Fragmentation in the European Monetary Union: Is it really over? ⋆

Bertrand Candelon[a,1], Angelo Luisi[a,1], Francesco Roccazzella[a,1]

[a] *Université catholique de Louvain, Louvain Finance*

Abstract

This paper analyzes the fragmentation risk in the European Monetary Union, investigating the shock transmission mechanisms in the sovereign bond market. To achieve this goal, it builds a new methodology for modelling interactions, reconciling Factor and Global Vector Autoregressive models. This framework helps to disentangle interdependence from contagion and flight-to-quality effects, therefore assessing more precisely the degree of fragmentation. It turns out that fragmentation risk was already present and sizeable in the pre-European sovereign debt crisis period, but has been sharply mitigated after. The COVID crisis has put it back at the forefront of the scene and questions the European integration process.

⋆This research was conducted as part of the research program entitled "Financial and Extra-Financial Risk Modeling" under the aegis of the Europlace Institute of Finance, a joint initiative with Insti7. The usual disclaimer applies.

Email addresses: candelonb@gmail.com (Bertrand Candelon), angelo.luisi@uclouvain.be (Angelo Luisi), francesco.roccazzella@uclouvain.be (Francesco Roccazzella)

[1]Louvain finance, UCLouvain, Voie du Roman Pays, 34, 1348 Louvain-la-Neuve

1. Introduction

Since the recent $2010 - 2012$ European Sovereign Debt (ESD) crisis, the evolution of sovereign bonds among the euro area countries has been closely monitored. With the introduction of the euro, long term yields differentials between euro area government bonds were co-moving synchronously at low rates, respecting hence the well-known property of the uncovered interest rate parity in fixed exchange rate regimes. The ESD crisis has ruled out these stylized facts leaving place to heterogeneous and unprecedented high levels of divergence. This reflects the potential risk of fragmentation in the European Union between high and low-debt countries.

Indeed, the difference in sovereign bond yields reflects several risks, namely liquidity, exchange rate and credit. As shown by Favero and Missale (2012) or Sgherri and Zoli (2009), liquidity risk (high transaction costs in tiny markets) is not particularly relevant for the European bond market, which is quite mature. Similarly, the exchange rate risk has been drastically reduced since the introduction of the euro. It now solely resumes the probability for a country to exit the union as well as the possibility of a general collapse of the common currency. This risk is not necessarily insignificant as it appears with the Brexit, even if the United Kingdom was not member of the euro area. The exchange risk is nevertheless quite small. The remaining credit risk is therefore the most pregnant one. It concerns the ability of a country to repay at a finite horizon its public debt. Credit risk is driven by three factors. The country specific one, based on local macroeconomic fundamentals (public debt, public deficit, GDP growth,...). The European Union factor, such as the risk of the Euro break up that became sizeable after the sovereign debt crisis (De Santis, 2019), European institutions tackle this dimension, in particular the European central bank through unconventional monetary policies (quantitative easing policy) which consists in purchasing sovereign bonds, pushing hence down the public debt refinancing rate. The recovery plan (basically the issuance of European mutualized bonds in $2020 - 2021$) has also contributed to mitigate the credit risk, limiting the country specific debt. Finally, the credit risk is affected by a world factor and the appetite of the markets for risk. It modules the sensitivity of investors' demand for sovereign bonds to interest rates.

Several studies have tried to disentangle these three components aiming to better evaluating and forecasting the fragmentation risk on the sovereign bond markets. Sgherri and Zoli (2009) consider a dynamic state-space model to extract the common factors across European sovereign bonds. They show the predominance of common factors before the ESD crisis and the importance of specific factors after. Favero and Missale (2012) prefer to opt for a Vector Autoregression (VAR) representation to model it. They stress the importance of market sentiment. Global and European appetite for risk is therefore not constant over time, signaling the presence of contagion driven by shift in the market sentiment. More recently, Favero (2013) considers a Global VAR ($GVAR$) representation. $GVAR$ builds on local VAR models, augmented by the so-called star variable, i.e., the weakly exogenous weighted average of foreign variables, resulting in local $VARX^*$ models (Harbo et al., 1998; Pesaran et al. (2004)). The key point of these models is the transmission matrix W which relates the local models together. Favero (2013) considers interconnection in terms of fiscal fundamentals: the more similar two countries are in terms of debt- and deficit-to-GDP ratios, the tighter the interconnection between their sovereign yields. Candelon and Luisi (2020) prove statistically that a so-defined transmission matrix is misspecified as it is constraint to be non negative. It is therefore impossible to consider simultaneously contagion (positive transmission) and flight-to-quality (negative transmission) phenomena. Thus, they show it is optimal to consider two different W matrices, that associated with a negative coefficient (W^-) and that associated with a positive coefficient (W^+) in the local $VARX^*$ models. Using this approach, they show that fragmentation risk was important even prior the ESD crisis among European countries.

This paper reconciles the factor augmented VAR ($FAVAR$) and the $GVAR$ literature, by employing (static) principal components (PC) as a way to retrieve information from cross sectional dependence. Specifically, as in Elhorst et al. (2020), we confirm that in presence of high cross sectional correlation, the first PC captures the common factor underlying sovereign bond markets. This factor can be interpreted as the *global* factor. The second PC provides guidance for the presence of *intra-European* interconnection expressed as the idiosyncratic contribution to the residual cross sectional correlation. We therefore follow Bernanke et al. (2005) and retrieve the part of the second PC that is not dependent on the specific local market. We express this component as the weighted average of foreign counterparts (in the $GVAR$ fashion), but leaving the sign of the weights unconstrained. The analysis of the resulting transmission matrix provides evidence of the presence of flight-to-quality and/or contagion effect in the euro area.

This methodology is implemented for long term yield spreads between the 10 year euro government bonds and the German safe benchmark over three remarkable periods: The pre-ESD crisis, the post-ESD as well as the recent COVID period. It is noticeable that signs of "contagion" and "flight-to-quality" effects were already present in the pre-EDS period, suggesting a latent fragmentation risk between southern European countries (Portugal, Italy, Ireland, Greece and Spain) and the Northern ones. Such a finding contradicts existing literature regarding financial integration in the euro area before the ESD (Baele et al., 2004) but is in line with the recent results of Candelon and Luisi (2020). Soon after the ESD, the different programs of public bonds purchases enhanced by the European Central Bank have limited this risk, leading all European spreads to shrink back slowly but steadily to the pre-ESD period. The COVID crisis has pushed again the fragmentation risk at the forefront of the results. Despite the implementation of the European recovery program, contagion and flight-to-quality effects are present again, stressing the revival of the fragmentation risk.

The paper is sketched as follows: After a preliminary data analysis in Section 2, Methodology is presented in Section 3. The empirical analysis on the fragmentation risk is performed in Section 4, while Section 5 concludes.

2. Preliminary Data analysis

We start our analysis by examining the dynamics of the long term yield differential between euro area government bonds. The 10 years monthly yields are extracted from Refinitiv Eikon data set and are covering 11 countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain) over the period $2006:6-2021:2$ and shown in Figure 1.

What emerges from a first visual inspection, is that long term yields differentials between euro area government bonds and the German *safe* benchmark co-move following an unstable pattern over time.

In the following sections, we give a closer look to this dynamics, distinguishing across the pre-, $(2006:6-2010:3)$, during-, $(2010:4-2012:7)$, and post-, $(2012:8-)$, European sovereign debt (ESD) crisis periods. On the one hand, April 2010 is the indicative watershed that certifies the beginning of the European sovereign debt crisis. In particular, after the publication of the Greek quarterly national accounts data which signaled a persistent recession for the Hellenic economy starting in 2007, credit rating agencies then downgraded Greek bonds to the investment grade status in late April 2010. On the other hand, on the 26 July 2012 Mario Draghi, President of the European Central Bank, pronounced the famous "whatever it takes" speech, announcing the Outright Monetary Transactions (OMT) to neutralize the risk of a break up of the euro area.

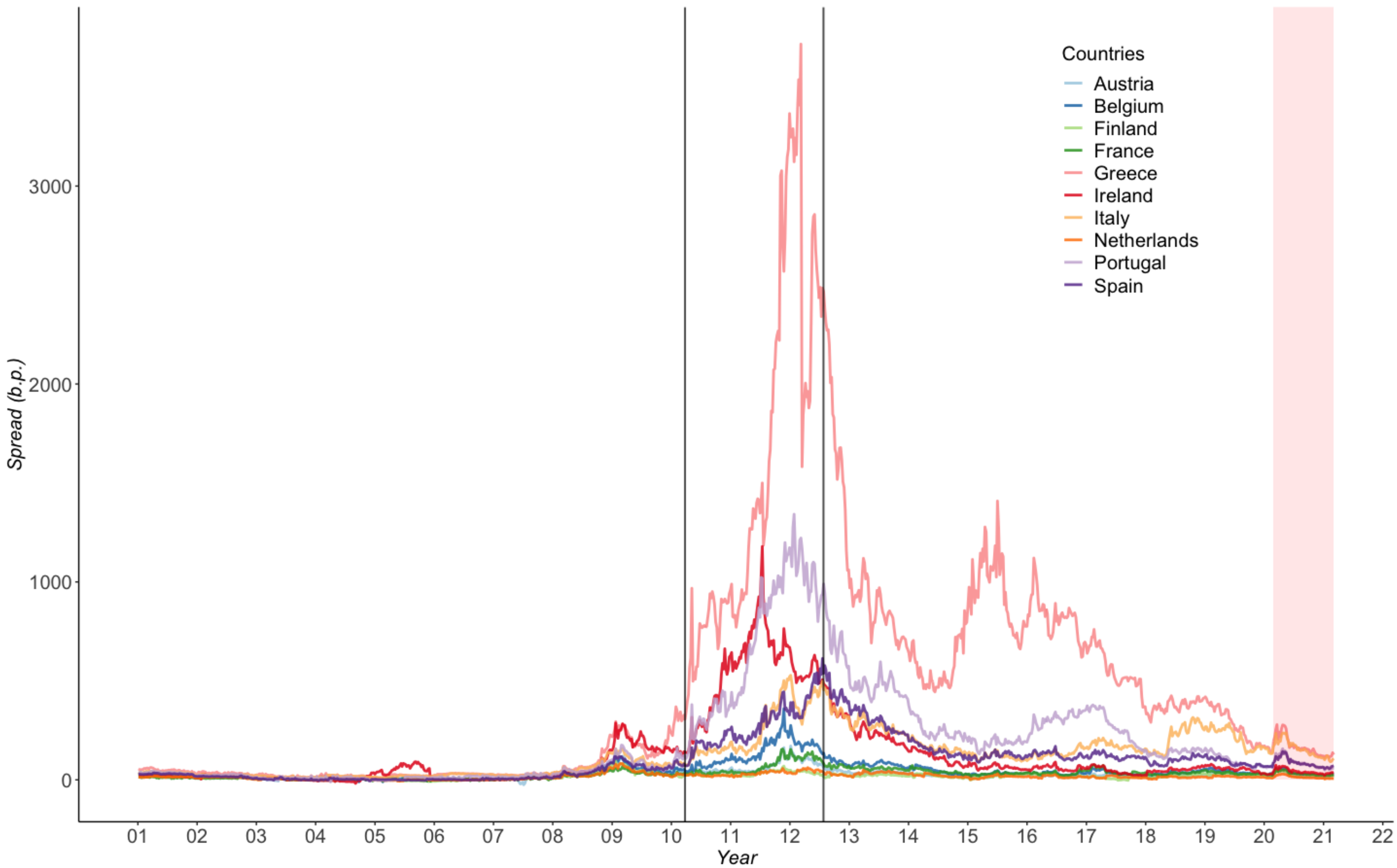

Figure 1: The figure reports the evolution of the government bond yield spread of 10 countries (Austria, Belgium, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal and Spain) vis á vis of Germany over the period $2006:1-2021:2$. The EDS crisis beginning and end dates are indicated with vertical bars.

2.1. Pre-crisis period

The dynamics of the spreads during the pre-ESD crisis period $(2006:1-2010:3)$ can be further decomposed into a convergence period and the subprime loans crisis period. In fact, despite market participants have never regarded the long term bonds issued by other euro area Member States as perfect substitutes of the German *Bund*, interest rate differentials co-moved synchronously at the very low-level until the burst of the subprime loans crisis. During 2008 and 2009, 10Y sovereign debt spreads became considerable. At this point the joint dynamics of euro area spreads began to fracture: a separate co-movement between high-debt and low-debt countries emerges. (Favero, 2013).

2.2. The sovereign debt crisis period

The euro debt crisis brought even greater magnitude in the $10Y$ differentials, than those of the $2008-2009$ period and a marked heterogeneity in the co-movement. The idea that long term government debt spreads follow a common dynamics in the euro area fades away: the core (Germany, France, Belgium, Netherlands, and Finland) and periphery (Greece, Ireland, Portugal, Spain, Italy) binary classification becomes predominant both in the political and academic debate when analysing the economic and financial turmoil in $2010-2012$ (House et al., 2020; Corsetti et al., 2014).

During the fall 2011, the $10Y$ differentials relative to the German *Bund* reached record heights: Italian $10Y$ sovereign yield spreads rising in a few weeks from 270 basis points in August to over 500 basis points in November. We can draw a similar picture for Ireland, Portugal and Spain. However, it seemed that such outcome were only partially connected to underlying fiscal fundamentals (De Grauwe and Ji, 2012), but it also reflected self-fulfilling prophecies and the existence of multiple equilibria (Corsetti and Dedola, 2016; Cole and Kehoe, 2000).

The risk of an euro area break-up became so real in the early 2012, that the Euro redenomination risk, i.e., is the risk that a euro asset is redenominated into a devalued legacy currency, significantly impacted sovereign yield spreads, with italian and spanish bonds being most negatively affected (De Santis, 2019).

Following Mario Draghi's, whatever it takes" speech, the ECB announced a new set of unconventional measures, the Outright Monetary Transactions (OMT). This programme explicitly aimed at relieving the financial fragmentation in the euro area and at neutralizing redenomination risk. As a fact, by September 2012, Irish, Italian, Portuguese and Spanish differentials relative to the German 10Y yield had already decreased by an average of 200 basis points.

With purchasing programs (Securities Markets Programme), the very long term refinancing operations ($VLTROs$) and with the announcement of the OMT, the ECB mitigated the fears in sovereign bond markets, reinforcing a slow but progressive return of spreads towards normal levels.

2.3. The post crisis period

The third period of analysis starts in August 2012, spanning the slow but steady return of spreads towards pre-crisis levels till March 2020, when the explosion of the COVID pandemic and the enhancement of the first travelling restrictions and lock-down measures across Europe started to be implemented (shaded area in Figure 1).

In late 2012, ECB's actions addressed the difficulties in the transmission of the monetary policy measures, the onset of a credit crunch and the risk of deflation.[2]

As a result of these measures, the consolidated balance sheet of the Eurosystem has more than doubled between 2010 and 2020, starting from $2,002,210$ EUR millions in 2010 and reaching $4,671,425$ EUR millions in 2019.[3] Consequently, given the massive liquidity injection operated by the ECB during the 2012-2020 period, the progressive decline of the $10Y$ government bond differentials relative to the German *Bund* should not come as a surprise.

---

[2]More precisely, in July 2013, the ECB began using forward guidance with the goal of strengthening the monetary policy transmission mechanism from short to long term interest rate. In June 2014, the ECB further cuts the main marginal lending facility rate to 0.4%, the refinancing operation rate to 0.15% and lowered the deposit facility rate to -0.10%. A series of the targeted longer-term refinancing operations ($TLTROs$) (June 2014, March 2016 and March 2019) have also been used to stimulate bank lending to the real economy. Starting in mid-2014, the ECB also launched the Asset Purchase Programme (APP), conducting net purchases of corporate sector ($CSPP$), public sector ($PSPP$), asset-backed securities ($ABSPP$) and covered bond ($CBPP3$).

[3]The Eurosystem consolidated balance sheet is published together with the Annual Accounts, and is included in the Annual Report of the ECB. The data is available at `https://www.ecb.europa.eu/pub/annual/balance/html/index.en.html`

2.4. *The COVID crisis period*

At the outbreak of the COVID pandemic in Europe in March 2020, euro area $10Y$ sovereign spreads suddenly increase. In this period, the European Commission, the European Parliament and EU countries have been seeking for an agreement to help repair the economic and social damage caused by the coronavirus pandemic and boost the recovery at the European level. In December 2020, the agreement for a 1.8 trillion EUR recovery plan was reached together with the return of generalized common and declining co-movement in the dynamics of $10Y$ government debt spreads. The novelty of this recovery plan is that it will be issued by the European Union as a whole and the associated debt will not be recorded in the countries national accounts. It should result in reducing the risk premium and foster the link between European countries.

3. Methodology

3.1. *GVAR Models as approximation of Factor Models*

The use of the Factor Model as a theoretical justification of $GVAR$ as a framework to model international interconnections comes from Dees et al. (2007). Assume that there are N countries in the global economy, and that our aim is to model the k_i with $i = 1, \ldots, N$ local macro-economic and/or financial variables collected in the vector x_{it} over time $t = 1, \ldots, T$. Given the general nature of interconnections, a good starting point for the analysis is the factor model:

$$x_{it} = \delta_{i0} + \delta_{i1}t + \Gamma_{id}d_t + \Gamma_{if}f_t + \epsilon_{it} \tag{1}$$

for $i = 1, \ldots, N$, and $t = 1, \ldots, T$. d_t represents the vector of the m_d global observed factors, f_t the m_f unobserved global factors. $\Gamma_i = (\Gamma_{id}, \Gamma_{if})$ is the $k_i \times m$ matrix collecting the factor loadings with $m = m_d + m_f$. ϵ_{it} is the vector of country specific effects.

To allow for cointegration and unit root properties of x_{it}, Dees et al. (2007) further assume that:

$$\Delta h_t = \Lambda(L)\eta_t, \quad \eta_t \overset{i.i.d.}{\sim} (0, I_m) \tag{2}$$

$$\Delta \epsilon_{it} = \Psi_i(L)\nu_{it}, \quad \nu_{it} \overset{i.i.d.}{\sim} (0, I_{k_i}) \tag{3}$$

with L being the Lag operator. Dees et al. (2007) prove that in such a setting factors can be approximated by cross sectional averages:

$$f_t \xrightarrow{q.m.} (\Gamma_f^{*\prime}\Gamma_f^*)^{-1}\Gamma_f^*(x_t^* - \delta_0^* - \delta_1^* t - \Gamma_d^* d_t - \epsilon^*). \tag{4}$$

The *star* variables being cross sectional averages of the initial variables in (1). The $GVAR$ framework, instead of considering the same factor for all countries under analysis, employs country specific ones built as weighted averages of foreign counterparts, where the weights capture the tightness of the interconnection between country i and country j as follows:

$$x_{it}^* = \sum_{j=0}^{N} w_{ij} x_{jt}, \quad w_{ii} = 0 \tag{5}$$

resulting in the local $VARX^*$ model counterpart of (1):

$$\Phi_i(L, p_i)x_{it} = a_{i0} + a_{i1}t + \Upsilon_i(L, q_i)d_t + \Lambda_i(L, q_i)x_{it}^* + \nu_{it}, \tag{6}$$

where p_i and q_i are the maximum lag considered for the local and foreign variables, respectively. The different coefficients treated as unrestricted for estimation purposes.

For a correct interpretation of the country specific weights employed, it is fundamental to disentangle the common components from the cross-sectional interactions when the different series are strongly co-moving along a common trend (Elhorst et al., 2020). This can be achieved in a two step approach as in Bailey et al. (2016a), *defactorizing* the observations and then modeling the residual cross sectional dependence. Vega and Elhorst (2016) argue against the two step approach in favour of a simultaneous approach. As observable measure of the unobserved factors, Principal Component (PC) analysis can be effectively employed (see, for example, Stock and Watson, 2016). Moreover, Bernanke et al. (2005) show that it is possible to disentangle the part of the information spanned by the PCs that is external to the specific local variables considered. Finally, the factors summarizing the *external* information can be included in a VAR specification as (weakly) exogenous variables following Balabanova and Brüggemann (2017).

Once local parameters in (6) are estimated, we can simultaneously solve the model to obtain the *Global VAR* representation of the world. We now summarize the procedure as in Pesaran et al. (2004).

Define the $(k_i + k_i^*) \times 1$ vector:

$$z_{i,t} = \begin{pmatrix} x_{i,t} \\ x^*_{i,t} \end{pmatrix} \tag{7}$$

and rewrite (6) as:

$$A_i z_{i,t} = B_i z_{i,t-1} + \epsilon_{it} \tag{8}$$

with $A_i = (I_{k_i},\ -\Lambda_{i0})$ and $B_i = (\Phi_i,\ \Lambda_{i1})$. For ease of explanation, we here abstract, without loss of generality, from including the deterministic component, the time trend and additional Lags.

If we collect all the local variables in $x_t = (x'_{0t}, x'_{1t}, \ldots, x'_{Nt})'$ for $i = 1, \ldots, N$ with $k = \sum_1^N k_i$, we can rewrite:

$$z_{i,t} = W_i x_t. \tag{9}$$

By substituting (9) into (8), we obtain:

$$A_i W_i x_t = B_i W_i x_{t-1} + \epsilon_{it}, \tag{10}$$

By stacking all the equations together, we obtain:

$$Gx_t = Hx_{t-1} + \epsilon_t, \tag{11}$$

As in Candelon and Luisi (2020), by defining the interaction matrix $\tilde{W}$ as:

$$x_t^* = \tilde{W} x_t. \tag{12}$$

We can express the matrices G and H as:

$$G = [I_k - \tilde{\Lambda}_0 \tilde{W}] \tag{13}$$

$$H = [\tilde{\Phi} + \tilde{\Lambda}_1 \tilde{W}] \tag{14}$$

Lastly, we can retrieve the $GVAR$ solution as:

$$x_t = G^{-1} H x_{t-1} + G^{-1} \epsilon_t. \tag{15}$$

Therefore, the $GVAR$ solution is the reduced form VAR representation of the world. This representation is particularly useful for forecasting, scenario analysis and Generalized Impulse Response function.

3.2. Taking the model to the data: Sovereign spreads in the euro area

$GVAR$ Models have been employed in the analysis of the interactions among European sovereign bonds spreads as a tool to unveil the tightness of financial interconnectedness and to identify the transmission channels of asymmetric shocks. Favero (2013) showed that the cross correlation among sovereign bond spreads follows an unstable pattern over time, implying that a correct proximity measure should take into account the shifts described in the preliminary data analysis in Section 2. Moreover, Favero and Missale (2012) showed how a shift in market sentiment following the emergence of a country financial distress can propagate to relatively safer countries. For example, they estimate that a shock in August 2011 could trigger a contagion on the Italian sovereign yield of the size of 200 basis points.

Following Favero and Missale (2012), the local *GVAR* specification in the case of sovereign bond spreads over the German *Bunds* $(Y_t^i - Y_t^{DE})$ can be expressed as follows:

$$(Y_t^i - Y_t^{DE}) = \beta_{i0} + \beta_{i1}(Y_{t-1}^i - Y_{t-1}^{DE}) + \beta_{i2}(Y_t^i - Y_t^{DE})^* + \beta_{i3}(Y_{t-1}^i - Y_{t-1}^{DE})^* + u_t^i \qquad (16)$$

where $i = 1, \ldots, N$ is the specific country under analysis, β_{i0} the deterministic component, β_{i1} the coefficient associated with the country specific lagged variable, and β_{i2}, and β_{i3} the coefficients associated with the (contemporaneous and lagged) *Global Spreads*, $(Y_t^i - Y_t^{DE})^*$. *Global Spreads* are computed for each country as the weighted average of foreign counterparts' spreads over the German *Bunds*, $\sum_{i \neq j} w_{ij}(Y_t^j - Y_{t-1}^{DE})$ for each $i \neq j$.

As recommended by Elhorst et al. (2020), we first perform the *CD*-test (Pesaran, 2021) on the cross section of spreads under analysis to prove their strong co-movement along a global trend (see Section 4). Based on this result, we augment the *GVAR* specification in (17) as follows:

$$(Y_t^i - Y_t^{DE}) = \beta_{i0} + \beta_{i1}(Y_{t-1}^i - Y_{t-1}^{DE}) + \beta_{i2}(Y_t^i - Y_t^{DE})^* + \beta_{i3}(Y_{t-1}^i - Y_{t-1}^{DE})^* + \beta_{i4}F_{1,t} + u_t^i \quad (17)$$

where $F_{1,t}$ is the first Principal Component (*PC*) extracted from the cross-section of yields.[4]

The common factor F_1 can therefore be interpreted as a long-run stable attractor proxying the global interdependence among European countries' sovereign bonds. By augmenting our specification in this way, we make sure that the *star* variables in (17) and the associated

[4]Observable common variables are often also employed in the literature for this purpose (for example, Favero, 2013, augments the specification with the long term corporate *Baa-Aaa* spread to account for global risk aversion).

coefficients deal with intra-European interconnection defined in a *GVAR* fashion.

The choice of the weights employed to build the *Global Spreads* is crucial. As outlined in Subsection 3.1, the *GVAR* specification demands the weights to summarize the *external* information through a weighted average of foreign counterparts. Existing literature has shown that misspecifying the channel of interconnection results in incorrect inferences (see, for example Gross, 2019). Candelon and Luisi (2020) show that in the case of euro area sovereign bond spreads, an empirically valid channel of interaction should take into account the asymmetric transmission of shocks among countries that exhibit positive (negative) interconnections.

Therefore, it is natural to start the interconnection analysis from the second factor of the cross section of sovereign spreads for several reasons. First, the second Principal Component F_2 summarizes the cross sectional information that is linearly independent to the first factor F_1, therefore its inclusion in (17) would not be problematic from an econometric perspective. Second, by construction F_2 is built to capture most of the cross sectional variance left unexplained by F_1, capturing therefore the interconnection among spreads as we aim to. Third, the loadings of the factors are not constrained to be positive, providing guidance for not only the size, but also the sign of the weight of each local yield contribution to the cross sectional variance explained. Four, it allows us to follow the procedure in Bernanke et al. (2005) to extract from the Principal Component the *foreign* information, as requested by the *GVAR* framework, where the *Global* variable is a weighted average of foreign counterparts. Finally, the inclusion of the factors summarizing external information as (weakly) exogenous variable can be included in a typical $VARX^*$ fashion (see, for example, Balabanova and Brüggemann, 2017).

For all these reasons, we consider:

$$\hat{F}_{2,it} = \sum_{i \neq j} w_{ij}(Y_t^j - Y_{t-1}^{DE}) + v_{it} \tag{18}$$

for every $i = 1, \dots, N$ with $\sum_{i \neq j} |w_{ij}| = 1$. $\hat{F}_{2,it}$ is the part of the second Principal Component that is unspanned by the local economy i taken into account (Bernanke et al., 2005). Usually in the *GVAR* literature, the weights are constraint to be nonnegative. However, the normalization we propose allows keeping the original properties of the size of the weights (Pesaran et al., 2004), while considering also that sovereign bond spreads' interconnections can be positive and negative. Relaxing the nonnegativity assumption becomes particularly relevant when opposite mechanisms as contagion (see Metiu, 2012; Candelon and Tokpavi, 2016) or flight-to-liquidity (Monfort and Renne, 2013) are present. Specifically, during distressed periods, investors prefer safer and more liquid assets. This would result in an outflow of money from the peripheral countries to the core ones, causing rising yields for the high indebted euro area members (contagion) while financial sounder economies could benefit from lower rates (flight-to-quality). In our framework, this possibility is not ruled out thanks to the unrestricted sign of the weights.

Once the weights are retrieved by estimating (18) with OLS, we can build the foreign weighted averages as of (5) and estimate the local $VARX^*$ systems as specified in (17).

Armed with the local coefficients, we can proceed to solving the model in order to retrieve the *GVAR* representation in (15).

4. Results

4.1. Preliminary results

Following Favero and Missale (2012), and given the data analysis outlined in Section 2, we consider two separate periods: pre-*ESD* (June 2006 to March 2010) and post-crisis (from August 2012). Moreover, the COVID period is separately analyzed to further study the last part of the sample, where sovereign spreads seem to be back to the pre-*ESD* co-movements, despite the COVID crisis.

The sample split offers several advantages. First of all, by considering homogeneous periods in terms of cross correlation of the spreads, we can assess the changes in interconnectedness in those different phases (Forbes and Rigobon, 2002). Furthermore, using a narrative approach, the effect of the unconventional monetary policies in fostering financial integration can be assessed (Favero and Missale, 2016).

The first result reported in Table 1 regards the *CD*-test to assess the cross sectional dependence of the sovereign spreads under analysis. The *CD*-test (Pesaran, 2021) is defined as:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \tag{19}$$

with $\hat{\rho}_{ij}$ being the sample correlation coefficient between local variables of county i and country j. In Bailey et al. (2016a), we can find the order property of the average correlation coefficient:

$$\bar{\rho}_N = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij} = O(N^{2\alpha-2}), \tag{20}$$

where $\alpha \in [0, 1]$. As recommended in Elhorst et al. (2020), we first control that the null of weak cross sectional dependence ($\alpha < 0.5$) cannot be rejected in our sub-samples through the *CD*-test ($\hat{\bar{\rho}}$ and CD-statistic's columns in Table 1). Given the results, weak cross sectional dependence cannot be rejected given the high value of $\hat{\bar{\rho}}$.

Secondly, we assess the degree of cross sectional correlation through the two step procedure as in Bailey et al. (2016a).[5] In Table 1 we show that the cross sectional correlation in the sub-samples under analysis is really strong. Specifically, the estimated α is larger than 3/4, clearly pointing at the presence of common components at the basis of the behaviour of sovereign spreads. To correctly capture the interconnections among spreads, it is therefore important to *defactorize* the data. Following Vega and Elhorst (2016), we opt for a simultaneous approach as specified in (17).

To further document that *defactorizing* the data is important (and that no interconnection among units is considered at this stage), we show in Table 2 the loadings of the first Principal

[5] In the empirical application, we estimate α as in Bailey et al. (2016b)

Component. As expected in such a case, the loadings are evenly distributed among the different sovereign spreads under analysis. It supports hence the presence of a persistent interdependence trend among European sovereign yield spreads.

Table 1: Cross sectional dependence test

	$\hat{\bar{\rho}}$	CD-statistic	$\hat{\alpha}$	$\hat{\sigma}_{\hat{\alpha}}$
Pre-crisis	0.964	91.415	0.7559	0.0213
Post-crisis	0.945	133.355	0.8463	0.0258
COVID-19	0.918	63.409	0.9013	0.0499

Notes: This table reports the estimated average sample correlation between local country i and j, $\hat{\bar{\rho}}$, the cross-sectional test statistics, $CD - statistics$, as well as $\hat{\alpha}$ and its standard error, $\hat{\sigma}_{\hat{\alpha}}$

Table 2: First Principal Component: loadings

	Pre-ESD	Post-ESD	COVID
Austria	0.321	-0.319	-0.324
Belgium	0.322	-0.371	-0.335
Finland	0.309	-0.154	-0.315
France	0.320	-0.342	-0.322
Ireland	0.312	-0.361	-0.315
Italy	0.324	-0.296	-0.294
The Netherlands	0.320	-0.314	-0.327
Portugal	0.317	-0.335	-0.326
Spain	0.324	-0.363	-0.318
Greece	0.291	-0.242	-0.281
Variance explained	0.922	0.676	0.851

Notes: This table reports the factor loadings of the first static principal component over the three periods of investigation and the portion of cross sectional variance explained.

4.2. Interconnection matrices and their signs

Secondly, we proceed to the analysis of the estimated weights. As described in Subsection 3.2, the weights are retrieved by estimating (18) via OLS. The weights describe the contribution of each $j \neq i$ to the space of the residual cross sectional unexplained variance that is unspanned by country i's sovereign yields, as in Bernanke et al. (2005).

In Tables 3 to 5, we report the weights, row normalized. Each row i therefore features the tightness and the sign of the interconnection among country i and the foreign counterparts j. By looking at the values, we can easily notice the presence of sign heterogeneity, some weights being positive, while the other are negative. Such a stylized fact corresponds to the first proof of the presence of asymmetric interconnection. Specifically, already during the pre-ESD period, it was clear the distinction that emerged afterwords in the academic and public debate between core and peripheral countries. The sovereign yields of Spain, Italy, Portugal, and Greece feature an opposite sign for almost all specifications compared with Austria, Belgium, Finland, France, and The Netherlands. Such a result signals the presence of flight-to-quality from peripheral to core European countries already before the outburst of the ESD.

During the post-ESD period, while Portugal and Greece continue to exhibit the above mentioned features, we can see mixed signs for Ireland and Italy. This result points out at the convergence path started by European countries after the introduction of exceptional monetary policies inside the euro area.

By closely looking at the COVID period of our sample, we can clearly see that the same signs of fragility are back in the sovereign bond market. As a matter of fact, the blocks of countries exhibiting opposite signs are again core and peripherals, with the exception of Belgium, showing some similarities with peripheral countries.

4.3. Impulse response analysis

The analysis of the impulse responses can provide useful insights when we study a multivariate dynamic systems. In particular, the impulse response function maps the responses of the system to the effect of shocking one of the variables at different horizons. For example, we could be interested in the response of the Italian $10Y$ spreads to a 200 basis points shock on the Greek $10Y$ spread.

In our framework, we have three channels of transmissions of a shock from country i to j: a) via the contemporaneous factor $\hat{F}_{2,\cdot t}$, b) its lag $\hat{F}_{2,\cdot t-1}$ and c) via the correlations that

Table 3: Pre-*ESD*

	AU	BE	FN	FR	IR	IT	NL	PT	SP	GR
AU	·	-0.067	-0.258	-0.138	0.035	-0.071	-0.178	0.066	0.089	0.098
BE	-0.037	·	-0.263	-0.158	0.040	-0.088	-0.169	0.060	0.084	0.101
FN	-0.023	-0.083	·	-0.161	0.037	-0.164	-0.233	0.059	0.130	0.110
FR	-0.044	-0.107	-0.275	·	0.036	-0.093	-0.172	0.058	0.106	0.111
IR	-0.056	-0.138	-0.261	-0.089	·	0.002	-0.168	0.085	0.109	0.092
IT	-0.050	-0.086	-0.297	-0.164	0.036	·	-0.132	0.053	0.093	0.089
NL	-0.046	-0.075	-0.298	-0.161	0.039	-0.111	·	0.050	0.104	0.115
PT	-0.086	-0.101	-0.344	-0.071	0.031	0.045	-0.153	·	0.053	0.116
SP	-0.074	-0.078	-0.290	-0.122	0.038	0.006	-0.196	0.096	·	0.099
GR	-0.072	-0.097	-0.205	-0.080	0.022	0.086	-0.224	0.127	0.088	·

Notes: This table reports the weights w_{ij} extracted as indicated in (18).

Table 4: Post-*ESD*

	AU	BE	FN	FR	IR	IT	NL	PT	SP	GR
AU	·	-0.091	-0.683	0.052	0.0002	-0.015	-0.088	0.023	0.031	0.017
BE	-0.215	·	-0.509	0.098	-0.035	0.00003	-0.085	0.010	0.033	0.016
FN	-0.227	0.115	·	-0.092	0.048	-0.065	-0.394	0.013	0.023	0.022
FR	-0.211	-0.063	-0.511	·	-0.057	0.014	-0.061	0.019	0.047	0.017
IR	-0.137	-0.227	-0.360	0.200	·	0.017	0.030	0.007	-0.008	0.014
IT	-0.162	-0.026	-0.478	0.108	-0.026	·	-0.137	0.007	0.044	0.012
NL	-0.172	-0.070	-0.557	0.107	-0.025	-0.006	·	0.013	0.035	0.016
PT	-0.176	-0.209	-0.317	0.169	-0.039	0.025	0.033	·	0.018	0.014
SP	-0.158	-0.180	-0.390	0.187	-0.026	0.017	0.021	0.007	·	0.015
GR	-0.124	-0.219	-0.272	0.209	-0.050	0.022	0.049	0.010	0.044	·

Notes: This table reports the weights w_{ij} extracted as indicated in (18).

exist across the different shocks. In this last channel of transmission, it is crucial that the intra and inter-country correlations that exist across the different shocks are considered in an appropriate manner. Instead of using the original shocks, the traditional VAR literature uses Orthogonalized Impulse Responses (OIR) (Sims, 1980) or restrictions on the covariance matrix (Bernanke, 1986; Sims, 1986; Blanchard and Quah, 1989) to identify structural shocks. However, it is difficult to have a clear identification strategy in a $GVAR$ framework both when choosing the relevant restrictions in the covariance matrix of the global var and when deciding the order of countries and variables in the OIR set up. The Generalized Impulse

Table 5: COVID

	AU	BE	FN	FR	IR	IT	NL	PT	SP	GR
AU	·	0.026	-0.140	-0.377	0.058	0.063	-0.124	0.040	-0.126	0.047
BE	-0.177	·	-0.107	-0.256	0.068	0.061	-0.210	-0.002	-0.067	0.050
FN	-0.213	0.027	·	-0.317	0.063	0.060	-0.147	0.025	-0.102	0.047
FR	-0.282	0.111	-0.156	·	0.040	0.038	0.007	0.079	-0.232	0.056
IR	-0.165	-0.050	-0.101	-0.174	·	0.066	-0.331	-0.042	-0.013	0.058
IT	-0.192	-0.078	-0.051	0.062	0.068	·	-0.338	-0.093	0.064	0.054
NL	-0.176	0.028	-0.124	-0.344	0.064	0.065	·	0.033	-0.117	0.049
PT	-0.181	-0.002	-0.110	-0.262	0.068	0.061	-0.199	·	-0.067	0.050
SP	-0.143	0.046	-0.142	-0.481	0.042	0.059	-0.015	-0.020	·	0.052
GR	-0.124	-0.090	-0.032	-0.082	0.092	0.069	-0.425	-0.046	0.040	·

Notes: This table reports the weights w_{ij} extracted as indicated in (18).

Response function ($GIRF$) is an alternative method that is invariant to the ordering of the variables and the countries in the $GVAR$ (Pesaran and Shin, 1998; Pesaran et al., 1999) and does not require any restrictions on the covariance matrix of the residuals. In our framework, the $GIRF$ consists of inducing a one-period shock only on one variable, e.g., the $10Y$ spread of country i, and then, ruling out the historically observed distribution of the errors, studying the effect of such shock on the system at different horizons.

In the following subsections, we present the generalized impulse response functions in the pre- and post-ESD crisis with a supplementary focus on the COVID pandemic.

4.4. Pre-ESD period $2006:6-2010:03$

Figure 2 reports the generalized impulse responses to a 200 basis points (b.p.) shock to the Spanish 10Y differentials. Spain was selected as it is a large peripheral country, which has been quite affected during the ESD crisis period but also by the COVID pandemic.[6] First, despite our study does not include the ESD crisis period, our model captures a first sign of fragmentation of euro area into core and periphery has already taken place before the beginning of the European sovereign debt crisis. On the one hand, Italy, Ireland, Portugal and

[6]Italy for example has been less affected in term of GDP by the recent pandemic.

Greece are impacted in a similar manner by a 200 b.p. shock to Spain: their differentials are all expected to increase. Beside the sign, the size of such effect is also relevant: the estimated impact is well beyond 100 b.p., with the only exception being Portugal, for which, however, the impact is particularly persistent. On the other hand, core economies' differentials are expected to decrease: this is a first sign of the flight-to-quality behavior that will be then typically studied in the context of the European Sovereign Debt crisis. A second important aspect that will be a common feature of our results is the humped shape of the $GIRF$. In fact, while the first transmission of the shock occurs at the level of the covariance matrix of the $GVAR$, then subsequent effects and the persistence of the impact are mostly due to the global factor and its lag. The case of Belgium is exemplary of this: despite a first increase of its differential with respect to Germany, the 10Y spread then drops in the negative territory, aligning Belgium to the other core economies.

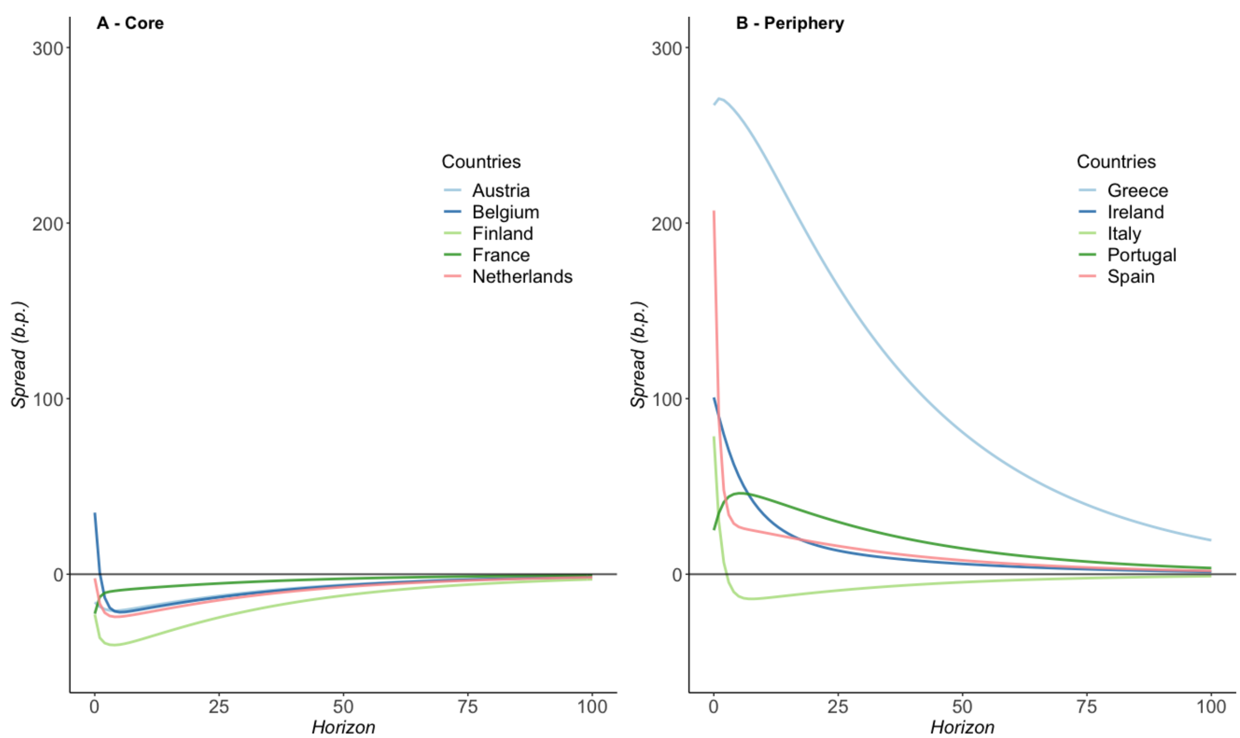

Figure 2: The figure reports the Generalized Impulse Response Functions to a 200 b.p. shock to the 10Y Spanish Spread in the pre-crisis period (2006 : 6 − 2010 : 03). In panel A, consider the core economies, i.e., Austria, Belgium, Finland, France and Netherlands, while we consider in panel B the periphery, i.e., Greece, Ireland, Italy, Portugal and Spain.

4.5. Post-ESD period 2012 : 09 − 2019 : 02

Figure 3 reports the generalized impulse responses to a 200 basis points (b.p.) shock to the Spanish differentials. Compared to the pre-ESD period, some differences are worth to be underlined. The shock to the Spanish differentials is expected to induce a generalized increase on the spreads of both periphery and core economies: there are no signals of a flight-to-quality behavior. Nevertheless, there is still a marked difference in the size of the impact: while the response of the core economies is particularly contained in size, the impact of the same shock on the other peripheral country remains important (e.g., over 400 b.p. for Greece) and persistent. Figure 3 depicts a picture where, despite the unconventional monetary policies of the ECB, and the OMT in particular, have neutralized the perception of the risk of a break up of the euro area, markets still acknowledge the financial fragility of the periphery relative to the core.

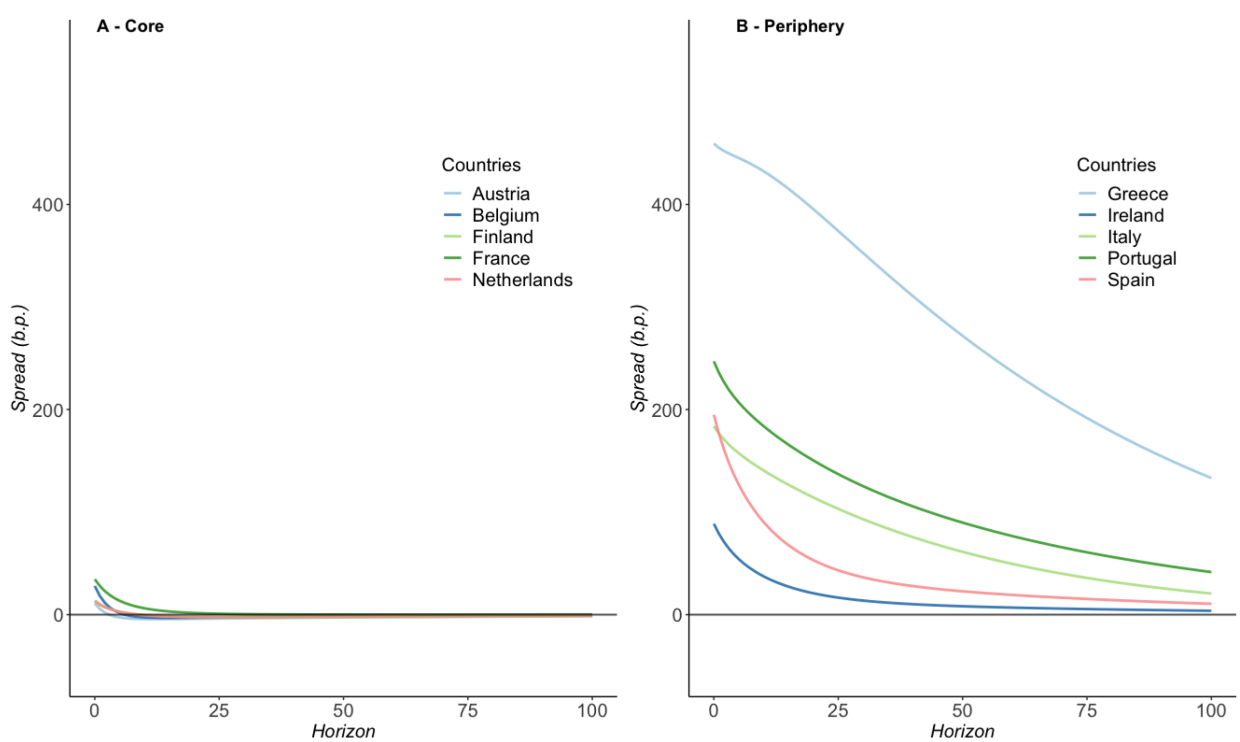

Figure 3: The figure reports the Generalized Impulse Response Functions to a 200 b.p. shock to the 10Y Spanish Spread in the post-crisis period (2012 : 09 − 2019 : 02). In panel A, consider the core economies, i.e., Austria, Belgium, Finland, France and Netherlands, while we consider in panel B the periphery, i.e.,Greece, Ireland, Italy, Portugal and Spain.

4.6. The COVID pandemic period $2019:03-2021:03$

As in the previous analyses of the $GIRF$s, we still consider a 200 b.p. shock to the Spanish spreads also in Figure 4. However, while for the pre-ESD and post-ESD crisis periods, we have considered a shock to the Spanish differentials to study how a shock in a peripheral economy affects the core and the other peripheral economies, in this case, we consider Spanish differentials because Spain has suffered from the most severe real GDP contraction in the euro area in 2020.

A question the naturally arises from the analysis of 4 is whether the convergence phase that followed the unconventional monetary policy measures and, in particular the OMT, is over. In fact, while the size of the responses to 200 b.p. shock to Spain of the peripheral economies remain somehow unchained compared to the post-ESD crisis period, Figure 4 depicts a completely different picture compared to Figure 3 with respect the responses of the core economies: the shock to the $10Y$ Spanish differentials also induces a generalized decrease in the $10Y$ differentials in core economies. This result highlights the revival of flight-to-quality effect, leading to an increase in the potential risk of fragmentation of the euro area.

5. Conclusion

This paper shades new light on the fragmentation risk in the European Monetary Union. A novel methodology reconciling factor augmented and $GVAR$ models, allows to disentangle interdependence from contagion and flight-to-quality. It is implemented for the long term yields spread between of 10 year euro area government bonds and the German safe benchmark over three remarkable periods: The pre-ESD crisis, the post-ESD as well as the recent COVID period. It appears that signs of contagion and flight-to-quality effects were already present in the pre-EDS period, suggesting latent fragmentation risk between southern European countries (Portugal, Italy, Ireland, Greece and Spain) and the Northern ones. Soon after the ESD, the different programs of public bonds purchases implemented

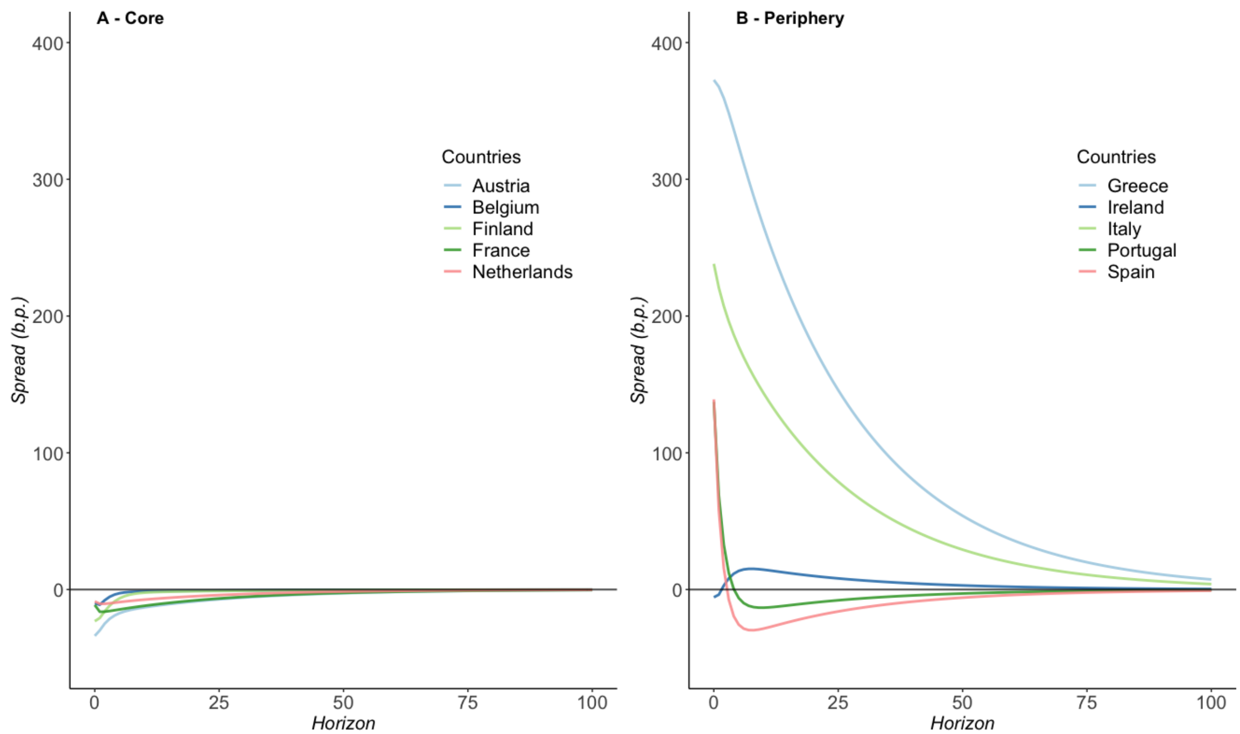

Figure 4: The figure reports the Generalized Impulse Response Functions to a 200 b.p. shock to the 10Y Spanish Spread in the COVID period $(2019:03-2021:03)$. In panel A, consider the core economies, i.e., Austria, Belgium, Finland, France and Netherlands, while we consider in panel B the periphery, i.e., Greece, Ireland, Italy, Portugal and Spain.

by the European Central Banks have limited this risk, leading all European spreads to reduce homogeneously. The COVID crisis has reintroduced again the fragmentation risk at the forefront of the European policy for the southern European countries. Contrary to the pre-EDS period, our findings show that a common exogenous shock (COVID) could transmit heterogeneously over countries, even if they share the same currency. It therefore rejoins the recent articles pointing the same results for the effects of the monetary policy as Corsetti et al. (2020).

The rise of the fragmentation risk in Europe and the heterogeneous transmission of common policy constitute then a challenge for European authorities. It also signals that the re-integration of the euro area government bonds is very fragile despite the huge and unprecedented amount of monetary and fiscal stimulus in place (see Borgioli et al. (2020)). Given the positive results obtained in the post-ESD, it sounds relevant to go on in this direction, accelerating in particular the fiscal integration. The common recovery plan is a first step, but should be followed for example by strict public spending monitoring in order to enhance economic convergence across European countries, reducing the fragmentation risk.

References

L. Baele, A. Ferrando, P. Hördahl, E. Krylova, and C. Monnet. Measuring European financial integration. *Oxford Review of Economic Policy*, 20(4):509–530, 2004.

N. Bailey, S. Holly, and M. H. Pesaran. A two-stage approach to spatio-temporal analysis with strong and weak cross-sectional dependence. *Journal of Applied Econometrics*, 31(1): 249–280, 2016a.

N. Bailey, G. Kapetanios, and M. H. Pesaran. Exponent of cross-sectional dependence: Estimation and inference. *Journal of Applied Econometrics*, 31(6):929–960, 2016b.

Z. Balabanova and R. Brüggemann. External information and monetary policy transmission in new EU member states: results from FAVAR models. *Macroeconomic Dynamics*, 21 (02):311–335, 2017.

B. S. Bernanke. Alternative explanations of the money-income correlation. *Carnegie-Rochester Conference Series on Public Policy*, 25:49–99, 1986. ISSN 0167-2231. doi: https://doi.org/10.1016/0167-2231(86)90037-0. URL `https://www.sciencedirect.com/science/article/pii/0167223186900370`.

B. S. Bernanke, J. Boivin, and P. Eliasz. Measuring the effects of monetary policy: a factor-augmented vector autoregressive (FAVAR) approach. *The Quarterly journal of economics*, 120(1):387–422, 2005.

O. J. Blanchard and D. Quah. The Dynamic Effects of Aggregate Demand and Supply Disturbances. *American Economic Review*, 79(4):655–673, September 1989. URL `https://ideas.repec.org/a/aea/aecrev/v79y1989i4p655-73.html`.

S. Borgioli, C. Horn, U. Kochanska, P. Molitor, and S. Mongelli. European financial integration during the covid-19 crisis. *ECB Economic Bulletin*, 2020. URL `https://www.ecb.europa.eu/pub/economic-bulletin/articles/2020/html/ecb.ebart202007_02~b27e8089c5.en.html`.

B. Candelon and A. Luisi. Testing for the Validity of W in GVAR models. Technical report, Université catholique de Louvain, Louvain Finance (LFIN), 2020.

B. Candelon and S. Tokpavi. A non-parametric test for Granger-causality in distribution with application to financial contagion. *Journal of Business & Economic Statistics*, 34(2): 240–253, 2016.

H. L. Cole and T. J. Kehoe. Self-fulfilling debt crises. *The Review of Economic Studies*, 67(1): 91–116, 2000. ISSN 00346527, 1467937X. URL `http://www.jstor.org/stable/2567030`.

G. Corsetti and L. Dedola. The Mystery of the Printing Press: Monetary Policy and Self-Fulfilling Debt Crises. *Journal of the European Economic Association*, 14(6):1329–1371, 12 2016. doi: 10.1111/jeea.12184.

G. Corsetti, K. Kuester, A. Meier, and G. J. Muller. Sovereign risk and belief-driven fluctuations in the euro area. *Journal of Monetary Economics*, 61:53–73, 2014. ISSN 0304-3932. doi: https://doi.org/10.1016/j.jmoneco.2013.11.001. URL `https://www.sciencedirect.com/science/article/pii/S0304393213001475`. Carnegie-Rochester-NYU Conference Series on "Fiscal Policy in the Presence of Debt Crises" held at the Stern School of Business, New York University on April 19-20, 2013.

G. Corsetti, J. B. Duarte, and S. Mann. The heterogeneous transmission of ecb policies: Lessons for a post-covid europe. *VoxEu*, 2020. URL `https://voxeu.org/article/heterogeneous-transmission-ecb-policies`.

P. De Grauwe and Y. Ji. Mispricing of sovereign risk and macroeconomic stability in the eurozone. *Journal of Common Market Studies*, 50(6):866–880, 2012. doi: https://doi.org/

10.1111/j.1468-5965.2012.02287.x. URL https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1468-5965.2012.02287.x.

R. De Santis. Redenomination risk. *Journal of Money, Credit and Banking*, 51(8):2173–2206, 2019. doi: https://doi.org/10.1111/jmcb.12582. URL https://onlinelibrary.wiley.com/doi/abs/10.1111/jmcb.12582.

S. Dees, F. d. Mauro, M. H. Pesaran, and L. V. Smith. Exploring the international linkages of the euro area: a global VAR analysis. *Journal of Applied Econometrics*, 22(1):1–38, 2007.

J. P. Elhorst, M. Gross, and E. Tereanu. Cross-sectional dependence and spillovers in space and time: where spatial econometrics and global VAR models meet. *Journal of Economic Surveys*, 2020.

C. Favero and A. Missale. Sovereign spreads in the eurozone: which prospects for a Eurobond? *Economic Policy*, 27(70):231–273, 2012.

C. A. Favero. Modelling and forecasting government bond spreads in the euro area: a GVAR model. *Journal of Econometrics*, 177(2):343–356, 2013.

C. A. Favero and A. Missale. Contagion in the EMU–the role of Eurobonds with OMTs. *Review of Law & Economics*, 12(3):555–584, 2016.

K. J. Forbes and R. Rigobon. No contagion, only interdependence: measuring stock market comovements. *The Journal of Finance*, 57(5):2223–2261, 2002.

M. Gross. Estimating GVAR weight matrices. *Spatial Economic Analysis*, 14(2):219–240, 2019.

C. L. House, C. Proebsting, and L. L. Tesar. Austerity in the aftermath of the great recession. *Journal of Monetary Economics*, 115:37–63, 2020. ISSN 0304-3932. doi:

https://doi.org/10.1016/j.jmoneco.2019.05.004. URL https://www.sciencedirect.com/science/article/pii/S0304393219300959.

N. Metiu. Sovereign risk contagion in the eurozone. *Economics Letters*, 117(1):35–38, 2012.

A. Monfort and J.-P. Renne. Decomposing euro-area sovereign spreads: credit and liquidity risks. *Review of Finance*, 18(6):2103–2151, 2013.

M. Pesaran and Y. Shin. Generalized impulse response analysis in linear multivariate models. *Economics Letters*, 58(1):17–29, 1998. URL https://EconPapers.repec.org/RePEc:eee:ecolet:v:58:y:1998:i:1:p:17-29.

M. H. Pesaran. General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 60:13–50, 2021.

M. H. Pesaran, Y. Shin, and R. P. Smith. Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, 94(446):621–634, 1999. ISSN 01621459. URL http://www.jstor.org/stable/2670182.

M. H. Pesaran, T. Schuermann, and S. M. Weiner. Modeling regional interdependencies using a global error-correcting macroeconometric model. *Journal of Business & Economic Statistics*, 22(2):129–162, 2004.

S. Sgherri and E. Zoli. Euro area risk during the crisis. *International Monetary Fund Working Paper 09/222*, 2009.

C. A. Sims. Macroeconomics and reality. *Econometrica*, 48(1):1–48, 1980. ISSN 00129682, 14680262. URL http://www.jstor.org/stable/1912017.

C. A. Sims. Are forecasting models usable for policy analysis? *Quarterly Review*, 10(Win):2–16, 1986. URL https://ideas.repec.org/a/fip/fedmqr/y1986iwinp2-16nv.10no.1.html.

J. H. Stock and M. W. Watson. Dynamic factor models, factor-augmented vector autoregressions, and structural vector autoregressions in macroeconomics. In *Handbook of macroeconomics*, volume 2, pages 415–525. Elsevier, 2016.

S. H. Vega and J. P. Elhorst. A regional unemployment model simultaneously accounting for serial dynamics, spatial dependence and common factors. *Regional Science and Urban Economics*, 60:85–95, 2016.