2. SOVEREIGN FINANCIAL ASSET MARKET LINKAGES ACROSS EUROPE DURING THE EURO ZONE DEBT CRISIS

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Abstract

We estimate a GVAR model of the European Union (EU) sovereign bond spreads and Credit Default Swap (CDS) differentials with respect to their German counterparts, based on monthly observations from November 2009 to March 2015. We capture time-varying interdependence among variables by computing annual weight matrices based on "macro distances" between countries. This measure of distance is similar to the "fiscal distance" recently used in literature, but more comprehensive. The model is augmented with a Dominant Unit, comprising a number of three market-based global variables. Aggregating the country variables into four regions (Eurocore, Europeriphery, non-euro CEE countries and Non-euro Developed countries), we perform a dynamic analysis to investigate: the propagation of shocks coming from Greece or from Europeriphery to the EU sovereign markets; the behavior of the two non-euro regions sovereigns; the main channels of contagion across each region; the interactions between the EU sovereign markets and the global risk sentiment; the spillover effects of the latest policy actions of the ECB outside the Euro Zone.

Keywords: bond spreads, CDS differentials, macro distance, spillover, contagion, propagation, shocks, European Union

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I. Introduction

The vast majority of papers studying the sovereign financial asset market interactions during the Euro Zone sovereign debt crisis are obviously focused on the countries of the Euro Zone, for which either sovereign yields, sovereign bond spreads with respect

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to different benchmarks, sovereign Credit Default Swap (CDS from now on) spreads or CDS spread differentials are analyzed. The present paper extends the analysis to (almost) all the countries within the European Union (EU), without regard to their affiliation to the European Monetary Union (EMU). Sovereign bond spreads and sovereign CDS differentials are computed with respect to their German counterpart. We aim to study the influence, across the entire EU, of a number of shocks originating from the EMU periphery. Additionally, we analyze shocks coming from the EMU core countries, as well as global shocks, by making use of market proxies. Figures 1.1-1.4 in the Appendix[4] show the evolution of the variables over the studied period.

The sovereign variables are jointly modeled using the GVAR methodology, each spread/differential being computed as a weighted average of all the other EU spreads/differentials. The weight matrices are built using the flows between the countries, but these flows are not based on a „fiscal distance" as in some recent studies, but on a new measure of distance, called „macro distance", which is computed using forecasts of DG-ECFIN (Directorate General for Economic and Financial Affairs) for public debt, government balance, current account and economic growth. Therefore, we do not analyze the direct influence of these four fundamental factors associated with each country on its spread/differential. This influence is only indirectly analyzed, by means of the coefficients derived from the time-varying weight matrices. We augment the GVAR model with three variables that have a global influence on the analyzed sovereign spreads/differentials and which are part of a Dominant Unit. The dynamic analysis is conducted by analyzing Impulse Response Functions and Forecast Error Variance Decomposition over the first five periods after the simulated shocks to various variables in our model

Given the recent problems in Greece, one might or might not say that the period generically known as „the sovereign debt crisis" is, by now, history. Whichever the case, the fundamental disequilibria between sovereigns continue to exist within the borders of the EMU and the EU. The challenges currently faced by the policymakers include the lack of economic growth, low inflation and zero bound interest rate limitations. Accordingly, the tools used by the European Central Bank (ECB) mimicked those of American FED or Bank of Japan. The Public Sector Purchase Program (PSPP), EMU's quantitative easing program, has driven the front end of some *Eurocore* sovereign yield curves into negative territory up to 4 or 5 years maturities, while the cost of funding for some *Europeriphery* countries has fallen at levels which would have been considered improbable, to say at least, several years ago. Investors hungry for yield are hunting returns higher than what the Euro Zone can currently offer. The Central Banks of the *CEE* countries which are not members of the EMU should pay close attention to the speculative volatile capital flows that might be attracted by carry-trades, if their yields are considerably higher than those of the Euro Zone countries.

In such circumstances, a sovereign yield curve analysis/forecasting by itself has limited usefulness for a fixed income fund manager. In the present market environment, where asset returns are highly correlated, a global model of bond yield spreads or CDS differentials, as the one proposed by the current paper, is much more useful not only for policy makers, but especially for practitioners, dealers or portfolio managers alike, which

[4] *The Appendix is available as a supplementary resource on http://www.rjef.ro*

can form anticipations with regard to the proper timing of trades based on analyzing the impact of shocks propagation across the sovereign markets. For example, a bond portfolio manager fully invested in German Bunds, seeking higher returns in the sovereign EU markets, could use the model to perform a relative analysis of spreads and, consequently, buy the bonds he expects to outperform or sell those expected to underperform. Alternatively, he can use CDSs to cover the risks of some of the newly bought bonds in his portfolio.

The rest of the paper is organized as follows. Section 2 reviews some of the results of the related literature. In Section 3, the GVAR model is estimated and after the data properties are analyzed and the validity conditions of the GVAR methodology are verified, a dynamic analysis is performed. Section 4 concludes and, finally, Section 5 presents all the references used in performing this research. The technical results of the econometric research, all the figures and tables are presented in the online Supplementary Appendix.

II. Literature Review

A large part of the recent literature studies the impact of fundamental macro factors, such as real GDP growth, inflation, public debt-to-GDP ratio, government balance-to-GDP ratio, current account balance-to-GDP ratio, real effective exchange rate, as well as global risk aversion factors, such as VIX or a US corporate spread between Baa and Aaa rated bonds, on sovereign bond spreads: Dewachter *et al*. (2014), Hordahl and Tristani (2013), De Haan *et al*. (2013), Barrios *et al*. (2009), D'Agostino and Ehrmann (2013), Cimadomo *et al*. (2014), Arghyrou and Kontonikas (2011), Di Cesare *et al*. (2012), Giordano *et al*. (2012), Afonso *et al*. (2012), De Grauwe and Ji (2013, 2014). Some of these studies take into account the „forward-looking" nature of spreads and use, accordingly, forecasts for the above-mentioned fundamental variables when constructing the sovereign spreads: Arghyrou and Kontonikas (2011), Hordahl and Tristani (2013) use the DG-ECFIN forecasts, Di Cesare *et al*. (2012), D'Agostino and Ehrmann (2013) use the Consensus Economics forecasts, while De Haan *et al*. (2013) use some measure of market-based expectations. The spreads are computed either with respect to an overnight interest rate, German Bund yields or to other proxy for the risk-free rate, such as the difference between 10-year yields on German Bunds and associated German sovereign CDS spreads or 10-year EUR swap fixed rates.

Some of the papers try to find out if there is a component of sovereign bond spreads or sovereign CDS differentials which cannot be explained by the fundamental factors, but rather by contagion among the sovereign financial asset markets across the Euro Zone. Among the studies finding evidence of contagion across the EMU we find those of Caceres *et al*. (2010), Arghyrou and Kontonikas (2011), Di Cesare *et al*. (2012), Giordano *et al*. (2012), Afonso and Ramos Felix (2013), Ait-Sahalia *et al*. (2014). Giordano *et al*. (2013) and Beirne & Fratzscher (2013) argue that it is actually a form of "wake up call", and not pure contagion. Favero and Missale (2011) and Favero (2013) are employing the GVAR methodology and find that the evolution of the weakly exogenous foreign variables used to construct each sovereign domestic spread can signal contagion emanating either from changes in market perception with respect to risk or from expectations regarding the Euro Zone breakup, denomination and, subsequently, devaluation risk of national currencies. The GVAR models with weakly exogenous variables built using financial-type weights, especially chosen to reflect the deep financial integration within Europe, are used by Galesi and Sgherri (2009) or Sun *et al*. (2013) to demonstrate the existence of contagion among the European financial markets.

With respect to systemic risk, both Ang and Longstaff (2011) and Kalotychou *et al*. (2014) find, by analyzing sovereign CDS spreads, that it is rather determined by the evolution of global financial markets and less by the country-specific macro fundamentals; however, the weak fundamentals play indeed a role in augmenting each country's exposure to the global shocks.

The interlinkages among the two main segments of the sovereign financial asset markets, the sovereign bond and sovereign CDS markets, are studied by Calice *et al*. (2011), Fontana and Scheicher (2010), Gyntelberg *et al*. (2013), Palladini and Portes (2011), Badaoui *et al*. (2013) and O'Kane (2012). The results of these studies are rather mixed: some authors find evidence that the sovereign CDS markets lead the process of price discovery only in the *Europeriphery*, while in the *Eurocore* countries it is the bond markets that lead; other authors believe that CDS lead the process all across the Euro Zone, not only in the periphery. For a third group, the sovereign bond markets are a better proxy for credit risk, incorporating the credit risk component of the risk premium by a larger extent than the CDS markets, which, by their part, reflect mostly the liquidity component of the risk premium and as a conclusion to their findings, the process of price discovery should be led by the bond markets. The decomposition of sovereign spreads into two components, one reflecting credit risk and the other liquidity risk, is investigated by De Socio (2011), Bai *et al*. (2012), Monfort and Renne (2014). O'Kane (2012) discusses the interesting choice of the USD-denomination of the majority of quoted European sovereign CDSs, a fact that dealers should consider when implementing a "basis" trade.

Almost all the papers mentioned so far study sovereign variables of the EMU countries. More recently, Claeys and Vasicek (2012), Csonto and Ivaschenko (2013) or Heinz and Sun (2014) extend the analysis to other European sovereigns, an approach taken by the present paper as well. Claeys and Vasicek (2012), using the forecast error variance decomposition from a VAR with daily data spanning from 2000 to 2010 for sovereign bond spreads of the EU countries grouped into four regions, investigate the propagation of shocks both within and across the regional markets. They find that, overall, spillover between sovereign markets has increased since 2007, but it is rather heterogeneous, depending on the region of choice. For the Euro Zone countries, spillover is more significant and explains spreads better than the domestic factors, but there is no evidence of contagion emanating from the countries in the periphery of the Euro Zone, Greece in particular, towards the non-euro EU countries. There are spillovers across *non-euro CEE* sovereign markets, but not from the *Eurocore* countries towards the *CEE* countries. This is somewhat curious, especially for the case of Austria, which has strong financial interlinkages with these countries. Finally, United Kingdom, Sweden and Denmark are isolated from the impact of other EU countries sovereigns. Csonto and Ivaschenko (2013) show that the sovereign spreads of Bulgaria, Hungary and Poland are influenced by both macro internal fundamentals as well as global factors in the long run, but in the short run it is the global factors that matter most. Moreover, solid fundamentals make countries more resilient to sudden increases in the global risk aversion, for which the authors use the CBOE's VIX as a proxy. Heinz and Sun (2014) investigate the other indicator of sovereign risk, the CDS markets, for a number of 24 European countries, 14 in the Central and Eastern and South-Eastern Europe (CESEE) region, 5 in the *Eurocore* and another 5 in the *Europeriphery*, and find that spreads are well explained by macro fundamentals, global risk aversion and liquidity in the CDS markets. In particular for the CESEE countries, the deteriorated fundamentals, upward spikes in global risk aversion and drying market liquidity contributed to high sovereign CDS spreads during the global crisis of 2008-2009. Subsequently, during the Euro Zone crisis, a marked improvement in the macro fundamentals of the CESEE countries (reductions in fiscal deficits, better control of government debt, narrowing of current account deficits and gradual economic recovery) explained the region's resilience to financial market spillovers coming from the Euro Zone.

III. Econometric Research Methodology

III.1. Choosing the Variables and the Time Frame for Conducting the Research

The present paper uses the GVAR approach to jointly model the EU sovereign financial market variables; in particular, the 10-year sovereign bond spreads with respect to German Bunds and 5-year USD-denominated CDSs differentials with respect to their German counterpart. The GVAR model is augmented with three variables that may have a global influence on spreads, which are grouped into a Dominant Unit in the sense defined by Chudik and Pesaran (2013): CBOE's volatility index (VIX), the spread between two EMU reference interest rates (3-month EURIBOR and EONIA) and the 10-year EUR-denominated sovereign CDS of Germany.

The 10-year yields are used to define the Maastricht criterion on long-term interest rates (1992) and are therefore considered one of the most important maturities of the EU sovereign yield curves. Using the 10-year German Bunds as benchmark to compute spreads is similar to the approaches considered by Barrios *et al*. (2009), Favero and Missale (2011), Arghyrou and Kontonikas (2011), Di Cesare *et al*. (2012), Afonso *et al*. (2012), Favero (2013), Giordano *et al*. (2013), Hordahl and Tristani (2013), De Grauwe and Ji (2014) or Cimadomo *et al*. (2014).

The importance of the 5-year maturity of European sovereign CDS spreads is viewed by Palladini and Portes (2011) as a consequence of the maximum liquidity of this particular segment on the sovereign CDS term structure. The USD and not EUR-denomination is explained by O'Kane (2012) as a form of additional protection, should a sovereign entity experience default, which would put downward pressure on the common currency. The benchmark used to compute CDSs differentials is the corresponding German counterpart, as in Calice *et al*. (2012) and very similar to Bai *et al*. (2012).

The CBOE's volatility index (VIX), known as „The Fear Index", is one of the most employed proxies for global risk investor's sentiment, spiking sharply upward during acute "flight-to-quality" periods. VIX is investigated as a possible factor explaining sovereign spreads by Csonto and Ivaschenko (2013), Giordano *et al*. (2013), D'Agostino and Ehrmann (2013), Afonso and Ramos Felix (2013), Heinz and Sun (2014), Dewachter *et al*. (2014) among many others.

The 3-month EURIBOR-EONIA spread is the European correspondent of the USD LIBOR-OIS spread, considered by the former FED president, Alan Greenspan, a „barometer of fears of bank insolvency", according to Thornton (2009). The inclusion of this variable in the GVAR model is made in order to investigate the shocks coming through the Euro Zone money markets, perhaps as a result of Long Term Refinancing Operations (LTRO) or Outright Monetary Transactions (OMT) conducted by the ECB. The approach is similar to Giordano *et al*. (2013) or Monfort and Renne (2014).

Finally, to capture the effect of a fundamental shock to the "engine" of the Euro Zone, the 10-year EUR-denominated sovereign German CDS spread was included as one of the variables of the Dominant Unit. The choice of CDS over the corresponding German Bund yield tries to better quantify the sovereign credit risk, as Bunds double status, of "safe-haven" asset as well as collateral in the repo markets, would prevent their yields to fully reflect a fundamental macro shock originating from the German economy.

With respect to the analyzed time frame, it is worth mentioning that most papers consider November 2009 as being the starting month of the period generically known as the sovereign debt crisis in the Euro Zone. The trigger was Greece; whose newly elected PASOK government revised the fiscal deficit of the country to over 12%, more than double than it was previously reported. The turmoil that followed in the financial markets raised again the question of the viability of the Euro project and determined the ECB to step up in 2012, following the famous statement of Mario Draghi: „whatever it takes to preserve the euro", and take the necessary measures to calm down the markets. The econometric analysis therefore covers the time span between November 2009 and March 2015, the last month for which data series were available.

III.2. The GVAR Model (November 2009-March 2015):

III.2.1. Building the Model - Similar Approaches

The GVAR model construction is similar to the approaches employed by Favero and Missale (2011) and, more recently, by Favero (2013). A global model of sovereign spreads across the Euro Zone is specified by these authors such that each spread dynamics is determined by three factors:

a) forecasts with regard to the dynamics of fiscal fundamentals of each country as compared to Germany (general government debt-to-GDP, government balance-to-GDP): $E_t(b_i - b_{GER})$ and $E_t(d_i - d_{GER})$, respectively ;

b) a global risk aversion variable (a US corporate spread between Baa and Aaa-rated bonds): $(Baa_t - Aaa_t)$;

c) weakly exogenous, foreign-type variables, that reflect the joint influence on a sovereign spread of all the other countries spreads, modeled as weighted averages, with weights based on some "fiscal distance" between the countries.

More specifically, in Favero and Missale (2011), the weakly exogenous foreign variable that influences the country *i* sovereign spread is:

$$\left(Y_t^i - Y_t^{GER}\right)^* = \sum_{j \neq i} w_{ij,t}\,(Y_t^j - Y_t^{GER})$$

$$w_{ij,t} = \frac{w_{ij,t}^*}{\sum_{j \neq i} w_{ij,t}^*}, \text{ where } w_{ij,t}^* = \frac{1}{dist_{ij,t}}$$

$$dist_{ij,t} = 0.5 * E_t\left(\left|b_i - b_j\right|\right)/60 + 0.5 * E_t\left(\left|d_i - d_j\right|\right)/3\,,$$

where: $E_t(b_i)$ is an average of the 2-year ahead period of the DG-ECFIN forecasts for the debt-to-GDP ratio and $E_t(d_i)$ is an average of the 2-year ahead period of the DG-ECFIN forecasts for the budget balance-to-GDP ratio for country i.

For comparability purposes, both differences are rescaled with the respective reference values of 60 percent of GDP and 3 percent of GDP, specified in the Maastricht criteria. The closer the “fiscal distance” between two countries, the larger the influence of each of these countries spread in explaining the other country’s spread. By using time-variable weights, the “forward-looking” nature of spreads hypothesis is verified and the conditional correlations among country spreads during the studied time period can be better explained.

The model presented in this paper differentiates itself from the above-mentioned studies with respect to a number of criteria. ***First***, given the fact that Favero and Missale (2011) find an insignificant influence of each country fiscal fundamentals forecasts as compared to Germany, the two differences are ignored in modeling the sovereign spreads.

Second and ***third***, the analysis is extended, on the one hand, to the CDS segment of the sovereign financial asset markets, and on the other hand, geographically, to all the EU sovereign markets. For this purpose, a number of 21 EU countries are analyzed, with Luxembourg, Cyprus, Malta, Latvia, Estonia and Croatia excluded for various comparability-related reasons: small secondary sovereign debt markets, no harmonized 10-year rates or, in the case of Croatia, non-EU membership since the very beginning of the period under investigation. For the purpose of conducting the dynamic analysis of the estimated GVAR model, the remaining 21 countries are then aggregated into four regions, based on an average of their marketable sovereign debts values for 2008-2010 time period: *Eurocore* (Austria, Belgium, Finland, France, the Netherlands, Slovakia, Slovenia), *Europeriphery* (Greece, Ireland, Italy, Portugal, Spain), *CEE* (Bulgaria, the Czech Republic, Hungary, Lithuania, Poland, Romania) and *Noneuro* (Denmark, United Kingdom, Sweden). Although Slovakia and Slovenia both present characteristics of the *CEE* region, they were included in the *Eurocore* because of their EMU membership. Lithuania, on the other hand, was included in the *CEE* region because its membership of the EMU became effective since 2015.

Fourth, instead of using the US corporate spread as the risk-aversion global variable, a Dominant Unit in the sense defined by Chudik & Pesaran (2013) is employed in our GVAR model to capture the global effects of three variables on the sovereign assets.

Finally, a new measure of distance is defined, a “macro distance”, which includes in its formula the DG-ECFIN forecasts for the current account balance-to-GDP ratio and for GDP growth, in addition to the two measures used to compute the original “fiscal distance". The inclusion of these additional variables follows the approaches considered by Giordano *et al*. (2012), De Haan *et al*. (2013) or De Grauwe & Ji (2014) when trying to explain the sovereign spreads. With regard to the four fundamental variables used to model the spreads, the current paper matches somewhat the approaches of Beirne & Fratzscher (2013) or Heinz & Sun (2014). The difference lies in how these fundamental variables are employed in each model. If the above authors allow for the fundamental factors to directly impact spreads, we are only allowing the four factors to influence spreads indirectly, and with a time-varying influence. More specifically, the formula for the "macro distance" between countries i and j is:

$$dist_{ij,t} = 0.25 * \frac{E_t(|b_i - b_j|)}{E_t(|b_{EU}|)} + 0.25 * \frac{E_t(|d_i - d_j|)}{E_t(|d_{EU}|)} + 0.25 * \frac{E_t(|g_i - g_j|)}{E_t(|g_{EU}|)} + 0.25 * \frac{E_t(|ca_i - ca_j|)}{E_t(|ca_{EU}|)}$$

$b_{i,j,EU}$ = debt-to-GDP for countries i, j, and the EU, respectively

$d_{i,j,EU}$ = budget balance-to-GDP for countries i, j, and the EU, respectively

$g_{i,j,EU}$ = percentage change in GDP for countries i, j, and the EU, respectively

$ca_{i,j,EU}$ = current account balance-to-GDP for countries i, j, and the EU, respectively.

It should be noticed that:

a) A mathematically correct formula of distance in a four-dimensional Euclidean space would be:

$$\|i - j\| = \sqrt{\left[\frac{E_t(b_i - b_j)}{E_t(b_{EU})}\right]^2 + \left[\frac{E_t(d_i - d_j)}{E_t(d_{EU})}\right]^2 + \left[\frac{E_t(g_i - g_j)}{E_t(g_{EU})}\right]^2 + \left[\frac{E_t(ca_i - ca_j)}{E_t(ca_{EU})}\right]^2} .$$

The formula we use instead, based on the arithmetic average, verifies, however, the conditions of a metric space:

$dist_{ij} = 0$ if and only if *i=j* (identity of indiscernibles)

$dist_{ij} = dist_{ji}$ for any i and j (symmetry)

$dist_{ij} + dist_{jk} \geq dist_{ik}$ for any i, j and k (triangle inequality).

b) The four differences are rescaled for comparability reasons with averages of the 2-year ahead period of the DG-ECFIN forecasts for the respective values across the entire EU.

c) There are some limitations in the formula we used, related to the denominator of each fraction, but they can be overcome. In any situation the denominator equals zero, we could conveniently use instead some other variables of choice for rescaling (for example, forecasts for one-year ahead only, etc).

d) The frequency of the DG-ECFIN forecast reports is three times per year, but the "macro distances" and the associated weight matrices are built annually, based on the Autumn forecast reports. This caused modeling limitations but, nevertheless, it is still very useful, given the rather narrow approach we initially took in writing this paper, that of a fixed income portfolio manager mandated to rebalance portfolio at the end of each calendar year.

III.2.2. Individual VARX* Country Models

A quick visual inspection of the variables of interest confirms the absence of deterministic time trends. We can write the general form of the individual VARX*(p_i, q_i) model for a country *i* in our GVAR model, with *i* taking values from 1 to N=21 countries, no trend, time-varying weights and a Dominant Unit in the sense defined by Chudik and Pesaran (2013) as:

$$x_{it} = a_{i0} + \sum_{j=1}^{p_i} \Phi_{ij} x_{i,t-j} + \sum_{k=0}^{q_i} \Lambda_{ik} x_{i,t-k}^* + \sum_{k=0}^{1} \Psi_{ik}\, \omega_{t-k} + u_{it}$$

x_{it} : (m_i x 1) vector of domestic variables with a specified maximum lag order of $p_i = 2$

$m_i = 2$ (bond spread and CDS differential) for all country models, except for Greece, for which the CDS series was not available for the entire time span, so $m_{Greece} = 1$

$x_{i,t}^*$: (m_i^* x 1) vector of foreign variables with a specified maximum lag order of $q_i = 1$

$m_i^* = 2$ (bond spread and CDS differential) for all country models

$x_{i,t}^* = \sum_{l=1}^{N} w_{il,t}\, x_{l,t} = w_{i,t} x_t$, where $w_{il,t}$ are (m_i^* x m_i) time-varying weight matrices such that $\sum_{l=1}^{N} w_{il,t} = 1$ and $w_{ii,t} = 0$; $x_t = \left(x_{1,t}', x_{2,t}', \dots, x_{N,t}'\right)'$ is a (m x 1) vector of endogenous variables, with $m = \sum_{i=1}^{N} m_i$ and $w_{i,t} = (w_{i1,t}, w_{i2,t}, \dots, w_{iN,t})$

ω_t : (3 x 1) vector of global variables, grouped into the Dominant Unit with a lag order of 1

Φ_{ij} : (m_i x m_i) matrices of coefficients associated with domestic variables

Λ_{ik} : (m_i x m_i^*) matrices of coefficients associated with foreign variables

Ψ_{ik} : (m_i x 3) matrices of coefficients associated with global variables

a_{i0} : (m_i x 1) vector of fixed intercepts

u_{it} : (m_i x 1) vector of country-specific shocks, assumed to be serially uncorrelated, with a zero mean and a non-singular covariance matrix; specifically, $u_{it} \sim iid(0, \Sigma_{ii})$, but a cross-country weak contemporaneous correlations among idiosyncratic shocks is allowed:

$$E\left(u_{it} u_{lt'}'\right) = \begin{cases} \Sigma_{il}, t = t' \\ 0, t \neq t' \end{cases}$$

We modeled the Dominant Unit with a VAR(p_ω) proces, where p_ω was allowed to take a maximum value of 2 and by using the AIC/SBC information criteria, we found that $p_\omega = 1$.

For the purpose of specification of the individual VARX* models, we followed the general lines of Smith and Galesi (2014) and treated the global variables in the Dominant Unit as foreign, weakly exogenous. Moreover, we modeled the Dominant Unit to allow lagged feed-backs from the rest of the GVAR model. Specifically, we considered that it was possible that sudden increases in sovereign bond spreads or CDS differentials in the EU area to have a lagged influence on global risk sentiment (VIX) or to cause shocks in Euro Zone money markets (EURIBOR-EONIA spread) or to modify investor perception with regard to Germany's exposure to inherent risks determined by major imbalances within the Euro Zone (10-year EUR-denominated German CDS). The lag order selected by the AIC/SBC criteria for the feed-back variables (bond spreads and CDS differentials) within the Dominant Unit model was 1.

Once the individual VARX*(p_i, q_i) for each country specified, it may be noticed that the GVAR model allows for interaction between the component units (countries) through three channels:

a) contemporaneous dependences of domestic variables on their foreign counterparts and their lagged values;

b) dependences of country domestic variables on the global variables included in the Dominant Unit and their lags;

c) contemporaneous dependence of shocks in unit (country) *i* on shocks coming from unit (country) *l*: $\Sigma_{il} = cov(u_{it}, u_{lt}) = E(u_{it}u'_{lt}) \neq 0$.

III.2.3. The Data and Properties of the Series

The sovereign bond spreads were computed based on the monthly data available from Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=irt_lt_mcby_m&lang=en). The data reflect secondary market sovereign bond yields with a residual maturity of 10 years and are harmonized, allowing for full comparability, both between countries and over time.

The 5-year USD-denominated CDS differentials were computed based on the monthly averages of daily closing mid-spread quotes, reported in the Reuters Eikon database. A series for Greece was not available for the entire period, given the credit event declared by ISDA in March 2012.

The global variables from the Dominant Unit (VIX, EURIBOR-EONIA spread, 10-year EUR-denominated Germany sovereign CDS) were also calculated based on monthly averages of closing quotes for the respective variables from Reuters. All the above variables were used in levels as basis points, with the exception of VIX data, which were used in logarithm.

There are 65 monthly data points for each of the above series, for a time span between November 2009 and March 2015. The codification of series and descriptive statistics are presented in Appendix,Tables 3.1 - 3.4.

The presence of unit roots for the three categories of variables (domestic, foreign and global) was investigated using the Weighted Symmetric Dickey Fuller (WS-ADF) test of Park and Fuller, the lag order being chosen based on the AIC. A maximum accepted number of 4 lags was specified. The WS-ADF test revealed the existence of unit roots for 82 out of the 86 variables in the model. Almost all the variables are I(1), except for some of the domestic variables: the sovereign spread for Denmark and sovereign CDS differentials for Austria and the Czech Republic seem to be I(0). The sovereign bond spread for Lithuania appears to be I(1), but in this case the ADF test was used, because the WS-ADF gave an integration order larger than 2. The test results are reported in Tables 3.5 - 3.7.

The time-varying weight matrices were built for 7 years, based on flows derived from the "macro distances" computed as above-mentioned, using the Autumn forecasts of the DG-ECFIN. The Autumn forecasts published between 2008 and 2014 were used to construct the weight matrices for each of the years 2009-2015. These matrices are shown in Tables 3.8 - 3.14.

Finally, the data sources for the 2008-2010 sovereign marketable debt values (in USD), used to aggregate countries into regions and to construct the feed-back variables in the Dominant Unit model, were the OECD site (http://stats.oecd.org/#) for the OECD members and the Central Bank sites for Bulgaria, Lithuania and Romania. An obvious question is how representative is the average marketable debt value for the 2008-2010 period in an analysis covering the 2009-2015 time span. This approach may not be the best one, but we deem it satisfactory, given the limited statistical data available for these variables of interest.

III.3. Model Estimation (November 2009-March 2015):

III.3.1. Lag Order Choice Criteria and Individual Model Specification

Using the Akaike Information Criterion (AIC) and imposing a maximum allowed lag order of 2 for the domestic variables, due to the small data sample, we specified a number of 7 VARX*(1,1) and 14 VARX*(2,1) country models:

Since the large majority of model variables have a unit root, the individual VARX* models were estimated in their error-correcting form, VECMX*, by using the Johansen reduced-rank procedure. The cointegration ranks were derived based on the results of "trace" statistics, since this test is more flexible with regard to the assumption of normality of residuals and more robust in small samples than the "maximum eigenvalue" statistics. Moreover, as economic theory does not mention anything about the existence of trends in the analyzed data series, we opted for restricted intercepts and no trend coefficients in estimating the VECMX* models.

Writing a GVAR(p) model in its moving average representation:

$$x_t = \sum_{s=o}^{\infty} A^s \, \varepsilon_{t-s} \text{ , where } A^0 = I_m$$

or, using the identity $z_{it} = W_i x_t$, as:

$$z_{it} = W_i \varepsilon_t + \sum_{s=1}^{\infty} W_i A^s \, \varepsilon_{t-s}$$

the persistence profiles for the cointegrating vectors $\beta_i{}' z_{it}$, with respect to a system-wide shock ε_t, over *n* periods are:

$$PP\left(\beta_{ji}' z_{it}; \varepsilon_t, n\right) = \frac{\beta_{ji}' W_i A^n \Sigma_\varepsilon A^{n\prime} W_i' \beta_{ji}}{\beta_{ji}' W_i \Sigma_\varepsilon W_i' \beta_{ji}}$$

where: β_{ji}' is the j-th cointegration relation for country *i* and Σ_ε is the covariance matrix of innovations, ε_t.

There were 16 cointegrating vectors found in our particular model, as reported in Table 3.17.

The models for which no cointegrating vectors were found, including that of the Dominant Unit, were estimated in differences.

3.3.2. Validity Conditions for the GVAR Model Estimation

We tested for weak exogeneity, the main assumption behind a GVAR model, by using the F-test to verify the joint hypothesis that $\rho_{ij,n} = 0$, for $j = \overline{1, r_i}$, in the following regression:

$$\Delta x_{it,n}^* = c_{in} + \sum_{j=1}^{r_i} \rho_{ij,n} \widehat{ECM_{\imath\jmath,t-1}} + \sum_{s=1}^{p_i^*} \phi_{is,n}' \Delta x_{i,t-s} + \sum_{s=1}^{q_i^*} \psi_{is,n}' \Delta \widetilde{x_{\imath,t-s}^*} + \eta_{it,n}$$

where: $\widehat{ECM_{\imath\jmath,t-1}}$ are estimated values for the r_i cointegrating vectors in the model of country i with p_i^* and q_i^* orders of the lagged changes for the domestic and foreign variables, respectively. As already mentioned, the global variables in the Dominant Unit are included as foreign variables in the specification of the individual country models.

The weak exogeneity assumption is rejected at the 5% significance level for only two out of 70 variables, and we consider the outcome as acceptable to justify the estimation procedure of each country model in the GVAR.

Following Pesaran *et al*. (2004), we verify the three requirements deemed as sufficient for the validity of the GVAR methodology:

a) The global model should be dynamically stable. Writing the GVAR(1) model as:

$$\mathrm{Y_t} = \mathrm{BY_{t-1}} + \mathrm{E_t}$$

we verify that the eigenvalues of **B** lie either on or inside the unit circle. 28 out of the 132 eigenvalues are unitary.

b) The weights must be “granular”, such that:

$\sum_{l=1}^{N} w_{il,t}^2 \to 0$ as $N \to \infty$, for any $i = \overline{1, N}$ and any *t*. We verify this condition by checking the weight matrices reported in Tables 3.8 - 3.14. The largest weight is approximately 0.361, while the majority of values are lower than 0.10.

c) The idiosyncratic shocks must be weakly correlated across countries, such that:

$\frac{\sum_{l=1}^{N} cov(u_{im,t}, u_{lp,t})}{N} = 0$ as N → ∞ , for any *m* and *p* shocks in countries *i*, respectively *l*. The average pairwise cross-section correlations are reported in Table 3.20. Since the magnitude of the strongest correlation is -0.1679, we can safely conclude that this validity condition is also verified.

III.3.3. Impact Elasticities

The contemporaneous effects of foreign variables on their domestic counterparts are reported in Table 3.21, together with the t-ratios computed based on the Newey-West adjusted variance estimator, which allows for small sample correction.

Overall, the *Europeriphery* countries are the most sensitive to shocks coming from outside their borders. There is overshooting in the sovereign CDS markets of Ireland and Portugal and in the sovereign bond markets of Italy and Spain. Curiously, the bond spreads of Greece, Ireland and Portugal have reduced sensitivities. A possible explanation is that the small size of these particular countries bond markets made them react less strongly to the foreign shocks, as compared to Italy and Spain. On the other hand, sovereign CDSs were not influenced by the reduced volume of their associated bond markets, at least not until November 2012, when “naked” CDS writing was forbidden.

Among the countries in the *non-euro CEE* region, Hungary and Bulgaria sovereign CDS markets show evidence of overshooting, while Romania seems to have the most sensitive sovereign bond spread to the movements in its foreign counterparts, with a value of 0.75. The Czech Republic and Poland variables show resilience, which could be a result of their better macro fundamentals, as compared to the rest of the CEE area.

As for Denmark, Sweden and United Kingdom, since their sensitivity coefficients have insignificant values, they appear insulated from the shocks coming from the rest of the EU.

III.4. Dynamic Analysis

The dynamic analysis of the estimated GVAR model is undertaken by means of Generalized Impulse Response Functions (GIRFs) and Generalized Forecast Error Variance Decomposition (GFEVDs), following Galesi and Sgherri (2009) or Sun *et al*. (2013). This approach makes sense since, in our case, there are no “a priori” assumptions with regard to the ordering of the countries (units) in the model and no imposed restrictions backed by economic theory. Even though GIRFs cannot provide insights on the causality among the variables in the GVAR, their analysis is useful for the study of linkages and propagation of shocks across the sovereign markets. No bootstrap was performed either, since the limited dimension of the dataset most likely renders the GIRFs statistically insignificant and the parameter estimators inefficient. As for GFEVDs, given the existence of contemporaneous correlations among the error terms, the contributions of each country’s/region’s variable in explaining the forecast error variance of the simulated shock cannot be considered proportions (they do not sum to one). Nevertheless, GFEVDs can uncover the transmission channels through which spillovers are geographically propagated.

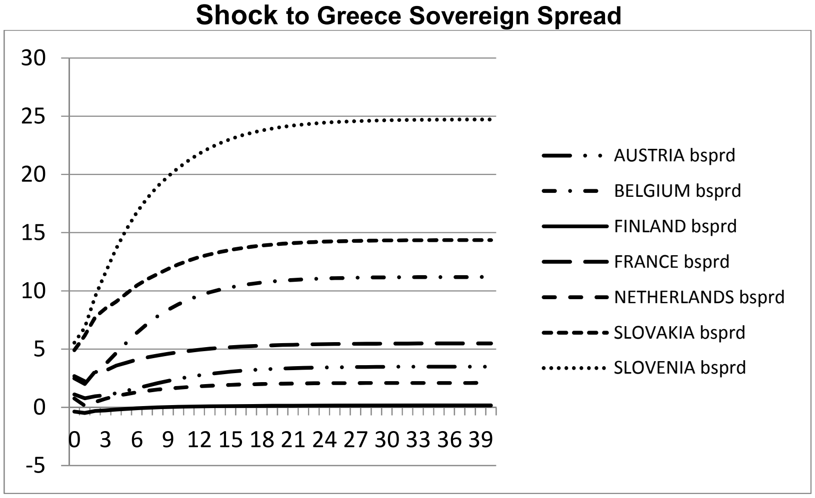
III.4.1. One Standard Error Positive Shock to Greece Sovereign Bond Spread

With the exceptions of Finland, Lithuania and the Czech Republic, all the EU sovereign bond spreads increase instantaneously. While Finland bonds behavior could be explained by an increased demand due to the solid macro fundamentals of the country, the results for the other two countries seem rather surprising. However, the magnitude of changes is small and the spreads for these two countries increase as well, in the 1st and 4th period, respectively. At a regional level, the largest instantaneous increases are found in the *Europeriphery* countries, with values between 11% for Ireland and 34% for Portugal. The sovereign spread increases for the *Eurocore* countries are much smaller and those for the *Noneuro* group of countries are insignificant. As for the *CEE* countries, the spread increases range between 4% for Poland and 7.83% for Bulgaria. The behavior of the CDS segment of the sovereign markets is similar to that of the bond segment. It is worth mentioning that Romania sovereign CDS differential rises by almost 10%, the largest increase among its *CEE* peers.

We show only Figure 3.2 here, the rest of graphs being available online, as a Supplementary Appendix.

Figure 3.2

GIRF of the *Eurocore* Sovereign Spreads for One Standard Error Positive Shock to Greece Sovereign Spread



The GFEVDs analysis reveals that during the first five post-impact periods the *Europeriphery* region explains most of the forecast error variance, contributing by 14%. The *CEE* region contributes by 9%, while the *Eurocore* and the *Noneuro* by only 4% each. Instrument-wise, sovereign CDS differentials contribute more than bond spreads across all regions, with the exception of *Europeriphery*, where the roles are reversed. This is an indication that across almost all the EU regions the CDS markets were the main channel of contagion, but not so much in the *Europeriphery*, where the bond markets took the leading role.

We present Table 3.22 here, the rest of tables being available online, as a Supplementary Appendix.

Table 3.22

GFEVD for One Standard Error Positive Shock to Greece Sovereign Spread

		0	1	2	3	4	5
cee	**bsprd**	0.02496	0.024771	0.024555	0.024579	0.02463	0.024672
cee	**cddif**	0.064459	0.063751	0.065192	0.066247	0.066635	0.066821
	total	0.089419	0.088522	0.089747	0.090826	0.091264	0.091493
core	**bsprd**	0.012307	0.011253	0.010534	0.010239	0.010141	0.010068
core	**cddif**	0.03091	0.02917	0.027765	0.027178	0.026955	0.026812
	total	0.043217	0.040422	0.0383	0.037417	0.037096	0.03688
noneuro	**bsprd**	0.007974	0.008591	0.008504	0.008254	0.00812	0.0081
noneuro	**cddif**	0.035786	0.035999	0.036101	0.035913	0.035689	0.035523
	total	0.04376	0.04459	0.044605	0.044167	0.043809	0.043623
periphery	**bsprd**	0.125342	0.124478	0.12417	0.124293	0.124424	0.124483
periphery	**cddif**	0.019638	0.019074	0.018086	0.017491	0.017301	0.017218
	total	0.14498	0.143553	0.142256	0.141784	0.141725	0.141701

III.4.2. One Standard Error Positive Shock to the Europeriphery Sovereign Bond Spreads

The magnitude of responses is largest for the *Europeriphery* sovereign markets and smallest for the *Noneuro* region, with responses from the *Eurocore* and the *CEE* in-between. An interesting point to notice is that across each region the percentage change is greater for the sovereign bond spreads than for the sovereign CDS differentials. This can be explained, on the one hand, by the special “safe haven” status of the German Bunds, the benchmark used for bonds, for which aggressive buying during the “flight to safety” periods drives their yields down, therefore increasing spreads, and on the other hand, by increased quotes for German sovereign CDSs, the benchmark used for CDSs, which now include a larger probability of default, caused perhaps by market signals with regard to the Euro Zone structural problems coming from periphery. This assumption is somewhat confirmed by the behavior of 10-year German CDS from the Dominant Unit, which increases post-impact.

Among the *CEE* countries, spreads increase the most for Bulgaria, Hungary, Romania and Lithuania during the first 5 post-impact periods. Poland and the Czech Republic, countries with better macro fundamentals, experience less pain.

3.4.3. One Standard Error Positive Shock to the Europeriphery Sovereign CDS Differentials

While the GIRFs reveal more or less the same order of magnitude as above, with the *Europeriphery* hit hardest and the *Noneuro* experiencing insignificant changes in variables, we notice here as well the effects of the shock on the global variables from the Dominant Unit. Both VIX and the 10-year German CDS face post-impact increases, an indication of the possibility that troubles in the periphery of the Euro Zone turned into an outright generalized risk aversion.

A comparative analysis of GFEVDs for the shocks to the two segments of the *Europeriphery* sovereign markets simulated so far indicate that in both cases the contribution of the *Europeriphery* region is the greatest and the contribution of the *Noneuro* region is the smallest. As for the other two regions, while the *CEE* has a larger contribution than the *Eurocore* in explaining the forecast error variance of the historical shock in the bond markets, the role is reversed in the CDS markets, with the *Eurocore* contribution being more important.

3.4.4. One Standard Error Negative Shock to the Eurocore Sovereign Bond Spreads

Assuming that a generalized decrease in the *Eurocore* sovereign bond spreads is the direct consequence of the recent Public Sector Purchase Program (PSPP) of the ECB, we study the effects of this policy measure and its transmission across the entire EU. Post-impact, the sovereign spreads and CDS differentials fall across all regions, with the *Europeriphery* benefitting the most, followed by the *Eurocore*. There are spillover effects in the *CEE* markets also, but no significant influence for the *Noneuro* sovereigns, for which the CDS differential faces a minor increase, probably caused by the decrease in the quotes for the benchmark used, the German CDSs, which might incorporate an even smaller probability of default following the ECB actions.

GFEVDs reveal that the *Eurocore* is the main channel of propagation for this shock, accounting for 73% of the variance of the shock at impact. More than two thirds of this regional contribution is explained by the sovereign bond spread and the rest by the CDS differential. The contribution of the *CEE* region is more important than that of the *Europeriphery* region.

3.4.5. One Standard Error Negative Shock to the EURIBOR-EONIA Spread

A narrowing of the EURIBOR-EONIA spread could be used as a market proxy for liquidity-driven operations conducted by the ECB in 2011-2012 (e.g., LTRO, OMT). The *Europeriphery* region seems to have benefited the most from the massive liquidity interventions of the ECB, with a -12% contemporaneous change in sovereign bond spreads. Interestingly, since the decrease in sovereign bond spreads is of a larger magnitude for the *CEE* region than for the *Eurocore* region during the first five post-impact periods, we can conclude that the *CEE* countries might actually have benefited more than the *Eurocore* countries from the ECB interventions. For the *Noneuro* region, the bond spread increased, the most probable cause being a decrease in the Bund yield used as benchmark.

3.4.6. One Standard Error Positive Shock to the VIX

The sovereign bond spreads most affected by an increase in the global risk aversion are those in the *CEE* region. Breaking the analysis by country, it should be noticed that Romania and Hungary experience the largest increases in the variables, while the Czech Republic is at the other extreme, being the least affected from among its *CEE* peers. A possible explanation would be the relatively higher country risk of Romania and Hungary as compared to that of Poland or the Czech Republic. For example, "flight to safety" periods can determine investors to sell bonds of the most risky countries and invest in countries they perceive as less risky. Countries with better macro fundamentals, such as Poland or the Czech Republic, benefit therefore from reduced yields and yield spreads to the detriment of countries that lack a favorable macro outlook. As for the sovereign CDS differentials, the *Europeriphery* countries are most affected at impact, but, surprisingly, percentage changes turn negative from period 4. One note of caution here: VIX analysis may be more appropriate for higher-frequency data, such as daily or even intra-day.

3.4.7. One Standard Error Positive Shock to the 10-year EUR-denominated German CDS

To analyze the influence of a fundamental shock to the "engine" of the Euro Zone, as Germany is sometimes named, we study the effects of a positive innovation in the 10-year German CDS, the global variable from the Dominant Unit. The sovereign bond spreads increase instantaneously across all four regions, while the CDS differentials increase for the *Eurocore*, the *Europeriphery*, the *CEE* and decrease for *the Noneuro*. We should note however that, starting with period 3, both the *Europeriphery* variables decrease relative to their base values, which is contradictory.

This particular behavior of spreads/differentials can be explained by the increase in VIX, implicitly in global risk aversion, following the simulated shock. The "flight to quality" mode triggered would make investors pile up into safe assets, such as the German Bunds, which would reduce their yields and increase spreads over Bund yields. A similar reasoning can be made for the CDS differentials.

IV. Concluding Remarks

1. At a regional level, the sovereign financial markets of the *Europeriphery* countries are more sensitive to shocks coming from the rest of the EU, with CDS markets, in particular, being more prone to overshooting than the sovereign bond markets.
2. The increase in Greece sovereign bond spreads has spillover effects across the entire EU, with the *Europeriphery* region contributing the most to the propagation of shocks. As for the main channel of contagion, this seems to be the CDS market, with the exception of the *Europeriphery*, where the bond market takes the leading role. This contradicts somewhat Calice *et al*. (2011), Fontana and Scheicher (2010), Gyntelberg *et al*. (2013), Palladini and Portes (2011), but is similar to Badaoui *et al*. (2013).
3. A regional positive shock to the *Europeriphery* sovereign spreads has a stronger influence on the bond spreads than on the CDS differentials across the entire EU.

This is explained by the benchmark used in each case. The German Bunds are "safe haven" assets that experience increased demand and lower yields during the "flight-to-quality" episodes in the market. Lower yields mean wider bond spreads. On the other hand, German sovereign CDS market quotes increase because they incorporate a greater probability of default as a result of modified investor perception with regard to the risk posed by the *Europeriphery* to the overall Euro Zone and, in particular, to Germany. Increased quotes for German CDSs push lower the sovereign CDS differentials.

4. Among the *CEE* countries, sovereign spreads for Poland and the Czech Republic are the least affected by shocks coming from the *Europeriphery* sovereign bond markets, perhaps as a result of their better macro fundamentals.
5. With respect to the relative importance of different EU regions to the transmission of shocks originating in the *Europeriphery*, the *Eurocore* countries seem to contribute more than the *CEE* countries to the propagation of shocks coming from the CDS markets, but the *CEE* countries contribution to the propagation of shocks coming from the sovereign bond markets is more important.
6. The *Europeriphery* troubles might influence the global risk aversion. A regional increase in CDS differentials in this area determined an increase in VIX beginning with post-impact period 1 (the approach taken in constructing the global variables in the Dominant Unit deems the contemporaneous change not relevant).
7. To the extent that a narrowing of EURIBOR-EONIA spread can be considered a good market proxy for the extraordinary measures undertaken by the ECB to provide liquidity to the markets in 2011-2012, it seems that the Central Bank action was effective, as sovereign spreads and CDS differentials decrease across all the EU regions, with the exception of the *Noneuro* region. Moreover, the *Europeriphery* countries seem to have been the main beneficiaries of such measures.
8. If we assume that the massive purchases of sovereign bonds conducted by the ECB within its recent quantitative easing program (PSPP) narrow first the *Eurocore* spreads, this particular shock will have positive effects not only on the *Europeriphery* spreads but there will be "spillover" effects on the *CEE* countries as well.
9. An increase in global risk aversion, as proxied by a positive shock in VIX, has the largest contemporaneous effect on the *CEE* countries if we are talking about sovereign bond spreads, and on the *Europeriphery* countries in the case of CDS differentials. However, beginning with post-impact period 4, the percentage changes become negative for the *Europeriphery*. This is a rather controversial result, which should be interpreted with caution: on the one hand, VIX analysis may be more appropriate for higher frequency data and, on the other hand, the dynamic analysis we employ is relevant for short periods only.
10. A fundamental negative shock to the economy of the Euro Zone "engine", Germany, for which a good market proxy would be an increase in the spread of the 10-year EUR-denominated German sovereign CDS, might determine an increase in the global risk aversion, as it determines an increase in VIX immediately post-impact. It also determines the widening of sovereign spreads across all the EU regions.

11. Denmark, Sweden and United Kingdom seem isolated from shocks coming from the Euro Zone. The dynamic analysis reveals extremely low values for all these countries' GIRFs post-impact. Moreover, their contribution to the transmission of shocks across the EU is insignificant.

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Note: A Supplementary Appendix including all the figures and tables referenced in the text is available online.