such as interbank exposures (Degryse and Nguyen 2007; Castrén and Kavonius 2009). This results in a matrix of bilateral balance sheet exposures.[3] Still other studies employ mapping tools to plot the structure of the financial system using detailed data sets with bilateral transactions. A full list of studies on national payment systems or cross-border payments is provided in Bougheas and Kirman (2015).

In this paper, we develop a measure of overall systemic risk that is based on the forecast error variance decomposition of a value-at-risk (VaR) model including different asset prices (Diebold and Yilmaz 2009, 2011). Shocks to an asset price contribute to explaining the variance in other asset prices. This percentage contribution measures the bilateral spillover between two markets; ie, the connection between two markets, A and B, is based on the impact that a shock to market A has on market B in a couple

[2] Therefore, most studies have isolated a few extreme events in bank stock prices. Gropp *et al* (2009) use a multinomial logit model on these events and find that cross-border contagion risk among EU countries has, importantly, increased over time.

[3] The matrix is consequently used to measure overall risk exposure and run some counterfactual simulations on the overall resilience of the banking system (Upper and Worms 2004; Van Lelyveld and Liedorp 2006). Similar Monte Carlo experiments have been run on payment data in large-value payment systems.

of days' time. We define a market as systemic if it both sends to many other markets and receives from many other markets shocks with a statistically significant impact. Our metric multiplies the skewness of the spillover a market sends to, and receives from, other markets. A market that sends (and receives) shocks in a uniform way is more connected to other markets than a market with a very skewed distribution. Unlike Markose (2013), our measure does not define a threshold beyond which a market can have systematic effects. It only defines the degree of connection a certain market might have. As with other market price-based systemic risk measures, the metric reflects linkages as they have occurred in the market over the sample period. As a consequence, during periods in which imbalances are most likely to build up and the volatility of markets declines, as in an asset boom, the measure does not reflect sufficiently the buildup of risk. To tackle this volatility paradox, we account for changes in volatility. The metric is also time-varying in order to track systemic risk in real time, and it gauges directly the strength of bilateral and multilateral exposure.

We apply the metric to EU sovereign bond markets and EU banks over the period May 2000 to November 2015. We first track the magnitude and direction of spillover between bond markets and bank markets separately; we then look at the interaction between both. Our results show that, since the start of the financial crisis, countries such as Spain have become systematically more important. Applying the same metric to a vector autoregression (VAR) model including the stock prices of the twenty major EU banks, we find that Spain's internationally grown banking sector transmits domestic fiscal trouble to the rest of Europe. Banking integration exposes eurozone countries to the domestic financial and fiscal problems of Spain. Systemic interdependencies within the eurozone banking system are the result of bank holdings on portfolios of domestic and eurozone sovereign debt. Purely domestic solutions to restore fiscal imbalances are a necessary, but not a sufficient, condition to restore calm in sovereign bond markets. European Economic and Monetary Union (EMU)-wide solutions have looked to stem the effects of ailing banking sectors and bad public finances as well as break the doom loop between banks and sovereigns. The creation of the European Financial Stability Facility (EFSF) and the European Stability Mechanism (ESM), in addition to European Central Bank (ECB) action, has helped to decouple the situation of Spanish public finances from those of EU banks. Given the strong linkages between markets, a credible solution can have a large stabilizing effect, even in the short term, by reducing systemic risk (Allen *et al* 2011).

The paper is structured as follows. In Section 2, we review the VAR model for measuring spillover based on the VAR method of Diebold and Yilmaz (2009), and derive our metric of systemic risk. The main empirical results are discussed in Section 3 for sovereign bond markets, and in Section 4 for bond and banking markets. Section 5 summarizes the main results and discusses some policy implications.

2 EMPIRICAL FRAMEWORK

2.1 A VAR model to measure spillover between markets

We use the approach proposed by Diebold and Yilmaz (2009, 2011), which bases the measure of spillover on the forecast variance decomposition of a VAR model including prices of different assets (x_t). Diebold and Yilmaz (2009) start from the estimation of a covariance stationary variable VAR(p),

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t, \tag{2.1}$$

with x_t, including n variables and $\varepsilon_t \sim (0, \Sigma)$, a vector of independently and identically distributed (iid) disturbances. The VAR can be rewritten in its moving average representation,

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}, \tag{2.2}$$

where some regularity conditions on the A_i matrixes apply. The moving average coefficients are the key to understanding the dynamics of the VAR. The decomposition of the variance of the forecast error of some variable i at h steps ahead records how much of the variance is owing to shocks in another variable included in the VAR h periods after the shock. Therefore, it shows the percentage contribution of a shock to one variable to the time series variation of another variable. Call θ_{ij}^h this h-step-ahead forecast error variance decomposition, and call $\lambda_{ij}^h = \theta_{ij}^h / \sum_{j=1}^{n} \theta_{ij}^h$ the percentage contribution of θ_{ij}^h in the effect of error variances in forecasting x_i due to shocks to x_j over all n variables.

2.2 Summary statistics of spillover

The decomposition of the contribution of the shocks identified in the VAR allows us to study the spillover between different asset markets, and to dissect the strength and direction of the spillover between any two markets. Let us define "own variance shares" as the fractions of the h-step-ahead error variances in forecasting x_i due to shocks to x_i for $i = 1, 2, \dots, n$. Let us define "cross-variance shares" as the fractions of the h-step-ahead error variances in forecasting x_i due to shocks to x_j for $i, j = 1, 2, \dots, n$, such that $i \neq j$. Diebold and Yilmaz (2009) suggest using these cross-variance shares to measure the spillover from one series, x_i, to another, x_j. In particular, we can compute the percentage contribution of a change in daily quoted asset prices on the variation in asset prices of each particular market included in the VAR model. The matrix Λ of all λ_{ij} contains all bilateral linkages to and from two different markets.[4] The column for a market A contains $\lambda_{\mathrm{A}j}$ and can be read as the contribution of a shock to market A to asset prices in other markets. The entry λ_{AA} is the percentage contribution of a shock in explaining the movement of the market's asset price. The row for some market B contains $\lambda_{i\mathrm{B}}$ and can be read as the spillover market B receives from a shock to other markets. The dimensions of Λ grow quickly when adding more markets, so we need some summary statistics to understand the strength and direction of interdependence.

A first group of statistics to measure the degree of spillover is proposed by Diebold and Yilmaz (2009). The total spillover index measures the contribution of spillover of shocks between all variables included in the VAR to the total forecast error variance. The total spillover TS^h is nothing but the sum of the cross-variance shares across all variables (at a certain forecast horizon h). When we express it as a ratio to the total forecast error variation, we get the total spillover index, ie,

$$\mathrm{TS}^h = 100 \cdot \sum_{i \neq j}^{n} \lambda_{ij}^h \Bigg/ \sum_{i,j=1}^{n} \lambda_{ij}^h. \tag{2.3}$$

The method permits calculating the direction of spillover. A market i receives a spillover from all other $n-1$ markets, and this directional spillover DS^h can be expressed as follows:

$$\mathrm{DS}_{\to i}^h = 100 \cdot \sum_{j \neq i}^{n} \lambda_{ij}^h \Bigg/ \sum_{i,j=1}^{n} \lambda_{ij}^h. \tag{2.4}$$

Measure (2.4) is the sum of the row elements of the matrix Λ. Similarly, we can measure the spillover that a market i transmits to all other $n-1$ markets by

$$\mathrm{DS}_{\leftarrow i}^h = 100 \cdot \sum_{j \neq i}^{n} \lambda_{ji}^h \Bigg/ \sum_{i,j=1}^{n} \lambda_{ji}^h. \tag{2.5}$$

Measure (2.5) is the sum of each column of the matrix Λ, not including the own contribution of each market.[5] The directional spillover details how much of the total spillover comes from, or goes to, a particular source. The net spillover from a market i to all other markets j is then the difference between the gross shock received from and sent to all other markets, ie, $\mathrm{NS}^h = \mathrm{DS}_{\to i}^h - \mathrm{DS}_{\leftarrow i}^h$. This measures how much each variable i contributes to all other $n-1$ markets on net. It is then also possible to calculate the net pairwise spillover that shows how much each market i contributes to another market j in net terms. For this, we need to obtain

$$\mathrm{NS}_{i \leftrightarrow j}^h = 100 \cdot \Bigg[\lambda_{ij}^h \Bigg/ \sum_{k=1}^{n} \lambda_{ik}^h - \lambda_{ji}^h \Bigg/ \sum_{k=1}^{n} \lambda_{jk}^h\Bigg]. \tag{2.6}$$

[4] It is like the weight matrix measuring distance spatial econometrics.

[5] Alternatively, one may include the own effect of the shock.

Since this is a gross measure, two markets may have the same net spillover, but this would be relatively more important for a market that exerts or experiences little spillover. We therefore define the net index of market A as the absolute value of NS^h over the own contribution of a market. A number larger than 1 indicates that the spillover effect dominates the domestic effect, implying that this market is having a large impact, since flows from and to that market exceed the idiosyncratic effect of a shock to that market.

2.3 A metric of systemic risk

The matrix Λ reflects the weight and direction of linkages between any two markets. As a consequence, all elements of Λ are estimated values and, therefore, nonzero, such that the matrix is always complete. The interpretation would be that the resulting network is random with no tiered structure. Standard network metrics cannot be applied unless some restrictions are imposed. Gross and Kok (2013) estimate a similar VAR model to ours and set to zero all linkages that are estimated to be insignificant. The higher the threshold p-value, the more significant the linkages remain, and the larger the network becomes. Gross and Kok (2013) then calculate the betweenness centrality of the resulting network structure.

The alternative we propose is based on the homogeneity of the distribution of the bilateral linkages λ_{ij} (either in columns or across rows). A market with similar linkages λ_{ij} across all markets is more connected to the entire set of markets than a market that has just a few important neighboring markets. A market with a small absolute value of skewness $|S_i|$ in the row (or column) is a market that has relatively more links to other markets and is more integrated, as it sends (or receives) shocks with a statistically significant impact to a uniform group of markets. We also combine the measure of skewness along row and column dimensions, and the coskewness $|S_i \cdot S_j|$ indicates the skewness upon both the emission and receipt of shocks. A market is well connected both in sending shocks to other markets and receiving shocks from other markets if $|S_i \cdot S_j|$ is low. We call a market systemic if it is strongly connected to all other markets.

Unlike the Gross and Kok (2013) approach, our method uses the entire distribution of linkages between all markets to determine the systemic position of a market. Hence, there is no arbitrary threshold after which a link is considered to be relevant, so the underlying network structure is not ignored. But like the approaches based on network metrics, we evaluate the relative strength of each node in a system and the direction of their links. Our measure does not define the overall risk in the system; ie, the method identifies the systemic players, but it does not define their marginal contribution to overall risk, as in Acharya *et al* (2010), or the overall level of risk, as in Markose (2013). Rather, we follow Martinez Jaramillo *et al* (2012) or Gross and Kok (2013), who examine network centrality parameters but do not relate them to the stability of the financial network as a whole. The metric could still be used as a complementary tool in these structural approaches, however. As with other market-price-based systemic risk measures, the metric reflects linkages as they have occurred in the market over the sample period. As a consequence, in periods in which imbalances are most likely to build up and the volatility of markets declines, as in an asset boom, the measure does not sufficiently reflect the buildup of risk. To tackle this volatility paradox, we account for changes in volatility in the time-varying estimation of the VAR model.[6] As a result, shocks in tranquil periods with subdued volatility are still identified. This makes the metric useful as an early warning signal: the metric tracks systemic risk in real time, so it gauges directly the strength of bilateral and multilateral exposure.

2.4 Measuring systemic risk with a VAR model

A VAR model allows us to simulate the effects of a shock to a certain market onto other markets. An assessment of the significance and size of these effects can identify the market that is most vulnerable to shocks, or, conversely, that is a source of shocks to the system as a whole. A multitude of mechanisms might create interdependencies between asset markets, as they depend on starting positions, the integration of markets, regulation, policy changes and economic circumstances (Erce 2015). Sovereign bond markets are linked via myriad channels that follow portfolio adjustments by investors in response to idiosyncratic or global events. Such adjustments can give rise to market externalities (spillover) or pure contagion. Banks are linked via different channels. Their mutual financial exposure reflects direct linkages, but this can be reinforced by banks' capital positions, and it depends on the regulatory environment. Between banks and sovereigns, different linkages are at work as well. Deposit guarantees or government guarantees on bank liabilities burden the sovereign directly. The economic fallout of a banking crisis can drag tax revenues down for long periods, often in a period in which spending has risen due to economic stimulus. Banks are exposed due to large sovereign debt holdings, which are often concentrated on a few markets.

The approach of Diebold and Yilmaz (2009, 2011) improves on partial equilibrium approaches, as it measures transmission from one market to another. The index is therefore not a simple measure of the co-movement of markets that reflects a similar response to a common shock, but rather it measures the importance of an idiosyncratic shock in a market onto other markets, which is in line with Forbes and Rigobon (2002). The macroeconomic literature on international spillover has bypassed the fact that asset markets are not equally integrated internationally (Kaminsky and Reinhart

[6] In a companion paper, we use the Diebold and Yilmaz (2009) method to develop a test for contagion that takes account of large changes in volatility in financial markets (see Claeys and Vašíček 2014).

2000).[7] If spillover between markets is relevant, then this will affect all neighboring markets in general equilibrium.

Network approaches to gauge systemic risk isolate a specific network of transactions that link financial institutions together. A network can be represented by a set of nodes (markets) and directed links representing the bilateral relationships. Typically, the topological properties of a network are based on financial transactions between different financial institutions. In contrast, estimating a VAR model using market prices takes into account the entire set of factors that determine an asset price. The market assessment of all possible factors is reflected in the price of each asset market. The VAR model estimates all linkages, rather than constructing each of those channels. The approach takes a broader view by considering both direct and indirect effects, and it is therefore better suited to take into account macroeconomic developments as well as policy events, which are more interesting if we look at the linkages between sovereigns and banks. The VAR identifies the individual sources of vulnerability and allows a ranking of those markets that are most likely to lead to domino-like events across markets.

Our method applies traditional finance tools to derive a network of linkages. We follow a reduced-form approach to measure the impact of an idiosyncratic shock to a market onto other markets (Bougheas and Kirman 2015). Our approach is closest to studies that look at the contagion between individual markets (the so-called horizontal view of systemic risk).[8] Acharya *et al* (2012) develop a model of systemic risk and look at the effect of financial shocks on the probability that a bank gets undercapitalized. This expected shortfall depends on the bank's leverage, equity volatility, correlation of the bank's equity with a market index, and tail dependence on extreme events. Brownlees and Engle (2010) extend the empirical application of this method to compute marginal expected shortfalls for individual banks and aggregate shortfalls for the financial system as a whole.[9] A similar method is applied by White *et al* (2015), who include in their VAR model the VaR measures of bank stock prices and the banking market in order to test the sensitivity of a bank's VaR to shocks to the entire banking sector. They apply quantile regressions to test contagion under extreme events, and they look at the impulse responses to these shocks for a group of banks.

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[7] In contrast to approaches measuring the effect of a benchmark external factor, the method reflects that prices move contemporaneously on different financial markets, and this spillover is stronger between markets that are more closely connected.

[8] For a full overview of empirical measures of systemic risk, see European Central Bank (2011) and Bourgheas and Kirman (2015).

[9] These measures of the expected capital shortfall of a bank are the basis of a variety of weekly risk measures for big financial firms, under various market scenarios, that are published online by the New York University Stern Volatility Laboratory.

Our VAR methodology is close to that of White *et al* (2011), as we use daily market data to estimate the systemic risk position of each market player. Following Brownlees and Engle (2010), we take into account the effect of each market's problems on total market conditions, and the feedback of market distress on the position of the agent. Hence, systemic players are those that do not only suffer most individually during the crisis, but also contribute most to overall market losses. Since both market conditions and the position of each individual issuer are endogenous variables, the VAR model estimates this interaction between systemic issuers and the market.[10] Hence, we do not only look at sequential events but also measure simultaneous impacts across markets. This overall assessment takes into account the endogeneity of interactions (see Segoviano and Goodhart 2009). They develop measures of the joint distress probability of the banking system in the wake of a crisis from a panel of individual default probabilities. As in this panel approach, the dimensions of the model grow large for a small number of markets, and the bilateral matrix measures pairwise contagion. Since we use daily data, estimation of the VAR does not pose particular problems. The complexity of all bilateral linkages can be captured in summary statistics, and time-varying estimation allows us to track these numbers over time, while we can still identify the individual sources of vulnerability.

As in other structural- or reduced-form approaches for testing systemic risk (Bougheas and Kirman 2015), using market prices to evaluate bilateral exposure causes us to run into the volatility paradox (Borio and Drehmann 2009). Market risk is usually underestimated in a boom period in the run-up to a crisis. The reason is that volatility in markets remains subdued for a long period as markets go up. Systemic risk is only detected with a market-price-based approach when markets turn down and correlations between asset prices increase (Markose 2013). Hence, these measures do not serve well as measures of systemic risk. We tackle this issue in two ways. First, as the variance decomposition depends on the ordering of variables in the VAR, Diebold and Yilmaz (2011) adopt the generalized VAR (GVAR) framework of Koop *et al* (1996) and Pesaran and Shin (1998). In contrast to the Cholesky identification of the VAR model, which attempts to orthogonalize shocks, under the generalized approach shocks may be correlated; however, this is accounted for by using the historically observed distribution of the shocks. As a consequence, GVAR estimates are invariant to ordering and also take into account the volatility of the shocks. The draws of the VAR residuals (the shocks to a market) are based on the most extreme values, as in Segoviano and Goodhart (2009) or Hartmann *et al* (2005), but the response to those shocks is taken into account so that even small shocks can produce significant

[10] Adrian and Brunnermeier (2011) develop a similar bivariate measure based on the VAR of a bank and the total market.

impacts on other markets. Second, we estimate a time-varying VAR model over a 200-day window to check for any changes in market conditions.

2.5 Specification of the GVAR model

We choose to include in the basic GVAR model two lags of the asset price, as in Gross and Kok (2013), Conefrey and Cronin (2013) and Heinz and Sun (2014). We further compute the forecast error variance decomposition at a horizon of ten days (two weeks), which should be sufficient to capture the horizon at which spillover across markets occurs (Gross and Kok 2013).

In a first step, we examine EU sovereign bond markets using sovereign bond yield spreads over the corresponding German bond yield. Most other studies use credit default swaps (CDSs) that reflect the default risk of the issuer directly. Data on CDSs is not available over long periods, as the markets for these financial tools started to develop in the early 2000s but were still very illiquid, even for larger issuers. As a result, we would not capture the period prior to the spread of the financial crisis, so the measure of systemic risk would not be put to a true test. Unfortunately, the selection of the benchmark risk-free rate can slightly distort the results if there is a flight to quality toward the safe-haven German bonds. This problem is, in our case at least, partially mitigated, as this flight affects the spreads for all countries in the same way; we measure spillover by the contribution of a shock to one country's spread to the forecast error of another, rather than look at a contemporaneous correlation that could arguably increase if a common change in risk-free rate occurs.

In our second step, we look at the linkages between twenty major EU banks. We use the return on their stock listing as the relevant market price. Diebold and Yilmaz (2011) apply the same GVAR model to the volatility of fourteen EU banks' stock prices in order to examine their bilateral linkages. Our paper is similar, but it examines return linkages, which better reflect investors' perceptions of bank risks. Other papers that have analyzed linkages between the banking sector and sovereign bond markets look at CDSs as a measure of default risk. Yet, CDS markets for banks were rather illiquid prior to 2006, so our inferences on systemic risk would be blurred if we used this instrument. Our alternative measure is more likely to reflect market perceptions and capture relevant macroeconomic developments that influence the position of a single bank. In our third step, we analyze the interplay between sovereign bond markets and large EU banks. We estimate the GVAR model including all sixteen sovereigns and twenty EU banks.

2.6 Data set

We examine EU sovereign bond markets using daily data on the ten-year sovereign bond yield spreads of sixteen EU countries over the corresponding German bond yield during the period January 2000 up to November 2015 (closing price). Part (a) of Figure 1 on the next page shows the spreads for Spain and the other PIIGS countries (Portugal, Ireland, Italy and Greece). Following a long period of calm in bond markets since the start of the EMU, spreads have boomed in the wake of the financial crisis to reach unprecedented heights in Greece. The explosion of spreads takes place once fiscal problems in Greece first come to the fore in late 2009. All PIIGS experience a gradual rise in spreads, with the strongest reaction in Ireland and Portugal. Spreads for Ireland or Portugal reach levels between 1000 to 2000 basis points (bps). For Italy or Spain, spreads rise to around 500bps. Ireland manages to set itself apart starting in June 2011, as its spread starts to fall back to 500bps. However, the Italian and Spanish bonds continue to rise until 2012, as do the Greek and Portuguese spreads. Only once the ESM is established and a decision is made in February 2012 to write down Greek debt do spreads fall for all countries except Greece, where the spread hovers as market access is cut off during the writing down. Spreads have gradually started to fall since, and remain close to 200–300bps for all PIIGS.

For the core EMU countries (Austria, Belgium, France, Finland and the Netherlands), spreads have been moderate but have nonetheless risen a lot since the start of the financial crisis (see part (b) of Figure 1 on the next page). They experience similar effects to those above after the problems with Greece's public finances come clear in November 2009. As in Italy or Spain since June 2011, Austrian, Belgian and French bonds trade at around 300bps at the height of the autumn 2011 crisis. The deal with Greek debt, together with the statement by the ECB president to save the euro, calmed down the bond markets in core EMU countries.

By contrast, non-eurozone countries have not experienced the same turbulence in bond markets (parts (c) and (d) of Figure 1 on the next page). Denmark, Sweden and the United Kingdom pay just a marginal spread over German bonds at levels that are not unusual, given the default and exchange rate risk that these bond markets have. They even trade at higher prices than German bonds in late 2011, due to a flight to safety at the height of the debt crisis in Europe. For the central and eastern European (CEE) countries, spreads do not move higher during the crisis, except for Hungary, which suffered a fiscal crisis itself and asked for International Monetary Fund assistance in November 2011.

3 SPILLOVER ON EU SOVEREIGN BOND MARKETS

3.1 Spillover and linkages across markets

Inspection of Figure 1 on the next page suggests there are important interlinkages between sovereign bond markets, and that these linkages are not equally strong between all markets, and also vary over time in response to economic and policy

FIGURE 1 Sovereign bond spreads of EU countries over German ten-year bond yield. [Figure continues on next page.]

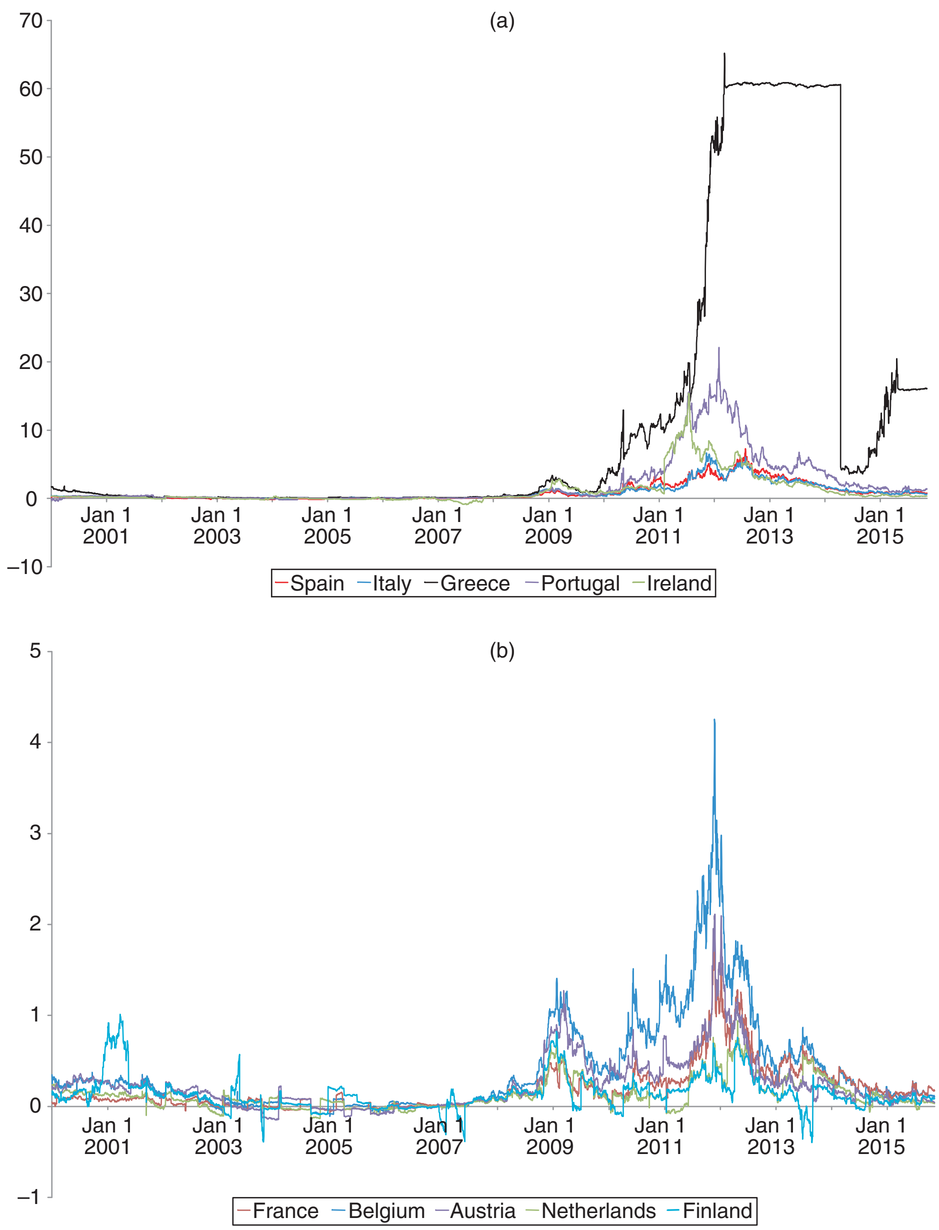
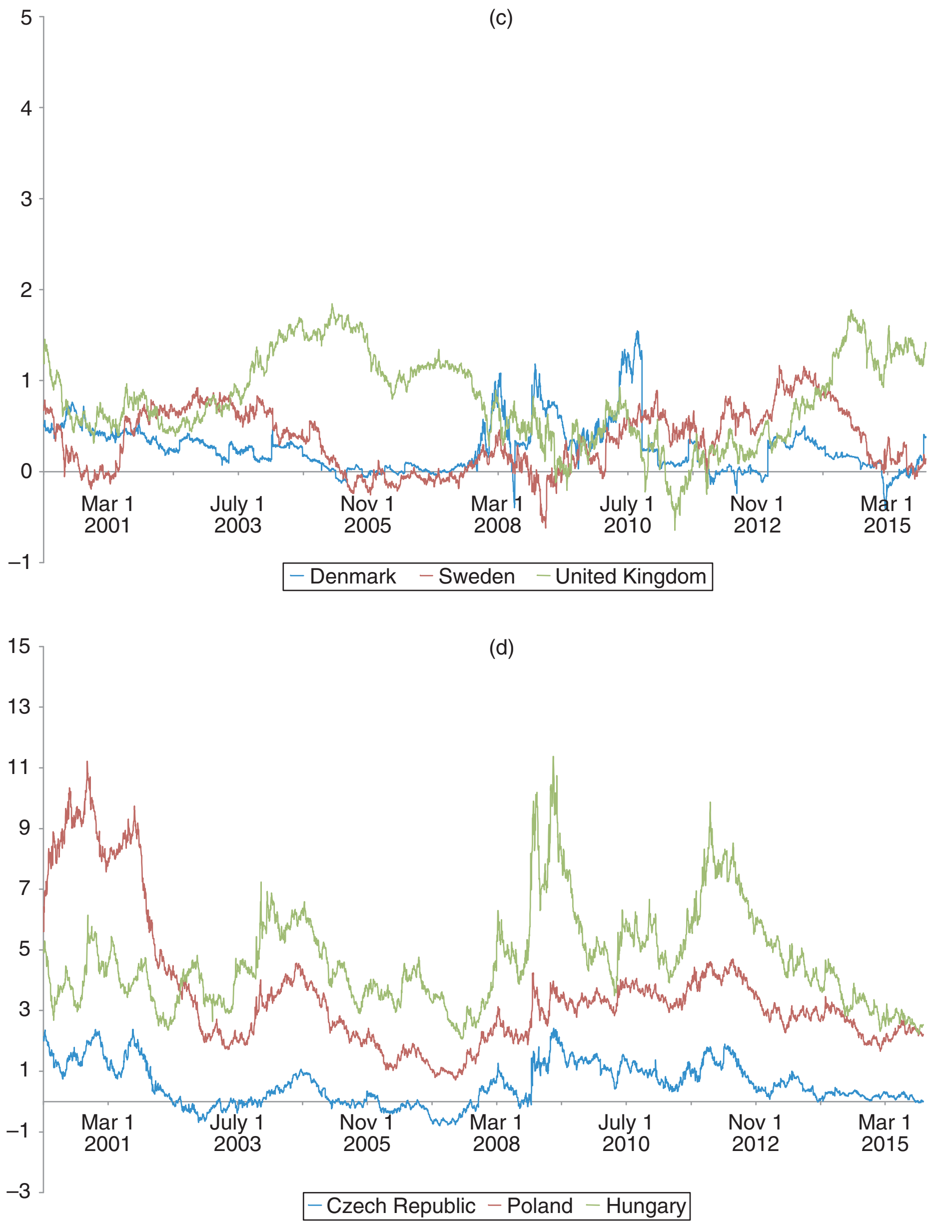


FIGURE 1 Continued.



Source: Bloomberg.

events. We first look at the spillover between all sixteen EU sovereign bond markets using the GVAR model, including all bond prices, over the full sample.[11] Table 1 on page 45 reports the contribution of a shock to bond spreads on other markets and some summary statistics. The bottom rows of the table sum the effect of shocks to a market on all others (either including the own effect or not). The right-hand column sums the effect a market receives from all other markets. We also report the net spillover of a market and its size relative to the total spillover (the net index). We then report the skewness for each direction of a shock from (and to) a market on the bottom (right) of each column (row). The coskewness measure of systemic risk follows in the right-hand column.

Table 1 on page 45 summarizes this directional spillover for the full sample from January 2000 to November 2015. It captures the linkages on financial markets and shows the structure and intensity of the degree of spillover between different sovereign bond markets on a color scale ranging from red for low spillover to green for the highest levels of spillover. Alter and Beyer (2014) label this the heat map of interlinkages. The total spillover amounts to 45%, meaning that slightly less than half of the variation in sovereign bond spreads can be explained by shocks to bond spreads in other countries. The other 55% of all movements are caused by purely domestic factors, ie, the idiosyncratic dynamics of the spread of the own market. This result confirms the importance of controlling for a global factor that reflects changes in other markets. The size of the global effect is in line with what other studies find: a substantial part of the bond spreads is not determined by domestic factors but by international bond markets.[12] In contrast to those studies, our result is not derived from a partial equilibrium assumption, in which global conditions cause domestic changes, but fully accounts for the feedback from domestic to international markets.

The spillover effects between bond markets are not homogeneously spread across markets. The bilateral entries in Table 1 on page 45 show that the country-specific effect is the largest for each country, yet while in non-EMU members (ie, Denmark, Sweden and the United Kingdom) the domestic factor accounts for a bit more than 80% of the changes in the bond spread, and for the CEE countries (ie, the Czech Republic, Hungary and Poland) it is around two-thirds, the idiosyncratic change varies between

[11] The results of the GVAR model are robust to changes in the number of lags included in the VAR, the number of steps ahead when making the forecast and the sample window. A GVAR model with four lags, a twenty-days-ahead forecast or a 400-day rolling window, respectively, will depict a similar evolution of the spillover over time.

[12] See Codogno *et al* (2003), Geyer *et al* (2004), Favero *et al* (2010), Dees *et al* (2007) or Manganelli and Wolswijk (2009). Financial integration has made investors' portfolios co-move more strongly, so that portfolio adjustments shift in one direction (in times of uncertainty, mainly to safe havens). This evolution has made bond yields increasingly dependent on global conditions, rather than on country-specific risk factors (Caceres *et al* 2010; Alper and Forni 2011; Kumar and Okimoto 2011).

25 and 60% for the EMU countries. Greece is an exception, as it is a completely separate market. This should not come as a surprise, given that the Greek government could not access the bond market anymore after early 2012. This confirms similar findings in Mink and de Haan (2013).

The color scale reveals that the bilateral linkages are quite distinct for non-EMU countries. Linkages are weak both among these and with the other EU countries. Less than 15% of the shocks to bond spreads for these countries spill over to other markets. The most extreme case is the United Kingdom, whose sovereign borrowing cost does not seem to have any effect on the other EU countries at all. The same applies to the spillover that non-EMU countries receive, as they are relatively insulated from bond markets in the eurozone. Nonetheless, Denmark and Sweden are substantially more linked to the EMU, probably because of their strong trade linkage to the core eurozone countries (as well as their participation in the Exchange Rate Mechanism (ERM II)). A similar explanation holds for the CEE countries, who have few effects on other markets, although their mutual linkages are strong. About one-third of all the spillover to other markets only occurs between the Czech Republic, Hungary and Poland. Despite its economic proximity and the importance of its banking sector, Austria's bond prices do not much affect the CEE, nor are they very much influenced by the CEE countries' bond markets.

Spillover dominates between EMU bond markets. They are strongly integrated and shocks to bond spreads affect other markets; they are not idiosyncratic. The spillover between EMU countries differs for the core of EMU countries (Austria, Belgium, France, Finland and the Netherlands); a group including Portugal, Ireland, Italy and Spain (PIIS); and, very differently from the others, Greece. For the core EMU group, the domestic effect is the strongest, but the spillover to other core EMU members and the PIIGS is just as important. For the PIIS group, bilateral linkages are very significant between individual PIIS countries, and this often explains up to 30% of the total variation in the spread. The Spanish spread, for example, affects Italy by 24%, Portugal by 11% and Ireland by 7%. The same is true for the Italian bond market. However, the PIIS also have a substantial impact on the core EMU countries: Spanish spreads affect Belgian ones by no less than 12%. Greece stands apart from the other bond markets: most of the evolution in Greek bond spreads is determined by domestic factors.

The Belgian bond market seems to be a systemic link in European bond markets. Its net index is the highest of all markets, and its net spillover to other markets is about 1.1 times as large as the effect of a shock on its own market. A similarly large net effect on EU bond markets comes from Italy (index 0.92) or Spain (index 0.79). The impact of shocks to the Belgian sovereign bond market is most equally spread over other EU markets. The skewness measure is the lowest for Belgium. The next two markets with the most evenly distributed impact are Italy and Spain. The markets that are most affected by others are France, Austria and Italy (column S_j in Table 1 on the facing page). Spain and Italy have a slightly more skewed distribution of the shocks they receive from others, in particular the PIIGS countries. Taken jointly, the coskewness measure indicates that the most systemic position in EU bond markets is taken by France, Belgium and Italy.

The reason that these three countries have such a strong impact across the EU depends on their economic size and their central position. Belgium economically belongs to the core EMU countries, and, despite a high public debt, it pays a subdued credit risk. This actually makes Belgium the country with the most open bond market in Europe: it is both the biggest receiver of shocks abroad and the country that most affects (in relative terms) the other EU countries. With regard to Spain, the size of its internationally grown banking sector strengthens the transmission of domestic fiscal trouble to the rest of Europe. Banking integration exposes eurozone countries to the domestic financial and fiscal problems of Spain. With regard to Italy, the size of its economy (the third-largest in the eurozone) and the bad shape of its public finances (associated with the largest sovereign bond market next to Japan) makes the transmission particularly strong. Our measure reveals what capacity countries have in the transmission of shocks onto other economies and leads to a classification that is similar to those in other studies (Gerlach-Kristen 2013; Blasques *et al* 2014). The skewness measure is comparable to the triggering capacity measure in Kalbaska and Gatkowski (2012). They compute a volatility adjusted correlation to account for contagion, along the lines of Forbes and Rigobon (2002), as the sum of the correlations from shocks in one market to another. They suggest the total impact depends on gross domestic product (GDP). Our measure, by contrast, includes this information and makes a direct ranking of the impact.

3.2 Time variation

The analysis based on full sample estimates might not fully uncover the change over time in all these bilateral linkages. The financial crisis is commonly believed to have significantly increased co-movements across asset markets, and the fiscal crisis starting in 2010 is thought to have done the same for co-movements across sovereign bond markets. A Bai–Lumsdaine–Stock test (Bai *et al* 1998) on the GVAR model for the central 70% part of the sample (between February 6, 2002 and May 4, 2010) shows that a significant break occurs between April 22 and 30, 2010 for the homoscedastic version, which corresponds to the first crisis meeting of the Eurogroup on the Greek fiscal situation.[13] Figure 1 on page 40 shows how the spreads of all EU countries have moved more closely together since early 2000, and how the PIIGS have seen a

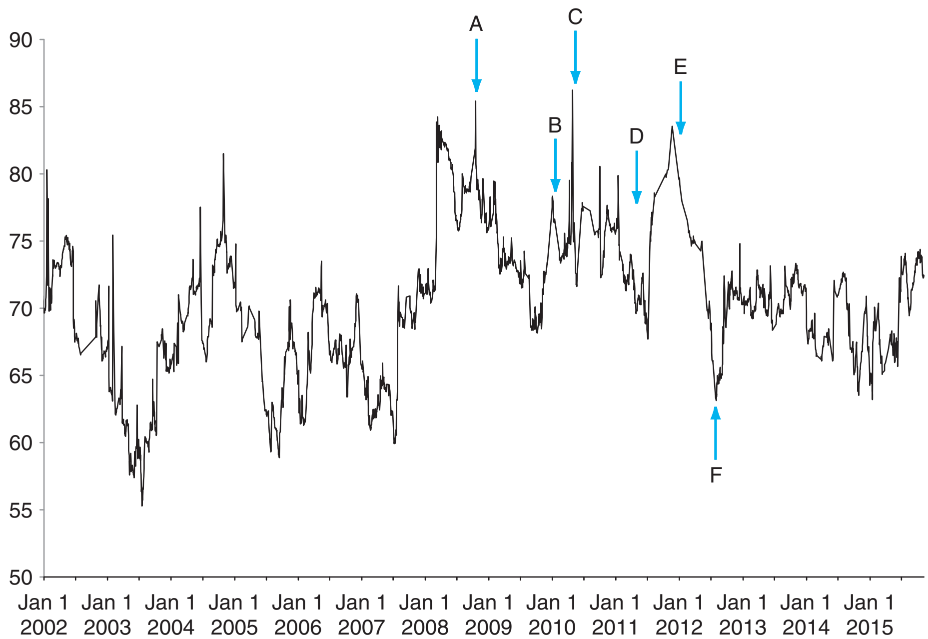
[13] The heteroscedastic version of the test indicates a break between July and September 2009, which marks the start of the gradual increase in spillover after the first peak in 2008.

TABLE 1 Map of bilateral spillover between EU sovereigns, May 2000–November 2015.

	Czech Republic	Poland	Hungary	Austria	France	Netherlands	Spain	Italy	Belgium	Greece	Portugal	Ireland	Finland	Denmark	Sweden	UK	from others	S_j	$S_i S_j$
Czech Republic	56.92	11.50	6.83	1.33	2.07	1.05	2.68	3.38	3.09	0.11	0.66	1.26	0.46	3.82	2.55	2.27	43.08	3.7	14.56
Poland	7.04	68.49	5.48	0.78	0.74	0.54	2.35	2.64	2.15	0.18	0.95	0.86	0.14	2.21	3.14	2.30	31.51	3.9	14.59
Hungary	5.28	11.93	62.14	1.51	1.25	0.71	3.24	3.58	3.16	0.36	2.04	1.03	0.13	1.53	1.09	1.03	37.86	3.7	14.76
Austria	2.00	1.78	2.17	28.33	14.69	8.62	7.92	10.10	17.69	0.20	1.01	1.62	2.43	0.74	0.33	0.39	71.67	1.7	4.36
France	2.39	1.60	1.51	11.52	27.63	8.20	8.72	12.48	17.57	0.38	2.42	1.51	2.34	0.71	0.57	0.45	72.37	1.6	2.94
Netherlands	1.87	1.42	1.36	8.82	12.47	45.20	4.39	6.46	9.63	0.32	1.62	1.17	3.15	1.21	0.57	0.33	54.80	3.2	11.39
Spain	1.99	1.81	1.35	4.78	6.13	3.07	38.31	21.77	9.39	0.38	5.84	2.92	1.16	0.50	0.35	0.23	61.69	2.6	5.79
Italy	1.93	2.11	1.41	4.50	7.58	3.86	24.09	30.73	12.92	0.50	5.02	2.94	1.11	0.26	0.59	0.45	69.27	2.0	3.40
Belgium	1.77	1.69	1.54	9.65	12.16	7.51	12.42	12.78	31.19	0.18	2.93	2.61	2.04	0.47	0.58	0.49	68.81	2.1	3.15
Greece	0.12	0.31	0.11	0.52	0.69	0.65	2.90	3.37	1.47	86.14	2.88	0.51	0.05	0.09	0.15	0.06	13.86	3.9	15.92
Portugal	0.50	1.33	0.62	4.07	5.86	1.84	11.25	11.03	10.94	0.93	42.08	8.43	0.54	0.16	0.26	0.17	57.92	2.9	11.21
Ireland	1.05	0.98	0.73	4.04	6.26	1.99	7.22	4.94	7.43	0.48	6.60	56.39	1.05	0.07	0.57	0.18	43.61	3.7	14.44
Finland	2.07	0.85	0.44	4.48	5.75	8.61	3.03	2.75	4.91	0.09	1.04	0.90	63.09	0.73	0.55	0.70	36.91	3.8	15.26
Denmark	3.54	2.79	1.36	0.64	0.54	0.74	0.78	0.36	0.63	0.28	0.27	0.30	0.29	83.90	2.14	1.44	16.10	3.9	15.85
Sweden	1.72	2.59	1.00	0.27	0.35	0.42	0.22	0.40	0.48	0.02	0.94	0.30	0.31	3.84	83.51	3.62	16.49	3.9	15.77
UK	2.12	1.76	1.01	0.61	0.48	0.62	0.86	1.38	1.03	0.01	1.05	0.42	0.48	1.04	5.78	81.36	18.64	3.9	15.82
Contribution to others	35.40	44.45	26.93	57.52	77.04	48.42	92.08	97.44	102.48	4.42	35.28	26.77	15.66	17.39	19.23	14.11	total spillover 45%		
Contribution including own	92.31	112.95	89.06	85.85	104.66	93.62	130.40	128.17	133.66	90.55	77.36	83.15	78.75	101.29	102.73	95.47			
From others	43.08	31.51	37.86	71.67	72.37	54.80	61.69	69.27	68.81	13.86	57.92	43.61	36.91	16.10	16.49	18.64			
Net spillover	7.69	-12.95	10.94	14.15	-4.66	6.38	-30.40	-28.17	-33.66	9.45	22.64	16.85	21.25	-1.29	-2.73	4.53			
Net index	0.14	-0.19	0.18	0.50	-0.17	0.14	-0.79	-0.92	-1.08	0.11	0.54	0.30	0.34	-0.02	-0.03	0.06			
S_i	3.90	3.73	3.91	2.55	1.74	3.46	2.21	1.65	1.48	4.00	3.77	3.87	3.97	3.98	3.97	3.98			

Source: Bloomberg, own calculation.

FIGURE 2 Dynamics of total spillover between EU sovereigns (rolling 200-day window, ten-steps-ahead forecast).



divergent move away from the German ten-year bond rate since 2010. To examine this time-variation in spillover, we follow Diebold and Yilmaz (2009) and run the GVAR model over a 200-day rolling window.

Figure 2 summarizes the evolution of total spillover. Spillover is substantial most of the time, as the index never falls below 50%. The 2001–6 period shows a high level of spillover, as most movements in bond rates were driven by the same factors. We can observe some specific spikes in spillover, for example, after the application of the Excessive Deficit Procedure to some EU countries, or following the revision of the Stability and Growth Pact in March 2005. The total spillover oscillates between 55 and 75% until the end of 2005, when it significantly declines to 55% in early 2007. This is an indication that the spillover measure with the volatility correction is able to detect common movement in spite of the subdued volatility on bond markets.

The start of the financial crisis in late 2007 raised the co-movement of sovereign bond spreads substantially. The spillover index shoots up to 70% and it has remained at this high level, with peaks of 85% until January 2012. We observe how the spillover peaks at the height of the financial crisis in 2008, when the crisis continues on financial markets in 2009 and as the eurozone sovereign debt crisis unfolds during spring 2010. We can discern the consequence of some major events on the co-movement of bond spreads, such as

(a) the collapse of Lehman Brothers (September 2008),

(b) the bankruptcy of Dubai World (November 2009),

(c) the fiscal trouble of Greece (May 2010),

(d) Portugal requests a bailout (February 2011),

(e) the spread of the fiscal crisis to Spain and Italy, and the set-up of the ESM (June 2011),

(f) the ECB president's speech on doing "whatever it takes" (August 2012).

We can further detail the spillover of a market onto others. We take Spain as an example, given its key position in EU bond markets. Part (a) of Figure 3 on the next page shows the total directional spillover of the Spanish bond spread onto other EU markets (including the own contribution of Spain). In order not to clutter the graph, we have grouped countries, as in Figure 1 on page 40, into core EMU, PIIGS, and the non-EMU countries, and each fraction shows the total spillover onto that group of countries. The overall level of spillover was subdued up until the start of the fiscal crisis, and a large part of its dynamics were determined by domestic shocks. The spillover from Spanish spreads did not shoot up from the start of the financial crisis; this only rose when fiscal trouble started to hit the country in 2009. The agreement on the European rescue fund in July 2011 dampened the spillover, yet ever since Spain asked for the bailout of its banks in June 2012, the spillover has remained at high levels. The spillover from the Spanish bond market mostly affects core EMU and PIIGS early in the sample, more or less in equal measure, but it becomes increasingly strong toward the other PIIGS countries. This can be seen in part (b) of Figure 3 on the next page, which plots the percentage contribution relative to the total contribution across country groups. The spillover to non-EMU countries is rather limited in all periods.[14] In a similar fashion, we can calculate the time-varying effect of shocks in all other markets' spreads on the spreads of the Spanish bond market (see part (c) of Figure 3 on the next page). The overall effect is rather stable, but there are stronger links from the core EMU and other PIIGS to Spain. This implies strong bilateral linkages, but the linkages from other markets are spread out in an even and stable way over time. The PIIGS seem to exert a slightly stronger effect from the start of

[14] This does not exclude changes within each group, for example, due to the decoupling of the Greek bond market.

FIGURE 3 Dynamic decomposition of the spillover of the Spanish bond market on EU sovereigns. [Figure continues on next page.]

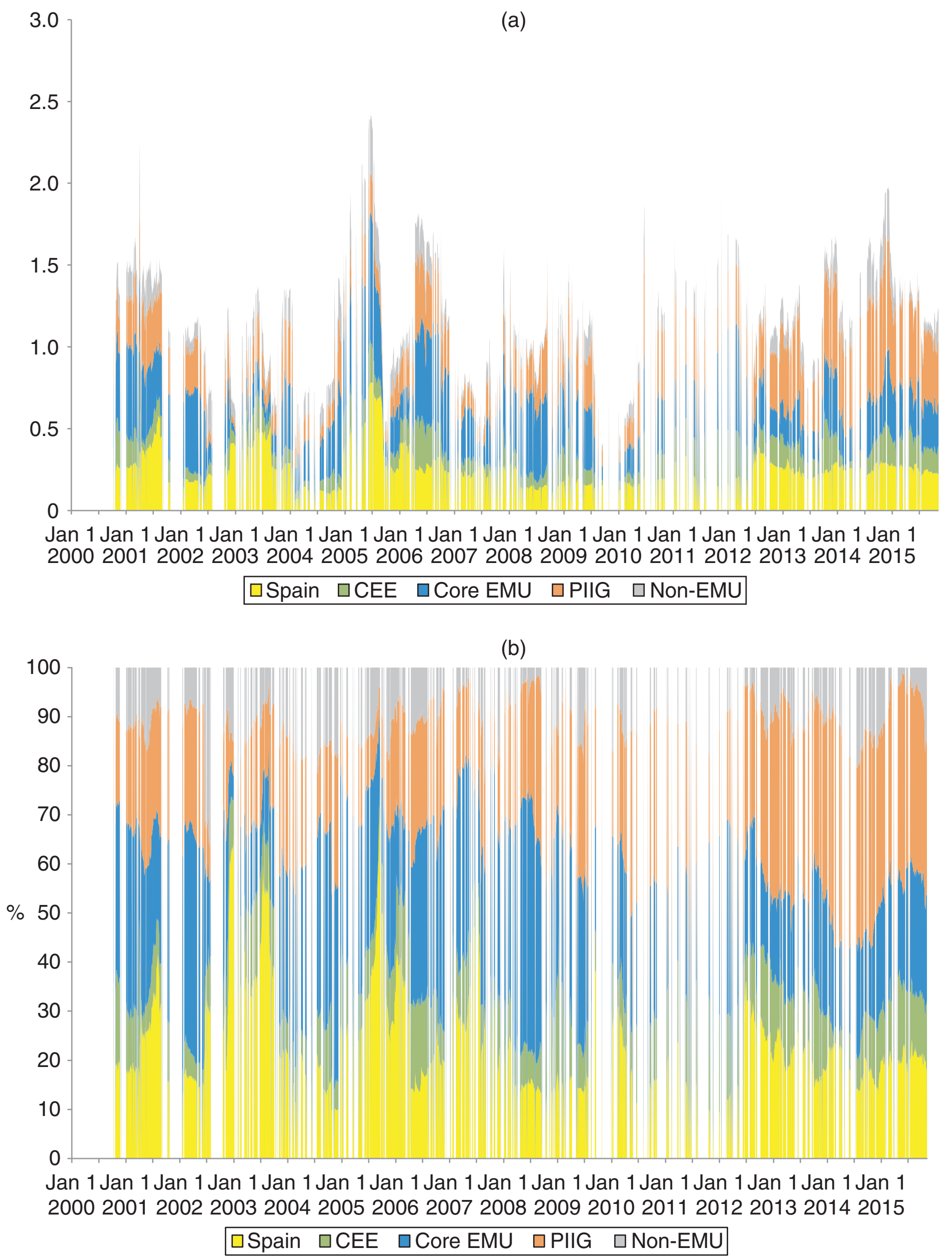
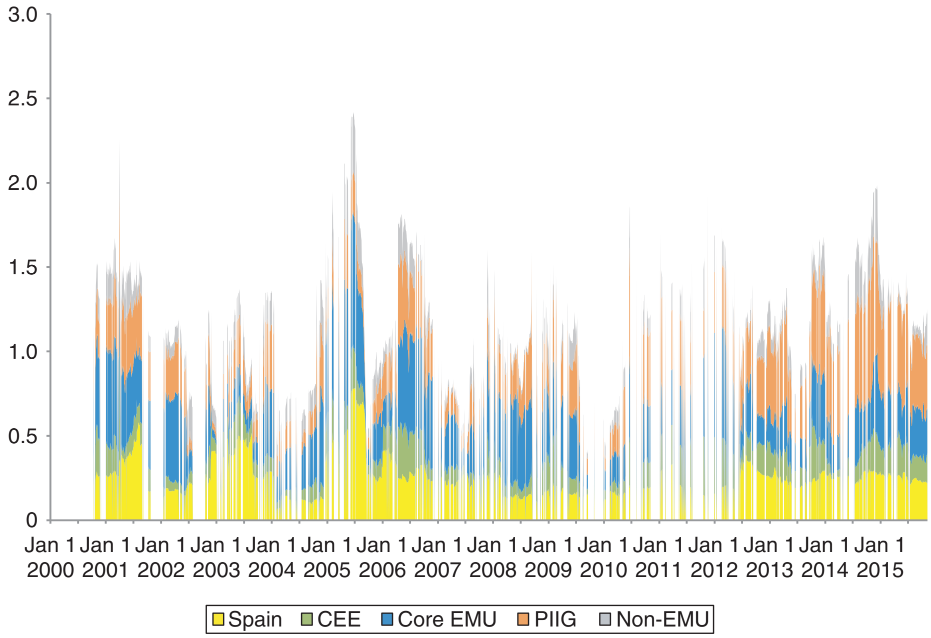


FIGURE 3 Continued.

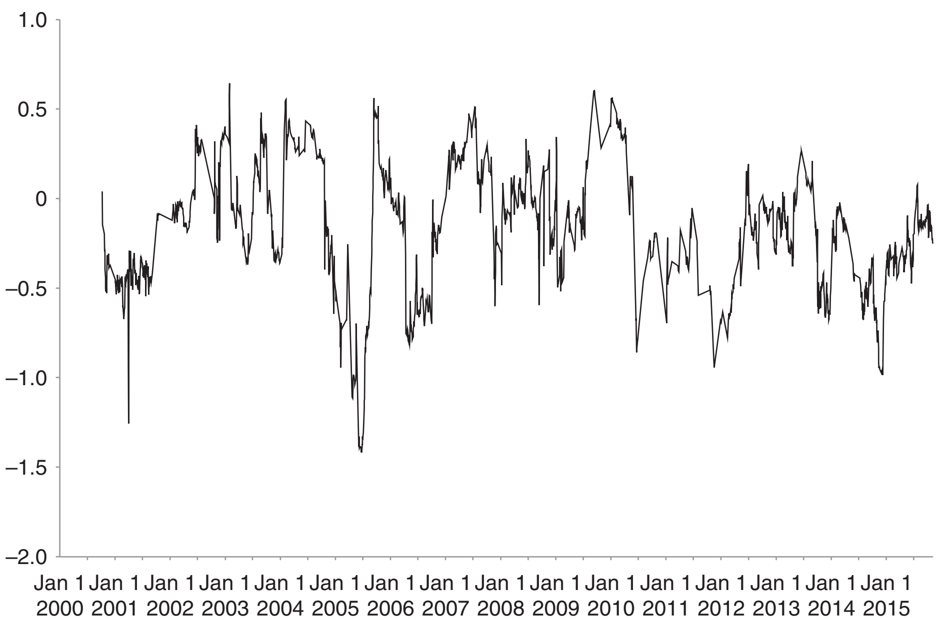


Spillover effect on core EMU, PIIG and non-eurozone countries ((b) scaled to 100%). *Source*: Bloomberg, own calculations.

the fiscal crisis. This likely reflects the contagion effect of Greek and Portuguese fiscal trouble to Italy and Spain. Consecutive rescue packages to Greece, Ireland and Portugal do not seem to have permanently separated those fiscal troubles from other bond markets (and, as Kilponen *et al* (2015) argue, only ECB actions directly geared toward easing the funding strains of the sovereigns and improving market liquidity have been effective in calming sovereign markets). During the autumn of 2011, the effect of core EMU becomes stronger again. This again corroborates the argument that the debt crisis has turned European, due to trouble in the Spanish banking sector.

Since Spain has stronger effects on other markets than it receives from those bond markets, this implies a positive net spillover of the Spanish bond market (see Figure 4 on the next page). Spanish public finances contribute to spread movements in other PIIGS and the core EMU countries, and this has been the case in particular since the start of the fiscal crisis. Figure 4 suggests that the increasing effect of Spain on other bond markets began once its fiscal problems started to grow, and it has only been halted by the readiness of the ECB to intervene in bond markets in July 2012. De Grauwe and Ji (2012) argue that the surge in spreads over 2011 is disconnected

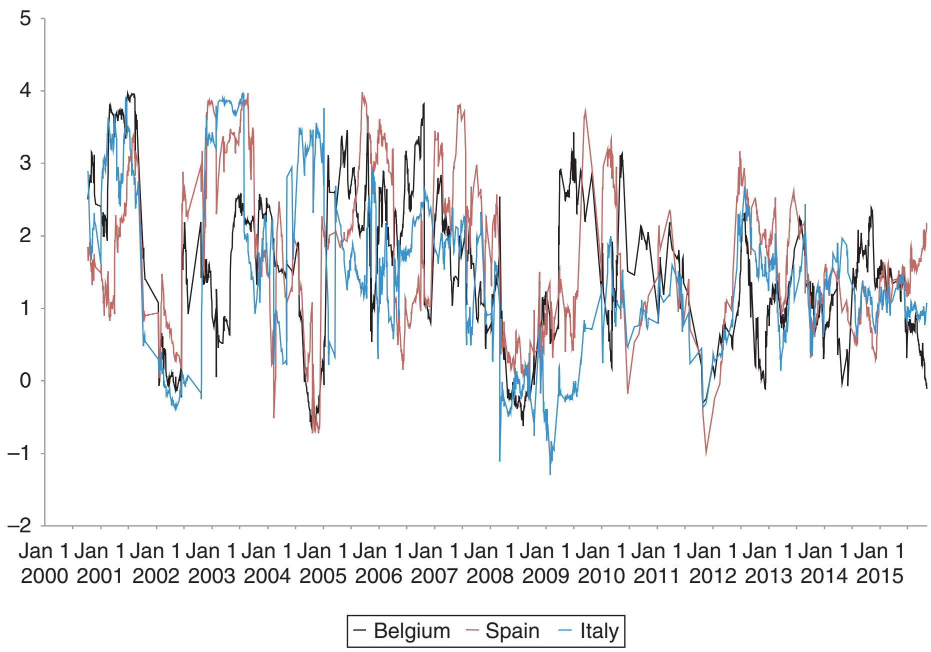
FIGURE 4 Dynamics of net spillover effect from Spanish bond market to EU sovereigns.



from the rise in public debt ratios and is a sign of the mispricing of sovereign risk. This makes spillover the main driver of sovereign bond spreads across the monetary union.

Figure 5 on the facing page then shows the variation in systemic positions by plotting the skewness measure for Belgium, Italy and Spain. The time-varying plot shows that as the crisis develops, these countries start to become much more central in the transmission of shocks on sovereign bond markets. The situation rebounds in early 2009 for Belgium, and later that same year for Spain and Italy too. The creation of the EFSF, to provide loans between eurozone countries in order to support failing financial institutions, again places Italy and Spain in a more central position in the bond markets, probably due to the worsened state of public finances. Further doubts in 2010 and 2011 on the solution of the Greek debt crisis accentuate the systemic position of all three bond markets. The strength of the impact of shocks on other EU countries only recedes once the ECB starts buying Spanish and Italian bonds in January 2012 under its Securities Markets Programme. This policy, and further ECB action in 2012, managed to reduce the centrality of these three sovereign bond markets in international transmission.

FIGURE 5 Dynamics of coskewness of Belgium, Italy and Spain.



4 SPAIN AT THE JUNCTION OF BOND PRESSURE AND BANK MARKETS

The financial and fiscal crisis is characterized by the speed of transmission and the strength of the feedback linkages across borders between sovereign bond markets and the banking sector. Spain has seen a rapid rise in public debt due to a strong fall in tax revenues since the housing bubble burst. The Spanish government could put the cost of a bailout of the banking system on a €100 billion rescue loan from eurozone funds requested in June 2012 (via the ESM). The problems of the Spanish banking sector were mostly concentrated in its ailing savings banks, which suffered the decline in real activity and the fall in housing prices. These hidden losses threatened the healthier parts of the Spanish banking sector and also public finances.

4.1 Linkages in the EU banking sector

We examine how the combination of mutual exposure between banks spills over across EU borders. We select a sample of the twenty major EU banks as per their level of average total assets over the period 2000–2011 (see Table 2 on the next page).

TABLE 2 Major twenty EU banks by total assets (average over period 2000–2011).

BNP Paribas	Crédit Agricole	Commerzbank	Natixis
Deutsche Bank	Banco Santander	Intesa San Paolo	STA
HSBC	Lloyds	Nordea	KBC
Barclays	Société Générale	Dexia	SEB
RBS	UniCredit	BBVA	Monte dei Paschi

The two major Spanish banks in our sample are Banco Santander and Banco Bilbao Vizcaya Argentaria (BBVA). We estimate the GVAR model using the returns on the banks' stock listing as the relevant market price.

We do not display all bilateral linkages in Table 3 on the facing page: we just summarize those from Banco Santander and BBVA. The reason is that, in contrast to the linkages between sovereigns, all banks are quite strongly linked with all other banks. For each bank, even if the shock to its own return has the largest impact, the linkages to other banks outweigh the idiosyncratic ones by far. On average, about 83% of a bank's return is determined by the shocks to other banks' returns. Most banks send and receive a lot of shocks to and from all other banks, so the distribution of the bilateral effects is rather uniform.

Both Spanish banks are mostly exposed to each other. Their strongest bilateral link is between themselves. In addition, they have a strong impact on other EU banks. Within the most important twenty EU banks, the net index shows that BBVA and Banco Santander are the third and, respectively, fourth banks with the most impact on other EU banks, just behind Société Générale and BNP Paribas (see Table 3 on the facing page). They also affect most uniformly the returns of other EU banks, with a skewness level that is higher only for BNP Paribas. At the same time, both Spanish banks are strongly exposed to shocks from other banks. BNP Paribas and Société Générale have the most uniform distribution of impacts, but BBVA and Santander follow closely with skewnesses of 1.18 and 1.37, respectively. As a result of this strong and uniform impact, it is no surprise that BNP Paribas, Société Générale, Banco Santander and BBVA are the four banks with the highest coskewness measures of systemic risk. The top five of strongly exposed banks is completed by UniCredit.

This result corresponds with other measures that have been suggested to measure the strength of links between banks.[15] Schoenmaker and Oosterloo (2005) propose a set of metrics on the cross-border penetration of banking assets. They look at the share of assets held by domestic and EU credit institutions as a percentage of the total assets of credit institutions in an EU country. They show that every EU bank market is still dominated by domestic banks. Table 4 on page 54 shows the ranking of the

[15] See Moshirian (2006) for an overview of the literature on international banking.

TABLE 3 Bilateral spillover from Banco Santander and BBVA to EU banks, January 2000–November 2015.

	Santander	BBVA	S_j	$S_i S_j$
BNP Paribas	6.47	6.61	1.02	1.57
Deutsche Bank	5.87	6.06	1.67	4.71
HSBC	5.55	5.62	2.60	8.82
Barclays	4.79	4.98	2.33	6.54
RBS	4.27	4.42	2.91	10.14
Crédit Agricole	5.75	6.12	1.53	4.20
Santander	12.08	9.92	1.37	2.73
Lloyds	4.52	4.74	2.47	7.43
Société Générale	5.99	6.40	1.11	1.88
UniCredit	6.20	6.70	1.63	3.90
Commerzbank	5.02	5.52	2.77	11.21
Intesa San Paolo	6.67	7.07	1.54	3.59
Nordea	5.40	5.60	2.49	8.89
Dexia	2.77	2.69	4.46	19.95
BBVA	9.55	11.66	1.18	1.86
Natixis	4.81	5.07	3.23	13.80
STA	5.53	5.66	3.09	12.25
KBC	5.27	5.64	3.08	12.92
SEB	5.17	5.45	2.44	8.29
Monte dei Paschi	5.73	5.93	3.46	14.82
Contribution to others	105.35	110.21	TS: 83.20%	
Contribution including own	117.43	121.87		
From others	87.92	88.34		
Net spillover	−17.43	−21.87		
Net index	−1.44	−1.88		
S_i	2.00	1.57		

TS denotes total spillover.

twenty-seven main EU banks in 2002 by total assets and their total activity abroad and in EU countries. The most international banking groups (ie, those with the most assets abroad) are HSBC Holdings, Deutsche Bank, BNP Paribas, HypoVereinsbank, ABN Amro, Santander, ING Group, BBVA, Fortis Group, Nordea Group and Westdeutsche Landesbank. Most of these international banks are not global players but EU banks, as they keep most activities in the EU. This is not the case for the Spanish banks. They hold relatively more assets in non-EU countries.[16]

[16] Schoenmaker and van Laecke (2007) update these numbers and compute a transnationality index (TNI), developed by Sullivan (1994), which weights the assets and revenues side, as well as employment, in branches at home and abroad as a percentage of total bank activity. The conclusions for EU banks are similar to those in Schoenmaker and Oosterloo (2005).

TABLE 4 Measures of cross-border activity of the twenty-seven major EU banking groups in 2001 (Schoenmaker and Oosterloo 2005).

Banking group	% of business domestically	% of business in EU	Banking group	% of business domestically	% of business in EU
HSBC Holdings	33	8	BBVA	34	10
Crédit Agricole	81	10	Intesa San Paolo	67	14
Deutsche Bank	39	30	Fortis Group	52	45
RBS	74	7	Commerzbank	72	21
BNP Paribas	46	24	Abbey National	92	6
HypoVereinsbank	50	29	Dresdner Bank	64	22
HBOS	93	4	Nordea Group	18	79
Barclays	71	7	UniCredito Italiano	68	7
ABN Amro	33	34	Dexia	56	40
Santander	38	7	Westdeutsche Landesbank	49	32
ING	43	45	Bayerische Landesbank	65	28
Rabobank	76	8	KBC Bank	51	36
Société Générale	64	13	Crédit Lyonnais	76	8
Lloyds TSB Group	84	8			

Other evidence on the degree of connectedness of Spanish banks comes from Schoenmaker and Wagner (2013), who compute measures of the integration of banks, country by country. They find that the German, Dutch and British banking markets are the most integrated in Europe, as they score highest both in terms of expansion abroad by domestic banks and from foreign banks domestically. The French and Spanish banks have experienced a strong expansion abroad, but few banks from other EU countries have established themselves in their market, so their banking market is not well integrated overall. For example, Banco Santander has expanded in the United Kingdom, but UK banks have hardly set foot in the Spanish market.

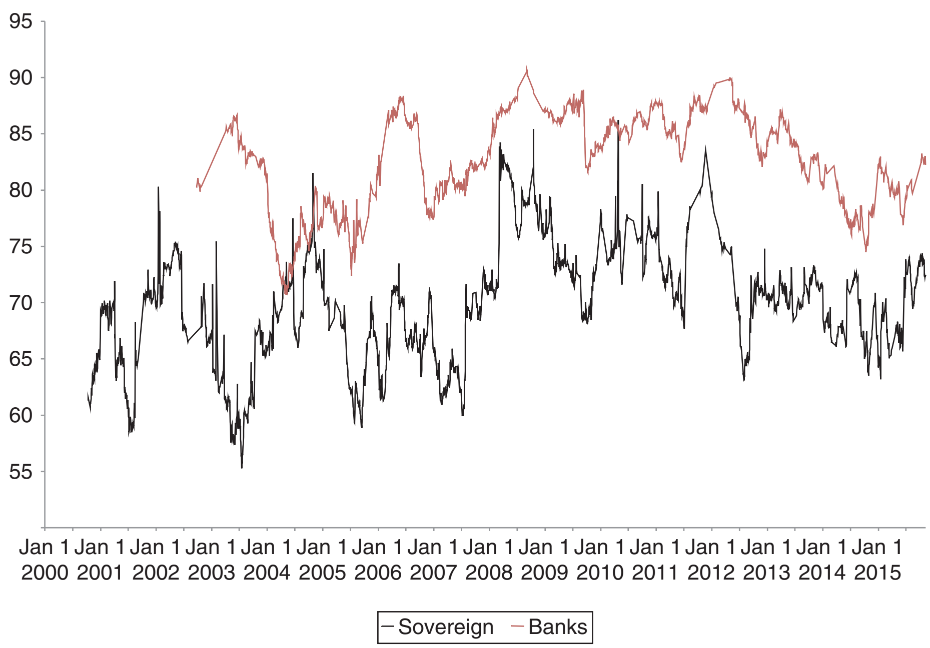
Our measure updates the evidence in Schoenmaker and Wagner (2013) to November 2015 and shows that the major EU banks are indeed exposed to each other, and that French and Spanish banks in particular are the most systemic ones. This exposure mostly comes from the expansion abroad of Spanish banks. Hence, the outward integration of French and Spanish banks has made them contribute to market sentiments in Europe, but it has also made them more vulnerable to these developments. As a result, Santander and BBVA are among the top systemic banks in Europe.[17]

The EU banking system does not seem to have experienced increased spillover since 2007. We can see this from a plot of the variation in total spillover over time (Figure 6 on the next page). The total spillover between bank returns is high and quite stable over time. The index fluctuates between 75 and 90%. In comparison with sovereign bond markets, the EU banking market is quite well integrated. Well before the start of the financial crisis, the spillover index had already started to rise, and it has stayed very high throughout. Hence, bilateral exposure between the main European banks predates the crisis.

The crisis does nonetheless play a role, and the fiscal positions of EU countries seem to have a particular effect on EU banks. We can see from Figure 6 on the next page that major changes in the index for banks and sovereigns move in the same direction during the crisis. When the spillover between sovereigns suddenly rises, there is also a contemporaneous rise in the spillover between EU banks. After the statement from Mario Draghi about doing "whatever it takes" in July 2012, the linkages between EU banks fall to substantially lower levels, while the linkages between EU sovereigns also drop to a lower level. ECB policies seem to have been very effective in diluting the feedback loop between sovereigns and banks. As fiscal problems became less of a common problem in the eurozone, EU banks did not get involved anymore, and markets started to recognize the differences between banks.

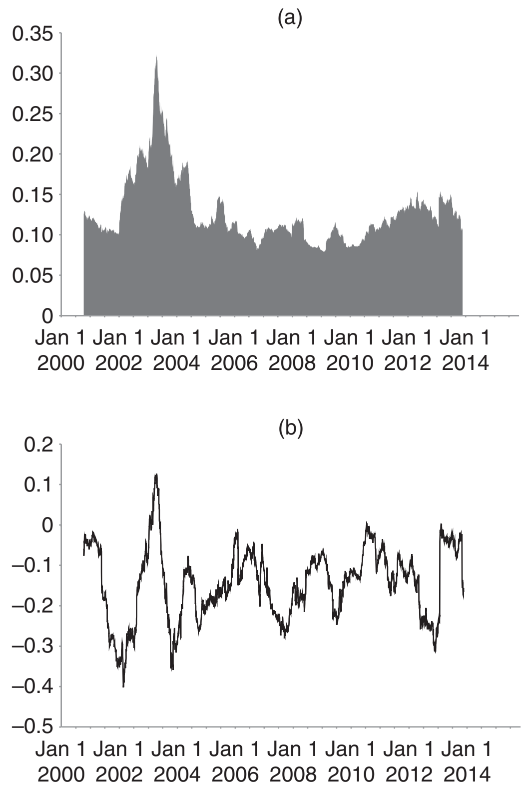
[17] See the Centre for Economic Policy Research Report by Allen *et al* (2011), which shows that the ratio of foreign to total assets for major banks in Europe is highest for Deutsche Bank, Banco Santander, UniCredit, BNP Paribas and Société Générale.

FIGURE 6 Dynamics of total spillover between EU sovereigns or EU banks (over a rolling 200-day window, based on a ten-steps-ahead forecast).



Likewise, the importance of the big Spanish banks in EU markets is not a by-product of the crisis. Figure 7 on the facing page shows in detail the positions of both Banco Santander and BBVA, and it plots (a) the total contribution and (b) the net spillover. They have always been strong contributors to EU banking markets: their total contribution to EU banking markets does not increase with the start of the financial crisis. However, their net impact starts to show a rather similar pattern from 2007 onward. While both banks have persistently been net contributors to market developments, their net impact moves more strongly together from 2007 onward. This high correlation should not come as a surprise, since their mutual linkages are so close. It is also, however, the consequence of both banks reacting in a similar fashion to common policy developments. The spillover gets especially strong in 2009, but this effect falls back during the spring of 2010, when the EFSF was created to bail out troubled banks in eurozone countries. Fiscal trouble in all PIIGS that came to the fore in 2010 and 2011 makes both banks' impacts increase to a higher level, BBVA in particular. The setting up of the ESM (February 2011) and the July 2011 agreement on the ESM seem to have had mixed effects on spillover. Only

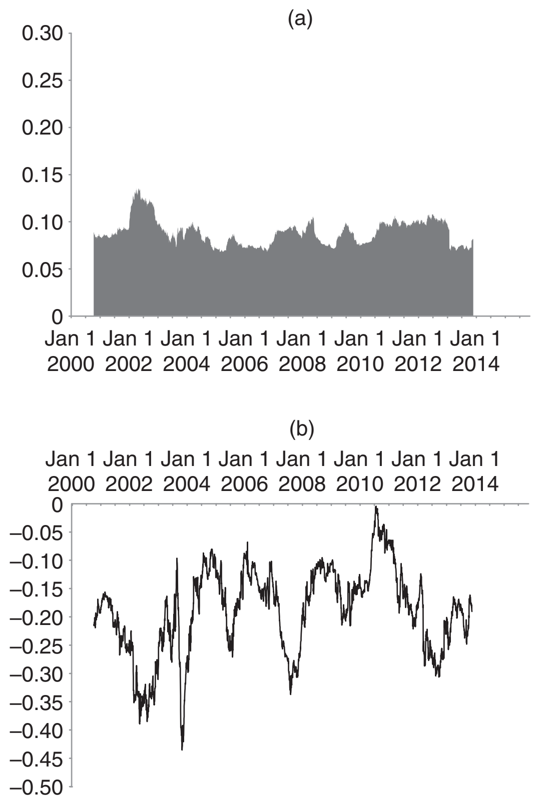
FIGURE 7 (a) Total spillover and (b) net spillover from Spanish banks: Banco Santander. [Figure continues on next page.]



interventions by the ECB as of July 2012 to provide easy financing means to banks seem to have controlled the net contribution of Spanish banks, mostly for Banco Santander.

We can further see the systemic importance of Spanish banks from the evolution of the coskewness measure of their total joint contribution to and from all other EU banks (parts (a) and (b) of Figure 8 on page 59). Their effect on other markets is rather concentrated in the early 2000s, but it has steadily dropped over time. This decline reflects the increased activity of both banks in international markets. During the crisis, both Banco Santander and BBVA emit shocks to all other EU banks. Since the effect of all EU banks on the Spanish banks is quite stable and high over time, Spanish banks are net contributors to instability in the European banking sector.

FIGURE 7 Continued. (a) Total spillover and (b) net spillover from Spanish banks: BBVA.

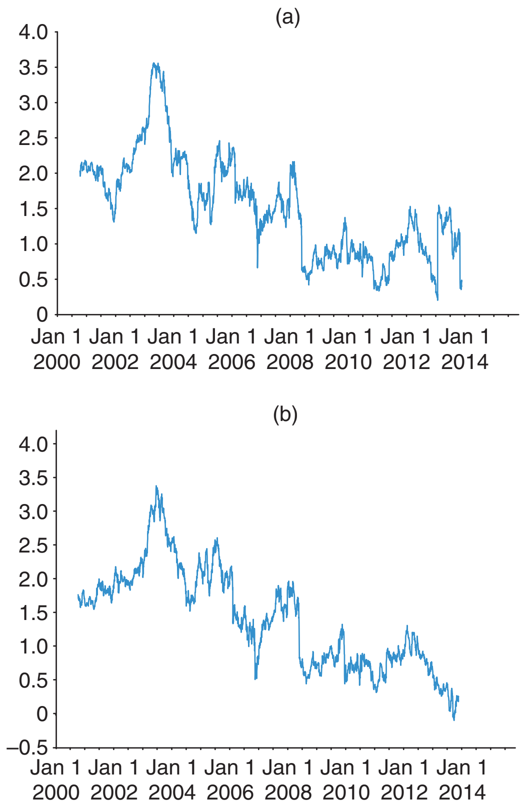


4.2 The banking sector, public finances and spillover

Banking crises have typically been followed by sovereign crises. The indirect effect of a disruption in the financial system is a prolonged negative effect on output (Kaminsky and Reinhart 1999). The recovery time tends to be a decade or longer, if there is a return to normal growth patterns at all (Cerra and Saxena 2008). Tax revenues fall to substantially lower levels for a prolonged period. The direct effect of a collapse of the banking sector is the fiscal cost it supposes as governments' intent to save the financial system (Honohan and Klingebiel 2003). Sovereign debt positions and the health of the banking system are therefore directly related (Mody 2009).

The growth of international banking, in particular in the eurozone, has become a key channel of international transmission. As a consequence, the effects of a purely domestic banking crisis now have consequences not just for the sovereign; through

FIGURE 8 Dynamics of the coskewness measure of systemic risk for Spanish banks.

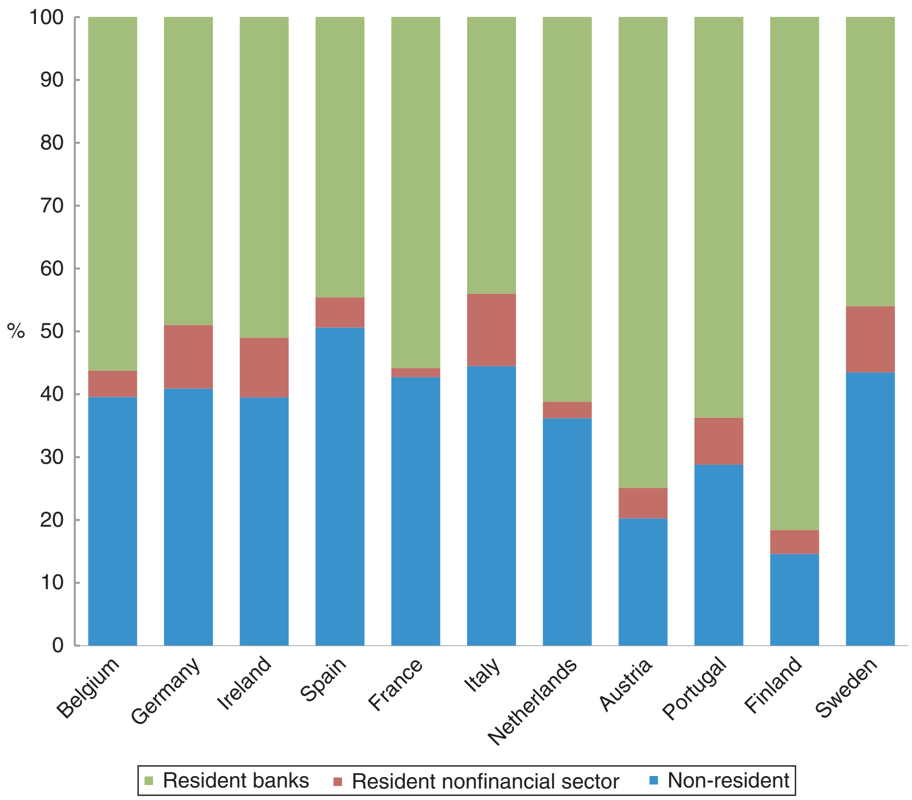


(a) Banco Santander. (b) BBVA.

the interbank market, they spread to other international banks. The direct impact is banks with an international presence in the market suffering the combined banking/sovereign crisis. The crisis implies a decrease in the value of collateral held by the banks (liquidity channel) and a decrease in the value of the banks' portfolios (balance sheet channel). The holdings of debt of the sovereign aggravate this problem, as higher rates further erode the value of collateral and the portfolio. This feeds back into difficulties in the "home" banking sector of the international bank, and it can also worsen the position of the "home" sovereign (Erce 2015).

The spread of a banking/sovereign crisis from Greece to other eurozone countries shows how fast relatively small problems can translate into a major banking and sovereign crisis. The especially virulent link between banking and fiscal crises

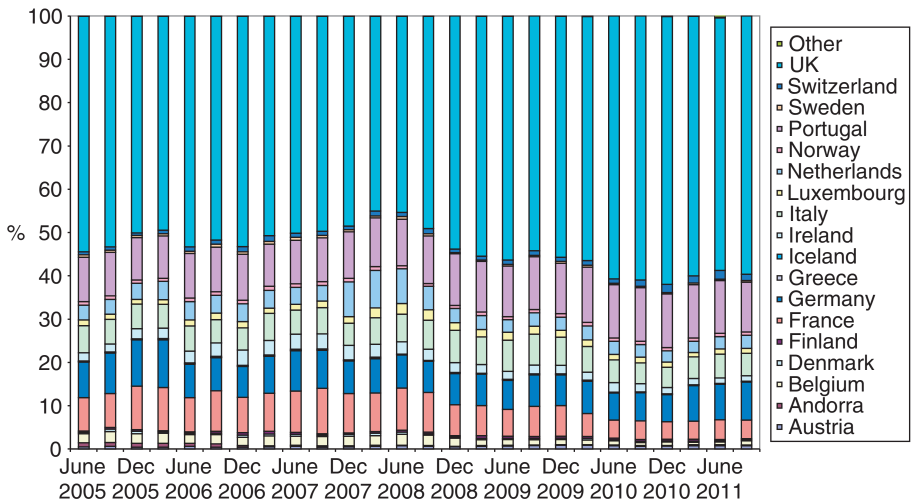
FIGURE 9 Holdings of debt by sector, 2010.



Source: Eurostat Government Statistics (2011).

in the eurozone is due to the absence of a European banking resolution framework in a closely integrated EMU banking market (Merler and Pisani-Ferry 2012). Even relatively small banks on a European scale are large banks for small eurozone countries. The latter cannot assume the fiscal cost of the failure of a big European bank. At the same time, European banks have held a large portion of sovereign debt at home. Although the introduction of the euro has made banks diversify their holdings of public debt across a portfolio of eurozone countries, the major part of public debt is still in the hands of domestic banks. Figure 9 shows that in all but a few small eurozone countries up to 40% of public debt is owned by domestic banks. Merler and Pisani-Ferry (2012) show how, during the crisis, the sale of public debt of the PIIGS countries by non-residents reinforced this home bias. Domestic banks have been using

FIGURE 10 (a) Exposure of Spanish banks to EU countries, as percentage of total foreign claims. [Figure continues on next page.]

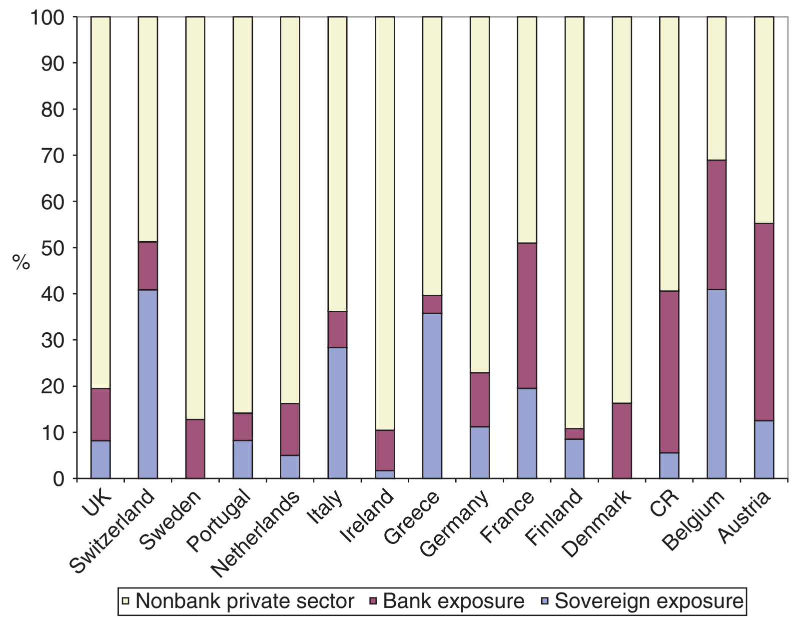


Source: Bank for International Settlements (2011).

in part the provision of liquidity by the ECB to buy domestic public debt. This implies that banks have become even more exposed to domestic sovereign problems.

Cross-border banking has accentuated the effect of fiscal trouble. Suspicions surrounding the troubled debt holdings of foreign banks restricted interbank lending, and liquidity in international financial markets dried up quickly. Figure 9 on the facing page also tells us that about half of all public debt is held internationally. For the eurozone countries, these international holdings are mostly holdings by other eurozone banks. Cross-border flows in the EU are dominated by bank flows, and they are the result of the bank-based nature of finance in Europe (Allen *et al* 2011). This means that EU banks have a diversified portfolio of public debt across the eurozone. These linkages increase their exposure to banking and sovereign problems in the rest of the eurozone. The Bank for International Settlements (2011) provides a breakdown of the debt holdings by the cross-border claims of foreign banks on the public sector in other eurozone countries. Part (a) of Figure 10 summarizes this external position of the Spanish banking sector as a whole, vis-à-vis all other EU countries. The main insight is that Spanish banks have a bias toward a position in the United Kingdom, which is mainly a consequence of the presence of Banco Santander in the United Kingdom. Portugal is the other main market on which Spanish banks have a claim. The rest of the claims are distributed according to the economic importance of the

FIGURE 10 Continued. (b) Exposure of Spanish banks to EU countries, distribution across sectors (September 2011).



Source: Bank for International Settlements (2011).

main eurozone countries. Part (b) of Figure 10 on the preceding page illustrates the distribution of these foreign positions by sector. Spanish banks have predominantly lent to the private sector, yet there is some exposure to Austrian, Belgian or French banks, and to the sovereign debt in Belgium, Greece, Italy and Switzerland. This snapshot of statistics seems to corroborate our finding of strong links between Spain, Italy and Belgium, yet the dominance of the United Kingdom does not show that clearly (see Table 2 on page 52).

We repeat the computations for a GVAR model including the sixteen sovereigns together with the twenty major EU banks. As a table with all bilateral linkages would be too large, we report in Table 5 on the facing page only the effects of the Spanish bond market and the Spanish bank. We reorder the table to also report the main summary statistics on the distribution of linkages. As in Section 4.1, the results show that banks are mostly integrated with each other, and their linkages are rather homogenously distributed. As in Section 3, three groups of EU sovereigns can be distinguished: the PIIGS, core EMU and non-EMU countries. The order of the bilateral effects is largely identical to our previous findings.

TABLE 5 Bilateral spillover from Spain, Banco Santander and BBVA to EU sovereigns and banks, January 2000–November 2015. [Table continues on next page.]

	Spain	Santander	BBVA	From others	S_j	$S_i S_j$
CR	1.83	2.39	2.78	66.01	5.35	30.50
Hungary	1.86	3.06	3.66	66.25	5.50	27.49
Poland	1.51	3.49	3.95	72.77	4.85	27.00
Austria	5.55	1.78	2.16	79.61	2.99	11.45
France	5.98	1.77	2.01	80.88	2.98	8.14
Netherlands	3.18	1.10	1.52	66.56	5.03	24.93
Spain	25.19	3.12	3.37	74.81	3.99	13.57
Italy	14.93	2.69	3.06	81.01	3.20	8.23
Belgium	8.26	2.09	2.42	79.09	3.49	8.68
Greece	2.42	0.79	0.77	22.08	5.97	35.84
Portugal	7.99	2.07	2.16	69.16	4.57	25.43
Ireland	5.49	1.26	1.70	58.45	5.58	32.26
Finland	3.39	0.67	1.04	52.60	5.47	32.55
Denmark	0.45	1.10	1.15	30.03	5.96	35.48
Sweden	0.30	0.11	0.14	22.16	5.93	35.26
UK	0.93	0.13	0.46	25.05	5.95	35.54
BNP Paribas	1.22	5.90	6.01	89.47	0.93	0.32
Deutsche Bank	0.79	5.46	5.66	87.92	1.19	1.24
HSBC	0.45	5.25	5.30	85.39	1.83	4.40
Barclays	0.64	4.44	4.62	86.55	1.57	3.05

The interlinkages between EU sovereigns and banks do not show particularly strong effects. There is no clearly distinguishable effect of an EU sovereign on its domestic banks. For example, shocks to the Spanish bond market do not affect Banco Santander or BBVA the most (in this case, it is the Italian banks UniCredit and Intesa San Paolo). But, in return, for both banks the shock from the domestic sovereign is the most important shock they receive from any sovereign. Table 5 shows the net index. Among the sovereigns, Italy, Belgium and Spain have the strongest effect on banks and other sovereigns. Among the banks, BNP Paribas and Société Générale lead the rankings, followed by BBVA and Banco Santander.

As a consequence, the coskewness measure results in a very similar ranking of the most systemic banks in the EU. French banks are most affected by shocks and have the largest impact on all other banks, closely followed by the Spanish banks. The largest bank in Europe, Deutsche Bank, completes the top five. Both Spanish banks are strongly connected players in bond and banking markets in Europe, after controlling

TABLE 5 Continued.

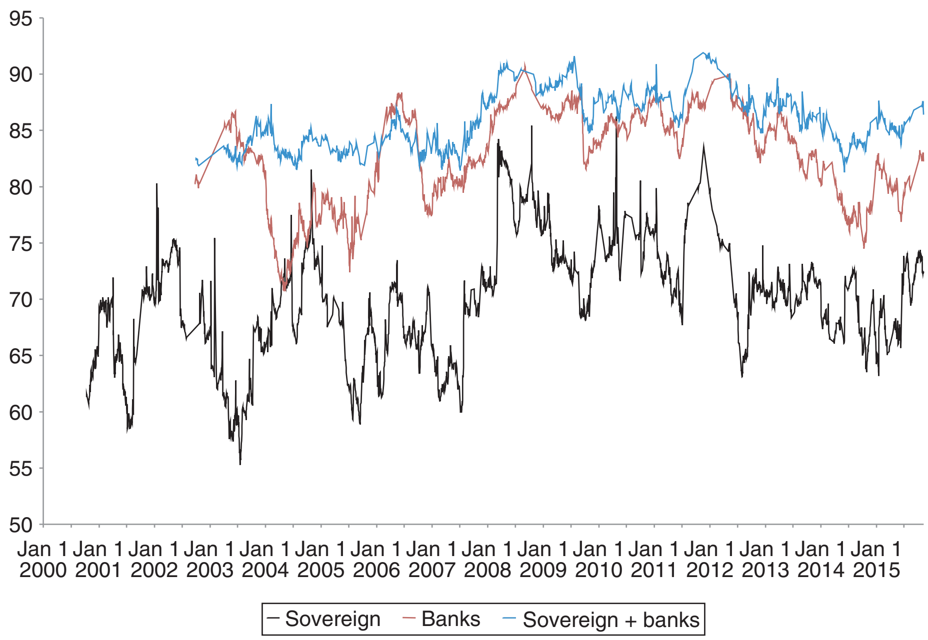
	Spain	Santander	BBVA	From others	S_j	$S_i S_j$
RBS	0.64	4.00	4.14	82.50	2.58	9.81
Crédit Agricole	1.30	5.19	5.52	88.59	1.19	1.16
Santander	1.46	11.10	9.07	88.90	1.24	0.96
Lloyds	0.69	4.22	4.43	84.36	2.11	6.44
Société Générale	1.29	5.43	5.81	89.39	0.96	0.37
UniCredit	2.01	5.44	5.87	88.27	1.39	1.78
Commerzbank	0.95	4.56	5.04	85.33	2.10	6.85
Intesa San Paolo	1.99	5.89	6.24	88.07	1.41	1.90
Nordea	0.68	5.03	5.22	85.38	1.93	5.46
Dexia	0.43	2.51	2.44	44.34	5.89	35.34
BBVA	1.59	8.61	10.57	89.43	1.12	0.64
Natixis	1.21	4.31	4.54	84.08	2.61	10.73
STA	0.48	5.14	5.28	83.48	2.46	8.84
KBC	1.36	4.75	5.10	85.83	2.12	7.02
SEB	0.51	4.82	5.08	85.51	1.87	4.92
Monte dei Paschi	2.16	5.11	5.28	79.96	3.56	18.31
Contribution to others	85.95	123.67	133.00			TS: 73.06%
Contribution including own	111.14	134.76	143.57			
From others	74.81	88.90	89.43			
Net spillover	−11.14	−34.76	−43.57			
Net index	−0.44	−3.13	−4.12			
S_i	3.40	0.78	0.57			

CR denotes Czech Republic. TS denotes total spillover.

for the effect of the Spanish sovereign. Figure 11 on the facing page adds to Figure 6 on page 56 the total spillover index of the GVAR model, including EU sovereigns and banks. The index shows that the total spillover between banks and sovereigns closely follows the spillover between banks and reflects the strong correlation between the fortune of banks and sovereigns at all stages of the crisis.

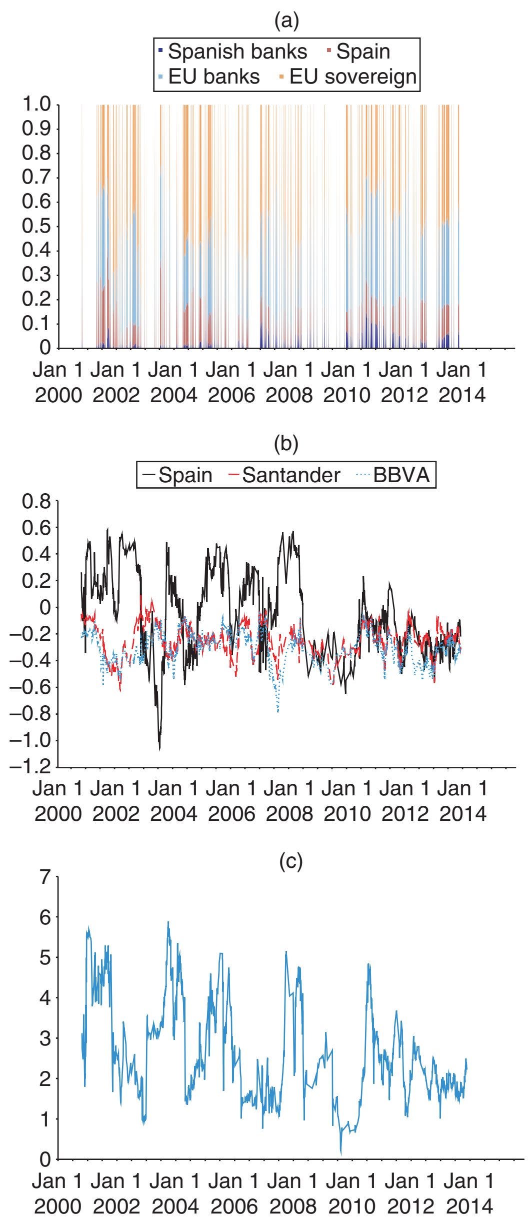
How the situation of public finances affects banks becomes clear from the total impact and the net spillover effect of the Spanish bond market and Spanish banks. Part (a) of Figure 12 on page 66 plots the total contribution of both on EU banks and sovereigns. The impact of shocks starts to rise in May 2010; this is when the ECB announced the beginning of the Securities Markets Programme to buy up sovereign bonds when the market of a particular country is not functioning smoothly anymore

FIGURE 11 Dynamics of total spillover between EU sovereigns and EU banks (over a rolling 200-day window, based on a ten-steps-ahead forecast).



(due to a lack of liquidity). Further, the EFSF was created to provide loans guaranteed by the eurozone countries to EU countries needing to support failing financial institutions. This policy led to a direct reaction in the return of other EU banks but reduced it on other EU sovereigns. A similar result is found in Gerlach-Kristen (2013) or in Kilponen *et al* (2015). The reason is that the bad shape of public finances in Spain would not be further burdened with a possible bailout of Spanish banks, and this would reduce the exposure to Spanish public debt. As a result, the net spillover of the Spanish sovereign fell back to zero (part (b) of Figure 12 on the next page). This effect did not last over time, and by the summer of 2011, concerns about a Greek default and the possible bailout of Portugal and Spain led to a strong rise in the impact of mainly the Spanish sovereign on EU banks. The consequence is that the net impact of both the Spanish sovereign and banks became larger. This spillover only eased when the ECB stepped in to purchase Italian and Spanish bonds in January 2012, as part of its Securities Markets Programme. In contrast to Gerlach-Kristen (2013), we find that the impact of ECB policies took effect later (ie, not from 2010 onward). Later in 2012, once the ESM officially started to function and Mario Draghi released his

FIGURE 12 Dynamics of spillover.



(a) Decomposition of the spillover between bond markets and banks in Spain and the EU. (b) Net spillover from Spanish sovereign bond market, Banco Santander and BBVA. (c) Coskewness of Spain.

"whatever it takes" speech, spillover faded away. Blasques *et al* (2014) find a similar result of reduced spatial dependence by using a time-varying spatial lag model. The intervention by the ECB has made the spillover of Spanish sovereign and bank risk to other eurozone markets less acute. Part (c) of Figure 12 on the facing page shows how these policy changes influenced the position of Spain in bond markets. The creation of the EFSF and the ESM, in addition to ECB action, helped to decouple the situation of Spanish public finances from those of EU banks. As can be seen from the coskewness measures for Banco Santander and BBVA, the same policies helped to reduce the systemic impact of both banks on the rest of the EU's banks. By also reducing the systemic position of the Spanish sovereign, the impact of a shock on other EU sovereigns and banking systems got substantially reduced.

5 CONCLUSIONS

Events since the start of the fiscal crisis in May 2010, with a very rapid rise in bond spreads and the downgrading of all EMU countries but Germany, show that Europe is not immune to contagion in sovereign bond markets. Troubles in the financial sector have greatly contributed to these linkages. Using the GVAR method of Diebold and Yilmaz (2009) to measure the degree of spillover, we proposed a metric for the systemic risk of a market. This metric considered the distribution of the impact from a market. We applied this method to the daily bond prices of EU sovereigns and stock returns of EU banks. Our indicator to measure systemic risk is but one in a list of risk measures developed at institutions such as the European Systemic Risk Board (ESRB) and the ECB, or research institutes such as New York University Stern.

Spain suffered the fall-out of a domestic financial crisis with a strong fiscal cost, both directly through the fiscal cost of restructuring its savings banks and indirectly through a drop in tax revenues. Spain also has a couple of global banks, Banco Santander and BBVA, that are well integrated into eurozone banking markets. Banking integration exposes eurozone countries to the domestic financial and fiscal problems of Spain. Its internationally grown banking sector transmits domestic economic trouble to the rest of Europe. Large EU cross-border banks in France or Italy create systemic interdependencies within the eurozone banking system. As these banks hold important portfolios of domestic and eurozone sovereign debt, they are also strongly exposed to fiscal problems throughout the eurozone.

Purely domestic solutions to restore fiscal imbalances are a necessary, but not a sufficient, condition to restore calm in sovereign bond markets. The large spillover of domestic policy choices also raises concerns about the legitimization of European policies domestically, and of domestic policies at the European level. Since eurozone sovereign bond markets and banks are so closely linked, and are a structural feature of European integration, EMU-wide solutions have looked at stemming the effects of ailing banking sectors and bad public finances and breaking the doom loop between banks and sovereigns. The creation of the EFSF and the ESM, in addition to ECB action, helped to decouple the situation of Spanish public finances from those of EU banks. Given the strong linkages between markets, a credible solution can have a large stabilizing impact, even in the short term, by reducing systemic risk (Allen *et al* 2011).

DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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