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# DIRECTIONALITY OF SPILLOVERS IN EUROPE: EVIDENCE FROM THE EU SOVEREIGN DEBT CRISIS[1]

**Abstract.** The presence of large systemic shocks on the European continent, such as the European Debt Crisis and more recently Covid-19, highlighted the fragility of the sovereign debt market. Our proposal aims at shedding light on this issue, relying on the use of the Diebold and Yilmaz methodology for the computation of directional spillover indices alongside a wavelet decomposition, in order to analyze the linkages among bonds yields and volatility in a sample of EU countries. Results indicate that linkages are relevant, and directionality is one-sided, for both yields and volatility of yields, pre- and post-crisis. We find two cluster of countries: one where spillovers drive other country bond yields' volatility and one where spillovers are absorbed but not emitted. With our wavelet analysis, we can decompose these spillovers further and provide insight into the temporal dynamics of bond investors. Overall, our analysis suggests that sovereign bond markets in Europe are highly connected, and sources of volatility are likely to be transferred easily between countries, hindering the financial stability of the Eurozone.

**Keywords**. Sovereign debt; spillover indices; bond yields; EU debt crisis, NGE.

## 1. INTRODUCTION

Sovereign debt markets in European countries have been at the center of attention in the last decades, because of rising levels of public debt, of calls for mutual risk sharing, and a striking difference in the consumption trends of different EU member countries. This has given rise to a growing literature aimed at studying the effect and repercussions of debt. Evidence suggests for example that higher debt is correlated with lower growth and higher volatility. In this report we explore the directionality of the spillovers of this volatility between the European sovereign debts. The start of the third millennium was a milestone in European integration, as several countries on the continent entered a monetary union. In the 20 years since, the path leading towards a degree of higher

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integration has steadily moved forward (Lane and Milesi-Ferretti, 2008). This growing integration has brought with it collateral effects in bond pricing, particularly with sovereign bonds (De Santis and Gerard, 2009; Baele *et al.*, 2004; Pagano and Von Thadden, 2004). The literature is unambiguous on the matter, but it is also clear from observation: some countries in the EMU lead in terms of economic performance, with positive spillovers for other countries. On the contrary, the precarious conditions of many countries have the capability of exposing others within the union to negative shocks. The example of the connection among banks of different countries is demonstrative (Ejsing *et al.*, 2011; Attinasi *et al.*, 2010; Gerlach *et al.*, 2010). These linkages – or better, spillovers – between highly interconnected economies have been a focal point of the literature in the past years. The 2008 crisis and its cascade of effects on Eurozone countries has pushed macro and financial economists to test the presence and the intensity of these connections and spillovers (Broto and Perez-Quiros, 2011; De Grauwe and Ji, 2012). In this proposal we address the following questions: with what intensity are Eurozone countries interlinked? Are there some cluster of countries and do they influence each other in a positive or negative way? Is the effect of the crisis significant on these linkages (Caceres *et al.*, 2010)?

We rely on several non-traditional methodologies in this field, that of Diebold and Yilmaz (2009 and 2011), based on a VAR approach of Koop *et al.* (1996) and Pesaran and Shin (1998), in order to compute the direction and intensity of bond-market volatility spillovers in the pre-period crisis and post-crisis period. We explore these relationships in greater detail by using wavelet decomposition, aimed at disentangling co-movements, direction, and intensity in the chosen time series. These algorithms are mostly used in the financial and energy economics literature in order to identify and isolate the linkages and co-movements in these commodities' yields and volatilities, across time and in different stock markets. However, we show that these techniques are valid and useful tools to analyze bond yields and volatilities in order to answers several questions and address the previously explained issues. Moreover, the standard econometrics tools on are not suited for our aims, because incapable of adequately capturing the endogenous components in yields patterns. Our purposes are to (i) perform an exercise in order to highlight the links and intensity – and their evolution across time depending on uncertainty periods – of the patterns in bonds yields and volatilities and (ii) address those relevant policy-driven questions related to the issue of growing public debts, that assumes a particular importance in light of the Covid-19 pandemic. The rest of the paper is organized as follows. We first present the data, its sources, and some statistics underpinning our results. Then we outline the various methodological strategies, before presenting our preliminary results. Finally, we conclude by summarizing our work and its scope, as well as offering suggestions and reflections on what comes next.

## 2. LITERATURE

Our work spans many fields of the economic literature. First, we rely heavily on the methodologies used in energy and financial economics. Within these fields, researchers have largely focused on isolating and analyzing the co-movements and intensity in the links among yields of several commodities in order to produce more accurate forecasts. They have also focused on the relationships with the macro stability in those countries – mainly developing – that largely rely on the value of these commodities, by analyzing their volatilities spillovers. We contribute to this literature by relying on their methodologies in a different setting and by shedding light on the macro risk induced by unseen linkages between sovereign bond yields, as it does instead for goods commodities.

Our proposal is mainly related to the field on public debt economics. In fact, our aim is to shed light on the potential adverse effects induced by public debts risks by identifying the intensity of linkages in the EU sovereign debt market. This has been a hot-tpoic issues since the 90's and has started to assume more relevance in 2020 in light of the Covid-19 pandemic, especially in the Eurozone where many countries public debts stocks are perceived as unsustainable, leading to spikes in yields and associated volatility that has become a source of instability during troubled times. The first evidence of this was during the 2010 crisis, and 2020 will likely be similar.

There is evidence of negative correlation – even though not causation – between public debt growth and GDP growth (e.g. Reinhart and Rogoff, 2010; Kumar and Woo, 2010; Checherita-Westphal and Rother, 2010; Cecchetti, Mohanty and Zampolli, 2010). However, several works (e.g. Rodrik, 2008; Kraay, 2012) have also highlighted that these previous works are likely to suffer from endogeneity, where public debt is correlated to some unobserved factors driving both the outcomes and the covariates. The result is hence an upward bias in the estimation, and the failing of the identification strategy in order to identify the causal link between the two. Endogeneity has been addressed in later works (Panizza and Presbitero, 2014; Eberhardt and Presbitero, 2015) relying on several instruments, finding evidence of a causal link between the two target variables which operates in a non-linear pattern and across different thresholds. However, the exogeneity of these instruments has never been fully proven, hence the standard econometric techniques might not be suited. Our proposal aims to contribute to this fields highlighting the damages of the growing public debt stocks, relying on novel algorithms that do not suffer of the standard endogeneity problem.

We shed light on the determinant and the intensity of yields spreads and volatility in the euro zone pre- and post-crisis, results which we believe pertain to the incoming post-Covid-19 pandemic. With different tools, our work is related to those regarding developing countries, such as those of Calvo *et al.* (1993), Fernandez-Arias and Montiel (1996), Montiel and Reinhart (1999) and Mody and Taylor (2007), and those regarding US and other developing countries, such as Edwards (1986), Eichengreen and Portes (1989), Cantor and Packer (1996) and Dooley *et al.* (1996). Among these results, the most interesting are those that show how financial and political turmoil are relevant drivers in increase in sovereign debt spread – and then yields – even in developed countries. We enrich this literature by looking at the endogenous side of the issue, hence by estimating whether and by how much sovereign bond yields influence each other, rather that the exogenous effects of countries' characteristics. In fact, at least in the EMU, countries financial and economic system are highly interconnected, both due to the high level of exchanges among themselves but mainly for the links among their banking system.[2] For all the previous reasons, we do believe – as our preliminary results also suggest – that the endogenous component is highly relevant, in addition to the exogenous one that has been already widely exploited.

Finally, our proposal aims in his later part to contribute also to a novel field of literature, that focusing on the impacts of the Covid-19 in several fields. In particular, certain research has focused on the macroeconomics implications by highlighting the disruptive and quantitative sizeable effects of the pandemic in pushing up spreads and in increasing volatility, focusing on the heterogeneity of

[2] It is well known in fact that banking systems'connections have been the main driver of the sovereign crisis in 2008 from US to Europe.

tough with significant, advantageous and fixed long-term interest rates - hence they will both necessarily increase – and by a large amount – the stock of public debt of all countries. This issue is definitely relevant for Italy, which already has a high stock of public debt with respect to GDP, and especially considering its growth since the early ’90s. Our work is aimed at pointing at the danger – both in term of increasing yields and volatility – induced by this fact. Policy makers should hence be careful on how to spend these funds to obtain log-term and significant growth trajectories capable of sustaining the high and increasing level of public debt, otherwise trouble times are yet to come in Europe.

## 3. Data

We use data on 5-year yields of 10 European sovereigns over the period 10/05/2006 to 13/11/2020. Data is taken from FactSet. Our country sample consists of Eurozone countries (Italy, France, Netherlands, Spain, Germany), alongside some control countries such as Norway, Denmark, Sweden, and the UK.[3] The decision to include the UK is because of the deep connection its economic system has with that all other countries, especially in its financial and banking appendix which are likely to be significant drivers of those spillover effects we are looking for. We expect Nordic countries to act as controls, being geographically close to the others but whose economies are less intertwined. Yields on 5-year bonds capture the medium run risk in default and hence we believe is a good proxy for the degree of financial risk we aim to analyze, with respect to the 1-year yield – which is too close – or the 10-year yield which instead is too far away and likely more dependent on country specific, unobservable, long-run characteristics.

When selecting data, we must consider the accessibility and the temporal extensiveness that will allow us to accurately implement the methodology used in this paper. While on the one hand we feel confident enough about the accuracy of the data, we are to a certain extent limited by missing values. To correct for this, we apply a series of simple imputations, including either bringing forward values

[3] A notable missing component of this sample is Portugal, which for reasons of missing data had to be dropped.

or applying a Forsythe, Malcolm, Moler cubic (spline) interpolation of our data.[4] While this certainly removes variability, the number of observations is sufficient that we still feel the results give an accurate depiction. In the end, the full data set goes from 10/05/2006, which is the earliest date on average for which FactSet provided historical data on sovereign bond yields, to 13/11/2020. To study the effects of the European sovereign debt crisis, we need to determine a threshold date to split the sample. The onset of the crisis is generally considered to be in late 2009, when the Greek government announced budget deficits were far higher than initially reported and called for external help in the coming months. We take our data therefore and split the sample into our control (pre-2009) and treatment (post-2009). To begin, we provide some descriptive statistics. Table 1 is for the pre-crisis period (2006-2009). Table 2 shows the descriptive statistics for the period 2009-2020. The series in our control sample is considerably shorter than our treatment sample. This is largely due to limitations with our data source.

TABLE 1 and TABLE 2

| | | N | Mean | SD | Min | Q1 | Median | Q3 | Max |
|---|---|---|---|---|---|---|---|---|---|
| 1 | BE | 967 | 4.00 | 0.37 | 3.25 | 3.72 | 3.98 | 4.24 | 4.98 |
| 2 | DE | 967 | 3.87 | 0.44 | 2.27 | 3.67 | 3.89 | 4.13 | 4.77 |
| 3 | DK | 967 | 0.54 | 0.05 | 0.42 | 0.50 | 0.54 | 0.58 | 0.69 |
| 4 | ES | 967 | 4.01 | 0.34 | 3.26 | 3.74 | 4.00 | 4.22 | 4.92 |
| 5 | FR | 967 | 3.96 | 0.39 | 2.69 | 3.71 | 3.97 | 4.20 | 4.88 |
| 6 | UK | 967 | 6.60 | 1.22 | 2.56 | 5.74 | 6.94 | 7.48 | 8.55 |
| 7 | IT | 967 | 4.11 | 0.33 | 3.57 | 3.83 | 4.05 | 4.31 | 5.08 |
| 8 | NL | 967 | 3.94 | 0.39 | 2.85 | 3.69 | 3.94 | 4.18 | 4.88 |
| 9 | NO | 967 | 0.56 | 0.07 | 0.29 | 0.51 | 0.57 | 0.61 | 0.69 |
| 10 | SE | 967 | 0.41 | 0.06 | 0.16 | 0.39 | 0.42 | 0.45 | 0.51 |

| | | N | Mean | SD | Min | Q1 | Median | Q3 | Max |
|---|---|---|---|---|---|---|---|---|---|
| 1 | BE | 4335 | 0.97 | 1.40 | -0.73 | -0.18 | 0.28 | 2.36 | 5.45 |
| 2 | DE | 4335 | 0.46 | 1.02 | -1.00 | -0.35 | 0.10 | 0.94 | 2.83 |
| 3 | DK | 4335 | 0.09 | 0.16 | -0.13 | -0.04 | 0.03 | 0.16 | 0.49 |
| 4 | ES | 4335 | 1.86 | 1.80 | -0.40 | 0.31 | 0.97 | 3.34 | 7.45 |
| 5 | FR | 4335 | 0.76 | 1.08 | -0.78 | -0.11 | 0.31 | 1.73 | 3.05 |
| 6 | UK | 4335 | 1.45 | 0.85 | -0.17 | 0.78 | 1.27 | 2.11 | 3.50 |
| 7 | IT | 4335 | 2.07 | 1.52 | 0.04 | 0.71 | 1.76 | 3.16 | 7.60 |
| 8 | NL | 4335 | 0.61 | 1.11 | -0.89 | -0.32 | 0.20 | 1.41 | 3.27 |
| 9 | NO | 4335 | 0.19 | 0.10 | 0.00 | 0.11 | 0.16 | 0.25 | 0.42 |
| 10 | SE | 4335 | 0.09 | 0.12 | -0.07 | -0.01 | 0.03 | 0.19 | 0.38 |

One evident stylized fact is that average yields, across countries, were much higher in the sample going from 2006-2009 as opposed to 2009 onward. We can attribute this to a series of idiosyncratic monetary policies as well as systemic shifts in the appetite for risk. It is well documented how central bank responses to the financial crises, even central banks outside of the Eurozone such as the Fed, impacted the yield curve through extensive use of unconventional monetary

[4] The interpolation method of choice is subject to discussion and dependent, among other things, on the observed structure of the data.



Table 1 Table 2

policy. Furthermore, countries show a clustering structure which is illuminating on the results we later find. In the build up to the crisis, average yields in southern European countries were substantially higher than their Nordic counterparts. Following the global shock, yields of certain southern European countries remained systematically higher than others. We hope to shed light on the dynamics of these bond yields, how different countries drive the movements of said yields following a large systemic shock such as the European Debt Crisis.

## 4. Empirical Strategy

This section outlines a series of methodological approaches that we use to assess the time-varying interdependence of European sovereign bonds. The structure of the empirical methodology is based on the work by Dahl *et al.* (2019), who use a dual strategy of conditional volatility estimation *à la* Engle (2001) and then compute spillover effects. To start we employ the Diebold and Yilmaz (2011) methodology, henceforth referred to as DY, for computing the simple directionality of spillovers between yields. We then look at second-order effects by estimating the conditional volatility and using it as inputs for our DY spillover indices.

In the second part we focus on the relationship between two particularly important players in the European Debt Crisis narrative by digging further into the structure of the series. Through a wavelet decomposition (Percival and Walden, 2000) we can separate the series into different frequencies to visualize the time-specific trends driving yields. Confronting the decomposed series of different European sovereign bond yields is illuminating for the purpose of understanding the impact of a large systemic shock such as the debt crisis was, or Covid-19 will be. Finally, we use the decomposed series to re-compute the DY spillover indices, looking at the relationships across different scales of the time series.

### *4.1. Yield spillovers*

The principal methodology of this paper is the spillover index as proposed by DY for computing the net contributions in spillovers between two assets. The method is based on a forecast error variance decomposition (FEVD) of the VAR representation of our N series. The advantage such methods with respect to traditional IRF computation through Cholesky decomposition is in the independence of the ordering of the obtained results. Following Koop *et al.* (1996) and Pesaran and Shin (1998), Equation 1 shows the H-step ahead generalized FEVD between two series i and j in the VAR representation:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1}\sum_{h=0}^{H-1}\left(e_i'\Theta_h\Sigma e_j\right)^2}{\sum_{h=0}^{H-1}(e_i'\Theta_h\Sigma\Theta_h' e_i)} \qquad (1)$$

$\Theta_h$ is the coefficient matrix multiplying the h-lagged shock vector in the infinite moving- average representation of the non-orthogonalized VAR. $\Sigma$ is the covariance matrix of the shock vector in the non-orthogonalized VAR model. $\sigma_{jj}$ is the jth diagonal element of covariance matrix, and $e_j$ is the selection vector with jth element unity and zeros elsewhere.

Equation 1 provides a spillover index in an NxN matrix where each element represents the contribution from asset j to asset i. From this matrix we can construct several spillover indices. In particular, the total spillover index is;

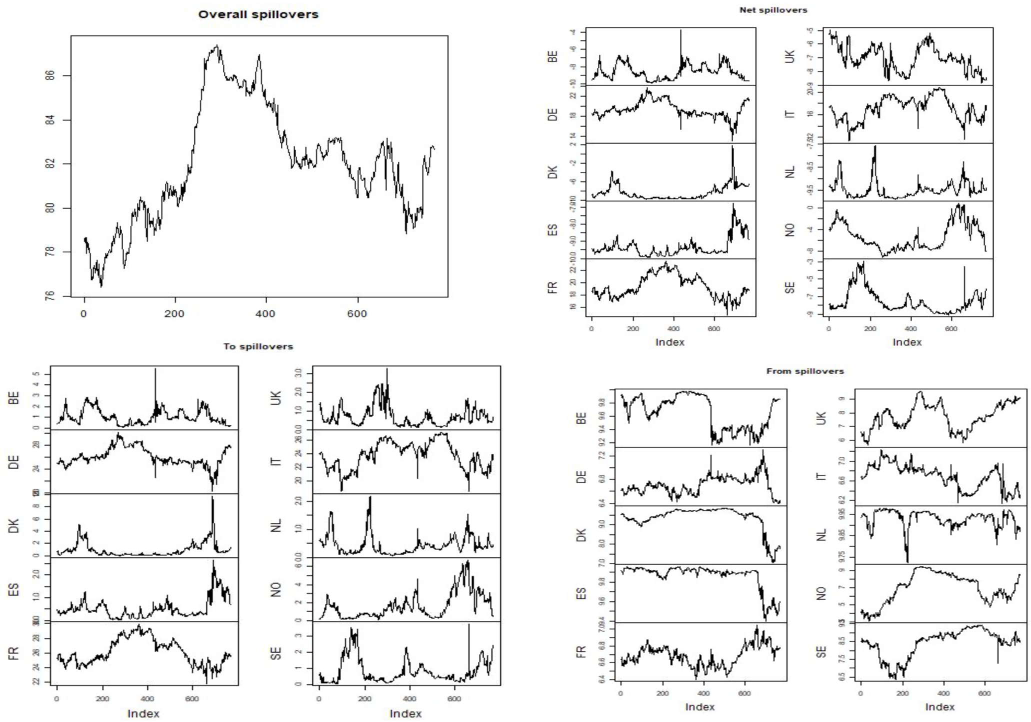
$$S^{g}(H) = \frac{\sum_{i,j=1}^{N}\theta_{ij}^{g}(H)}{N} \qquad (2)$$

which is the sum of all transmitted shocks for every combination of assets i,j. The directional spillovers, therefore, the shocks transmitted from every other asset j to a specific asset i, are instead defined as;

$$S_{i\leftarrow j}^{g}(H) = \frac{\sum_{j=1,j\neq i}^{N}\theta_{ij}^{g}(H)}{N} \qquad (3)$$

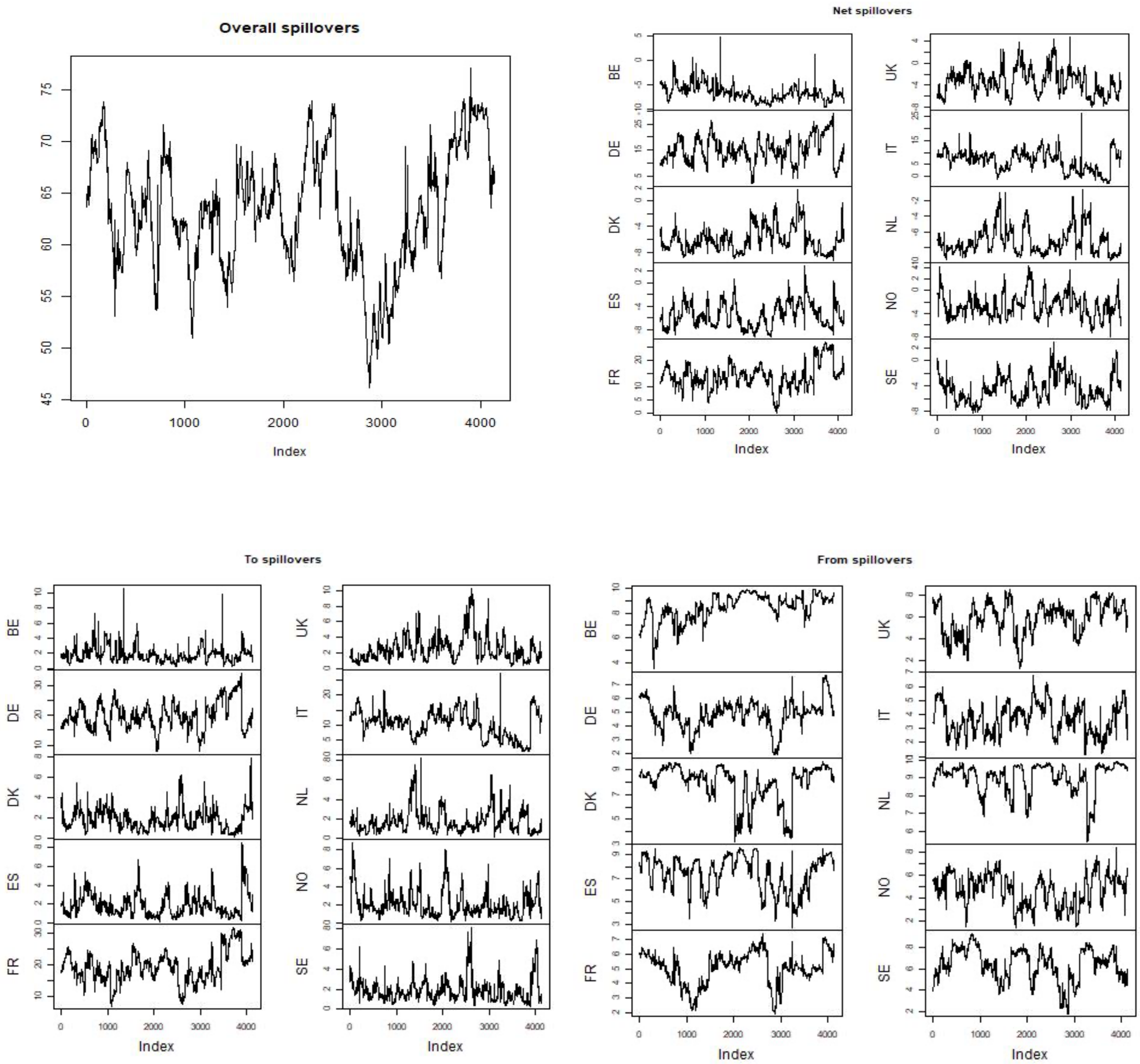
and so forth for every i. Intuitively then, the net spillover is the difference between the spillovers transmitted to and those received from other assets. The figures below plot our estimates of yield spillovers in the sample of 10 European countries before and after the onset of the European Debt Crisis. We utilize a VAR(1) representation, based on an AIC, from which we extract the relevant components described above to construct our DY spillover indices. The results in Figure A1 and Figure A2 therefore show the computed spillovers for European sovereign bond yields, before and after the onset of the debt crisis, respectively.

FIGURE A1




In the years building up the sovereign debt crisis, our results allude to the trend we observe throughout this paper; there is a clustering within Europe of countries that transmit spillovers but in turn are impacted more from domestic shocks rather than foreign, and a cluster of countries that are subject to spillovers from other countries. In our sample, France, Italy, and Germany account for the highest share of total spillover transmitted. Considering they are the largest and systemically most important countries; the results are in line with expectations. Specifically, large banks that are territorially linked to these countries, and therefore sensitive to domestic shocks or policy interventions, also underpin a large part of the EU financial system. On the other hand, these same countries are the ones that are less subject to spillovers from other countries. We can therefore postulate that the source of variability of yields in the markets of these bonds to domestic affairs more than foreign influences. The set of other, smaller, countries are less responsible for transmitting spillovers but instead absorb them. Within this set, we also find that there is a geographical component at play. Neighboring countries such as Sweden, Norway, and Denmark pass spillovers between each other more than they do with Belgium for example. Overall spillovers tend to increase steadily throughout the years up to the onset of the crisis in 2007, where they spike and remain substantially higher, recovering towards the end of the crisis. This is likely due to the banking crisis in systemic countries such as Italy and Germany, where later banks were bailed out with public intervention. As the table showed before, net spillovers for countries such as France, Italy are strongly positive, indicating they transmit considerably more than they receive.

FIGURE A2




As can be seen in Figure A2, our general results hold in the post-2009 period compared to pre-2009. We find again that the three central economies (France, Italy, and Germany) account for the largest share of spillovers transmitted to other countries, and in turn absorb proportionally less. However, the distribution of these transmitted spillovers is significantly different in the post-crisis era.[5] For example, in the case of Italy, while its transmitted spillovers were uniformly distributed across other countries before 2009, the largest share of its spillovers in post-2009 is concentrated Spain. This is less so the case with France and Germany, indicating that indeed Italian sovereign yields played a large role in determining Spanish sovereign yields. The same effect is not as strong the other way around. Another interesting result is the role of marginal countries such as the Netherlands or Norway. In the pre-crisis period, Dutch yields seemed to be affected evenly by other Eurozone countries, including Italy. However, once the crisis set in, Dutch yields remained subject to spillovers from France and Germany, but no longer Italy. In a way Norway as well, which is in Europe only in the geographical sense, became insensitive to fluctuations in yields from the continent. This gives some insight into how investors valued sovereign risk of the non-Eurozone countries once the crisis began. Finally, the results show the weak link between Italy and the other main transmitters, France, and Germany. Neither Italian yields are much affected by spillovers from these countries, nor are these countries affected by Italian yields.

### *4.2. Volatility spillovers*

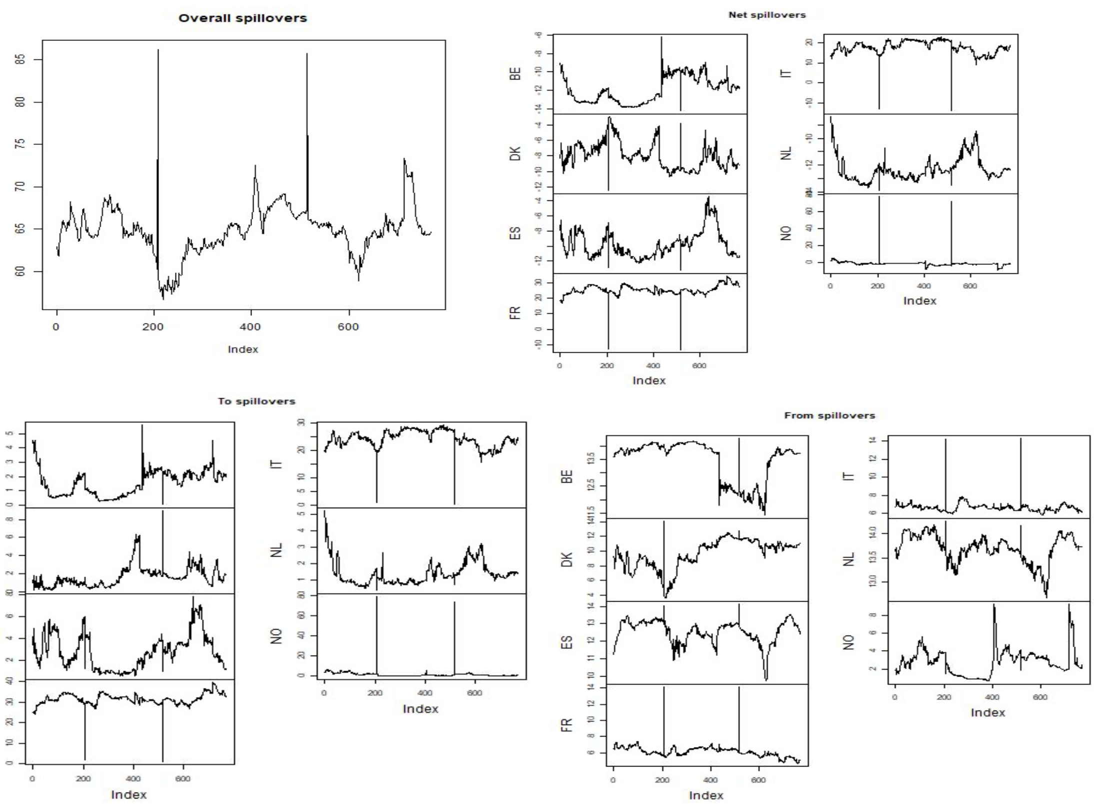
We now turn to estimating volatility spillovers. Following therefore the methodological approach of Dahl et al. (2019), we combine an estimated measure for the volatility of sovereign yields with the DY framework. To do so, we select the optimal autoregressive conditional heteroschedastic model to represent the time-varying volatility in our series of yields, for both the before and after 2009. We find that an eGARCH model of order (1,1) and with a skewed student-t distribution is optimal. The purpose of using such model for estimating the conditional volatility is that the series for yields may exhibit properties (serial correlation, volatility clustering, heteroscedasticity, leverage effects, and fat tails) which are better captured with a GARCH-type specification. Additionally, eGARCH models are more flexible and assume that negative and positive shocks have asymmetric effects on conditional volatility. From the estimated model we extract the conditional variance defined in Equation 4, which is then used as an input to compute the DY indices.

[5] Spillover tables decomposing the country-by-country effect are available upon request from the authors, and not reported here in the interest of brevity.

$$log\sigma_t^2 = \omega + \sum_{i=1}^{P} \beta_i log\sigma_{t-1}^2 + \sum_{j=1}^{Q} \alpha_j \left[ \frac{|\varepsilon_{t-j}|}{\sigma_{t-j}} - E\frac{|\varepsilon_{t-j}|}{\sigma_{t-j}} \right] + \sum_{j=1}^{Q} \zeta_j (\frac{\varepsilon_{t-j}}{\sigma_{t-j}}) \qquad (4)$$

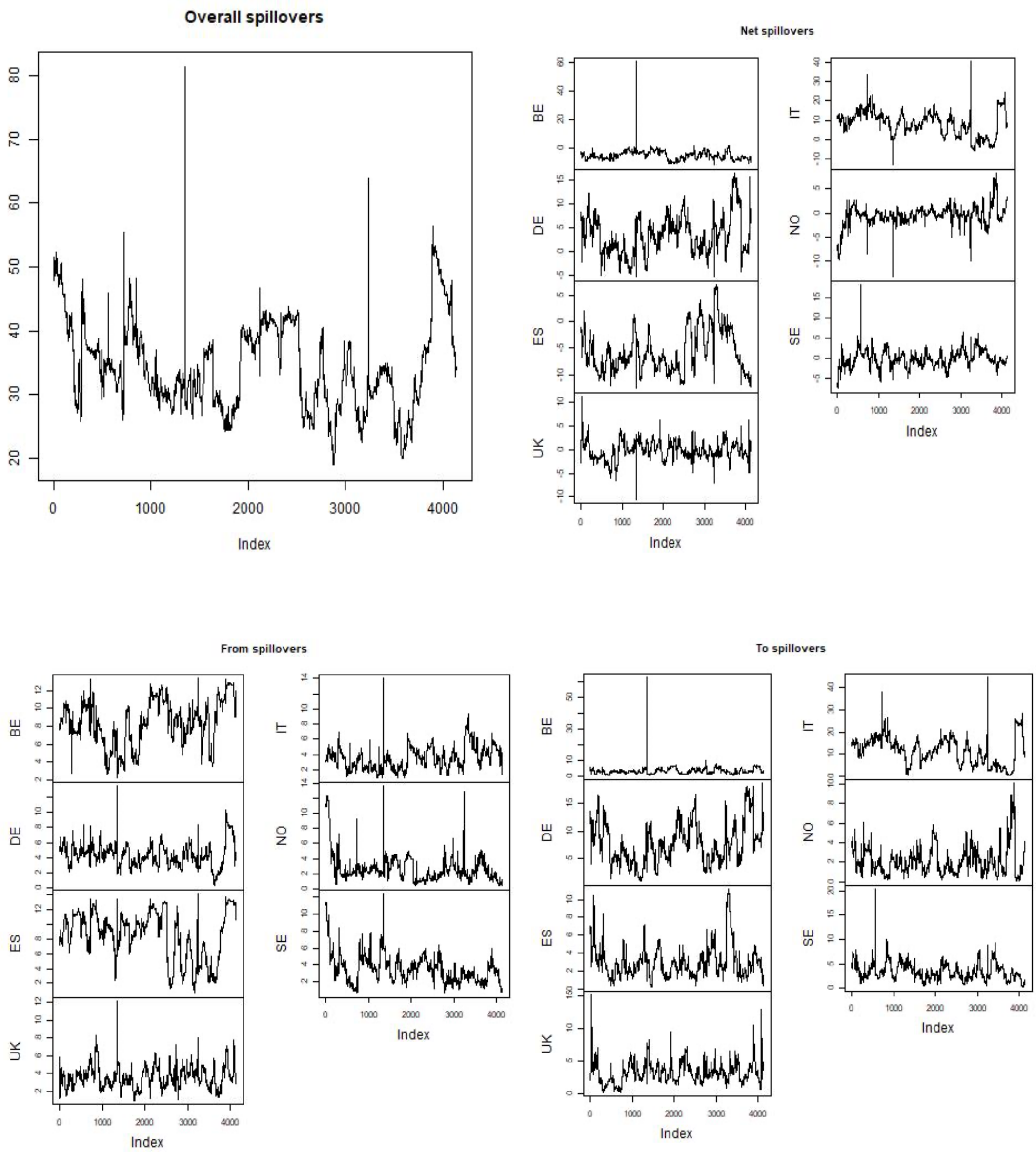
Figure A3 and A4 show our results. With the estimation of the volatility of yields we are now looking at the intrinsic risk in the European debt market. The volatility brings to light second-order dynamics in the sovereign bond market, highlighting the periods of high volatility we wish to analyze. We run into limitations with the volatility modeling, and our eGARCH is unable to converge for certain series. We find that our data for Germany doesn't converge likely because there is insufficient variance in the volatility of yields (risk) because it is such a stable country.

FIGURE A3




France and Italy again are protagonists in our analysis. They transmit a large share of the observed risk in our sample, but on the other hand absorb very little of the risk transmitted from other countries. We conclude again that these countries are subject to domestic instabilities rather than spillovers from other countries. We see that Norway acts as a control: it is in Europe and therefore could be linked to spillover effects, but we find it has little association with the other countries in our sample. It neither transmits nor absorbs a significant amount of risk. This is likely because Norway is not in EMU, nor in the Eurozone. It acts as a robustness check. Consistent with our previous results, we find that our sample follows a clustering between large systemic countries and smaller peripheral ones.

FIGURE A4



### *4.3. Wavelet decomposition*

In the following section we dive deeper into the relationship linking sovereign bond yields in the EU. Using wavelet analysis, we first decompose the data for into its different short-term and long-term components. Wavelet analysis has the benefit of highlighting the information on the time component of our series when decomposed. When we are dealing with high volatility data, wavelet decomposition becomes crucial to revealing underlying trends. As we will show, different market dynamics can influence different components of bond yields, be it short-term or longer-term trends. When we compare these trends for different European countries across significant economic shocks, such as the debt crisis, we provide a new perspective on the interdependence of EU sovereign bond markets.

The specific choice of wavelet decomposition used is the Maximal Overlap Discrete Wavelet Transform. The methodology follows closely Berger and Uddin (2016); we start with a symmetric Haar filter $h_0$; $g_0 = 1/\surd 2$, $h_1$; $g_1 = 1/\surd 2$. The MODWT wavelet and scaling factors are therefore obtained directly from these: $\hat{h}_0 = h_0/\surd 2$ and $\hat{h}_1 = g_0/\surd 2$. Through successive applications of the wavelet and scaling filters[6], we obtain the wavelet and scaling coefficients of a time series $X_T$ based on its previous values, for each MODWT of level j:

$$W_{j,t} = \sum_{l=0}^{L-1} \hat{h}_l X_{t-1} \, mod \, N \quad (5)$$

$$V_{j,t} = \sum_{l=0}^{L-1} \hat{g}_l X_{t-1} \, mod \, N \quad (6)$$

The set of scaling coefficients are then used to decompose the series. We consider 8 scales to capture long run dynamics of investor behavior in the market for EU sovereign debt. Intuitively, in an 8-scale decomposition, scales 1-3 can be viewed as short variations, 5-6 medium run, and 7-8 long run. Empirically, this means for example that scale 1 gives the variations on a 2-4–day window horizon, while scale 8 looks at the 1-2–year horizon.

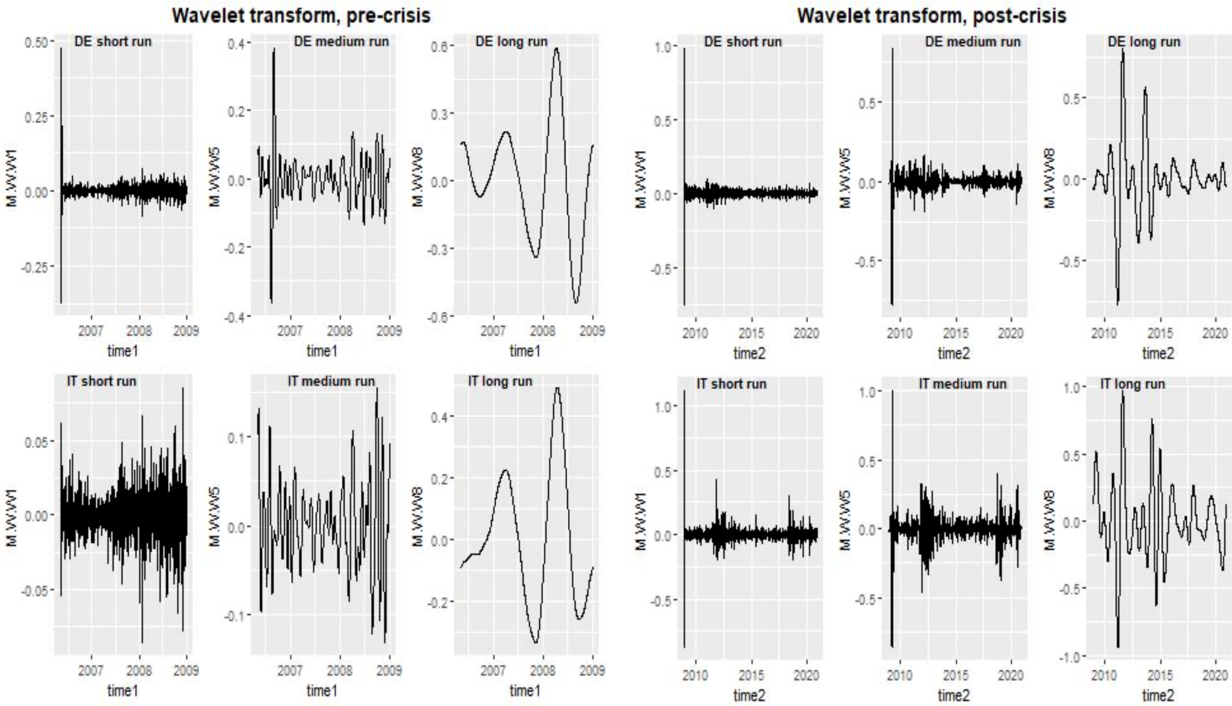
Figure A5 shows the wavelet decomposition scales for two of the series in our sample, volatility of 5-year Italian yields and volatility of 5-year German yields, in the pre-crisis period. In the context of our analysis on the interconnections

[6] Specifically, the process is that of the pyramid algorithm by Mallat (1989).

between sovereign debt instruments in Europe, these countries were at the center of the discussion. Intuitively, they show the short-term, high frequency variations of yields, and then the respective medium- and long-term ones. We get some important insights on investor behavior from these 3 horizons. The decomposed series show a clear pattern in German returns: the short run component, expect for a single and initial lag, is never significant, meaning that the daily or at least weekly trends and investor behaviors are not the main drivers of yields on German bonds. These movements are instead primarily driven by medium (i.e., monthly) and long-run trend (many months and yearly trends), with an increasing intensity. Hence German yields are not influenced according to short-run oscillations while they do move according to long-run trends that are presumably influenced by structural components. In synthesis, the yield on German bonds is not influenced by short-run investor behavior, but rather by long run behavior linked to economic fundamentals of the economy. The opposite happens for Italy, where the short-run variation intensity is stronger than in Germany. Again, in the case of Italy the long-run component – that related to economic fundamentals - is less significant at this stage. This means that for Italy investors took a short run, and likely speculative, approach. During this crisis period, Italy became more vulnerable, and this is reflected in the yield movements - which are a proxy of investors trustworthiness in a country - changing a lot in its short-run factors and therefore driven by minor forces (e.g., political declarations, foreign minor shocks etc..) rather than country economic fundamentals (that instead influence long-run movement in trend).

The second set of plots (right-had side of Figure A5) give the same wavelet transformation for Italian and German bonds, but in the post-crisis period. For Germany, the intensity of variations at the 3 scales considered (short, medium, and long term) remains essentially unchanged with respect to the pre-crisis period. For Italy however we find notable differences. The short run component – the one due to daily and weekly shock (e.g., political turbulence) – becomes relatively less significant with respect to its counterpart in the pre-crisis period. There is instead a shift in the intensity of variations into the medium term, and in general the decomposition is more equally distributed across the entire time spectrum. From these plots we therefore begin to see an overlap in the decomposed structure of sovereign bond yields for the two countries. Following the crisis, German movements in returns have changed significantly, with even more emphasis placed on longer frequency horizons, reflecting how the German economy has become more resilient to transitory shocks at least in the eye of the investor. The good news is that Italian yields now seem to follow a similar pattern, indicating that perhaps there are positive leading effects from the German bond market pulling Italy along. However, more analysis regarding this issue should be done in order to robustly assess our economic interpretation.

FIGURE A5




### *4.4. Wavelet spillovers*

A useful application of the wavelet decomposition is its application with our now familiarized DY framework. Figures A6 and A7 show these results. In this case, the spillovers refer to sovereign bond yields, but considering the different spectrum of the time series as described in Section 4.3. Figure A6 plots the overall, net, from and to spillovers for the pre-crisis period. The yield series for Germany and Italy, are decomposed into their short, medium, and long-run components. The net spillovers are particularly informative in this case. We see that the high frequency changes ("short run" component) of the two series are highly complementary. While Italy seems to be a net receiver along the high-frequency scale of the yield series, Germany is a net contributor. From the interpretation of investor behavior driving these yields, short run movements in Italian yields are closely connected to their German counterparts. For the same reasons, low-frequency, long-term movements are more independent of each other, as investors pay closer attention to the fundamentals of each individual country. There are fewer evident trends in the post-crisis period, as shown in Figure A7. Instead, the fact that spillover dynamics move together so closely along all the different spectrum is evidence that underlying trends drive the overall spillovers equally, as opposed to one country being a net contributor. As the debt crisis passed, yield interdependence loses significance.

FIGURE A6

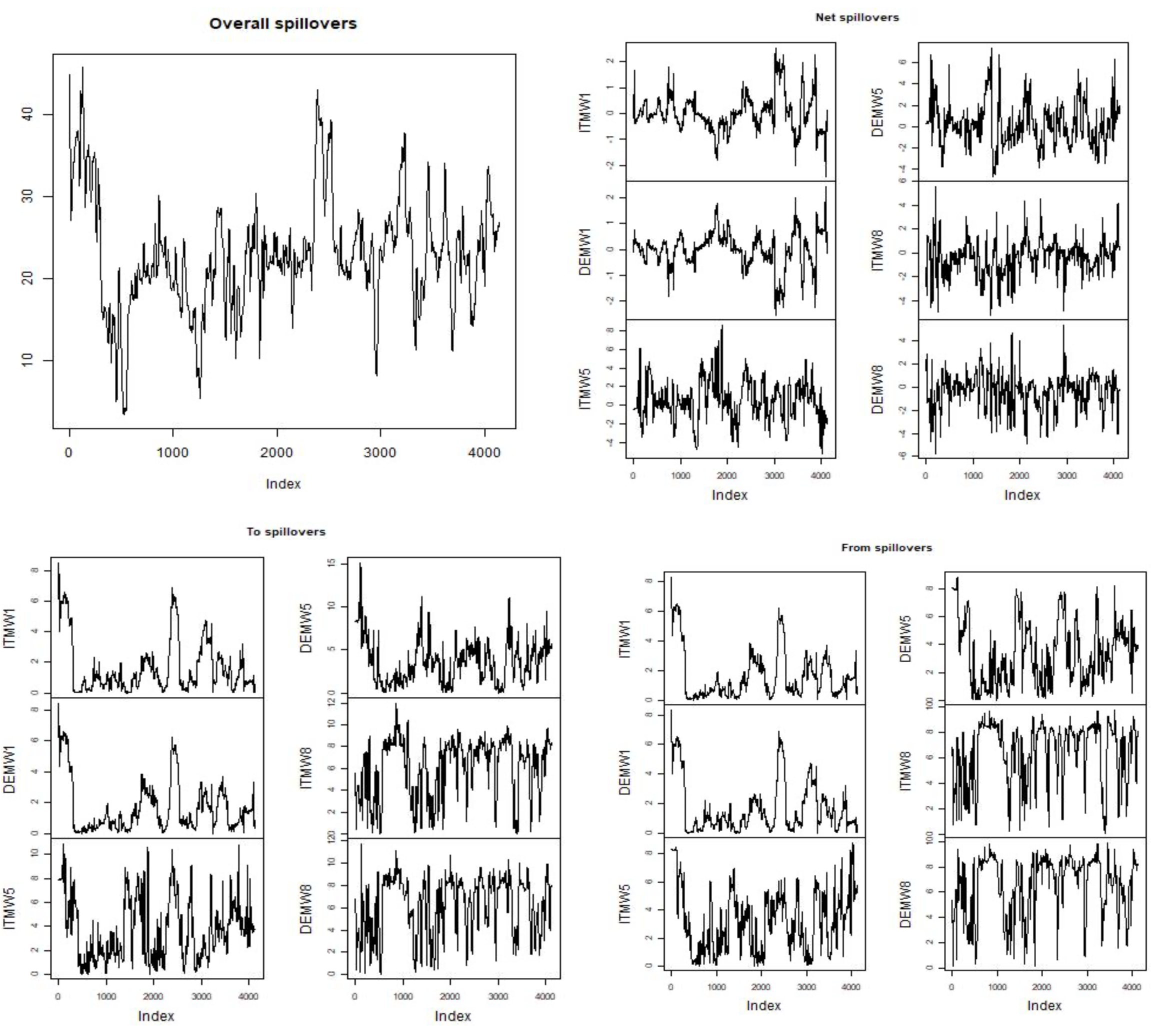
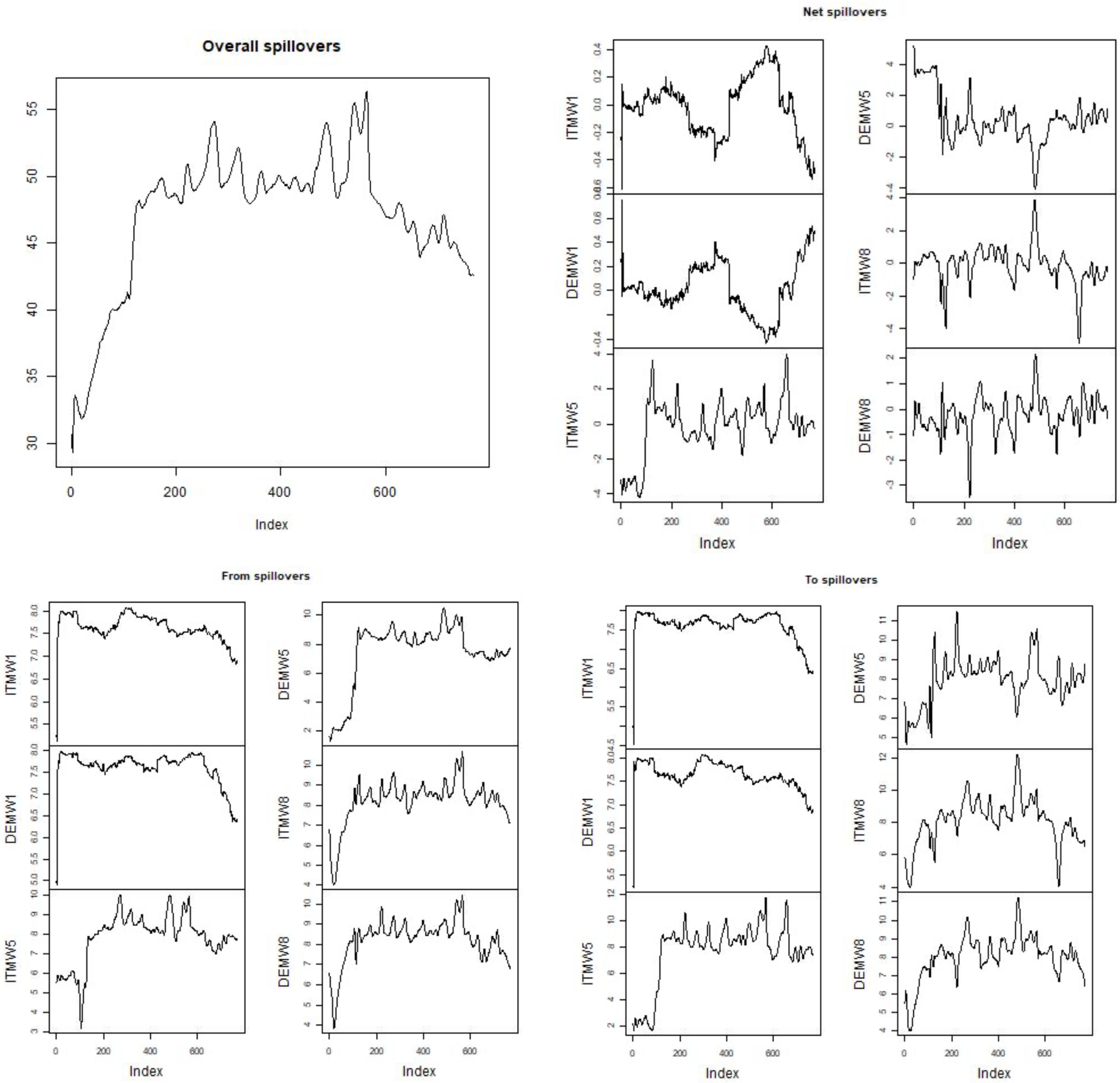


FIGURE A7




## *4.5. Robustness checks*

As a further exercise, we consider a series of robustness checks that should be verified in further iterations of the paper. To begin, we should note that the comparative nature of the results depends on the window fixed for splitting the full time series. From a methodological point of view, it is necessary to include a time series of yields for the control sample (pre-2009) which is significantly longer. However, we are limited by our data source. We expect that with a longer control series we would find similar aggregate results, but perhaps individuals indexes for directionality of spillover between some countries might change. We also chose to focus on 5-year yields, because it does not bias the interpretation of volatility spillovers. Had we used 10-year yields for example, the underlying volatility of yields could be representing investors long run perception of risk. Any calculated spillover effects might therefore be a result of long run trends that we can only speculate on. Finally, because our results indicate that countries with a systemic importance in the Eurozone play an important role in spillovers, it is necessary to investigate some mechanisms. For example, by using yields and corresponding measures of volatility associated to systemic banks across the same sample of countries to check if the hypothesized channels exist.

## 5. Concluding remarks

Or analysis aims at contributing to the literature of the spillovers induced by sovereign debt risk, by analyzing the interconnections among bond yields of a sample of EMU countries. We focus on the endogenous part as we have defined it considering yields and especially volatilities' (as a proxy of risks), rather than the exogenous one widely studied in the literature. We rely on the widespread methodology by Diebold and Yilmaz. As a preliminary evidence, we consider a full set of 10 countries (8 belonging to EMU and 2 from outside) and their 5-year sovereign yields. So far, our exercise results point in a straightforward direction. First, we find that total spillovers – both for returns and volatility – have steadily increased through the period of analysis, spiking after the crisis for few years and have yet to return to precrisis levels. We attribute this fact to the interconnection between the banking system that have been the main chain of transmission of sovereign defaults risk after the US 2008 crisis. Second, we identified in both sections two clusters of countries. Regarding the spillovers between yields, two cluster emerge: the first one made of systemic economics such as France, Germany and Italy with net spillovers that are highly positive and a second one – made of all others – with negative net effect. This means that there are 3 main economies of the EMU influencing the returns of the others, while they are only weakly influenced by them. The returns on their medium duration bonds are hence likely influenced primarily by domestic factors. Regarding instead volatility, similar results hold; mapping the countries on a two dimensions graph where the axes are the share of transmitted over overall spillovers and the share of absorbed spillovers over the total, we still observe the same two clusters. Italy and France still exhibit a powerful influence in transmitting risk, while they are not influenced. The opposite mechanism works for the second cluster: these countries do not transmit risk, but they are highly influenced by the firsts. Results hold to several robustness checks.

We also apply a comprehensive wavelet analysis to our question of integration among EU sovereign bond yields. We focus on the case of Germany and Italy. We find that the structure of Italian yields changes following the crisis: the intensity of medium and long scale frequencies increases dramatically while that of short-term ones fall, indicating that investors seem to have renewed confidence in the sovereign. Furthermore, the frequency structure matches closely that of Germany. We also find that German yields lead Italian ones during the peaks of the crisis (2011 and 2014) and for medium-term frequencies. Finally, we apply the DY spillover methodology to the decomposed time series, looking at the relationships between the series at different wavelet scales. We find that for Italy and Germany, at a high frequency scale which intuitively represents the short-term movements on the bond markets, the series are highly complementary; Italy is a net receiver while Germany is a net contributor. Even though promising, our results are preliminary and should be validated through further exercises as explained in Section 4.5.

Overall, our evidence indicates that our countries are highly dependent on each other. The intensity of these linkages is increasing through time as they tend to spike during troubled times. This should suggest policy makers a simple fact: EMU countries are deeply integrated and only through coordinated processes we can address relevant public finance issues. These simple facts assume an additional relevance considering the NextgenerationEU; countries and European policy makers should hence be really careful in designing effective plan in order to stimulate rate of growth capable of sustaining the high level of public debt generated by the pandemic.

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