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EUROPEAN MACROECONOMIC DYNAMICS ON FINANCIAL MARKETS AND ECONOMIC POLICY: A CROSS COUNTRY STUDY FOR SPILLOVER EFFECTS

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Abstract. What is the direction and extent of the spillover effects of sovereign bond yields in the European Union and which countries are transmitters and receivers of these effects? The motivation for this research is related to the need to better understand the interconnectedness of European Union sovereign bond markets in the context of rising budget deficits and public debt, as well as recent financial and sovereign debt crises, which have highlighted the importance of bond market interdependencies. The main objective of the paper is to investigate the direction and magnitude of the spillover effects of sovereign bond yields in the European Union and to identify the states that act as transmitters and receivers of these effects. The data used in the analysis include the evolution of the bond markets of the euro area member states and non-monetary union states, to allow comparison and assessment of their interconnectivity. To analyse the interconnectedness of bond markets, methods which provide a suitable analysis framework to assess volatility propagation between countries were used. The research results highlight that most of the contagion effects are concentrated in the peripheral countries, such as Romania, Portugal, Lithuania and Ireland, and the central countries act as transmitters of these effects.

Keywords: interconnectivity, bond markets, European Union, spillover effects, contagion.

JEL codes: C01, C51, C52, C53, C54, C58, C61, C63

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1. Introduction

The current context characterized by increasing budget deficits and public debt provides an opportunity to explore the existing bond market linkages between CEE countries and eurozone member states. The recent financial crisis that erupted in December 2007, as well as the recent sovereign debt crisis, highlighted the importance of bond market interdependencies. The analysis of these interdependencies between European countries leads to obtaining additional information about the evolution of financial crises and their specificity.

Even though more attention needs to be paid to equity market contagion, following the Greek crisis, research has increasingly focused on exploring the bond market. The lesson of the Greek crisis was simple for both investors and policymakers: a potential crisis in one European country can influence the volatility of many others. In this chronological context, this paper aims to explore financial inter-connectivity through the spillover effects of sovereign bond yields. Furthermore, the paper is motivated by the relatively limited research on the integration of the CEE bond market into the euro area.

The main objective of this paper is to identify the direction and magnitude of the spillover effects of sovereign bond yields in the European Union. The results provide a framework for future research investigating the degree of volatility and integration of bond markets.

As there is not universally accepted theoretical or empirical definition of inter-connectivity, we define the concept as inter-dependence or contagion (Chen, 2020; Acemoglu and Tahbaz-Salehi, 2015; Davidson, 2020). However, at the conceptual level the terms inter-connectivity and inter-dependence imply a long-term temporal element and do not necessarily imply contagion. Rather, contagion is defined as the short-term intensification of market linkages resulting from a shock within a market or within a group of markets (Karkowska and Urjasz, 2020).

The literature has used different methodologies and methods to assess either interdependence or contagion in bond markets. For example, numerous studies have used the copula methodology (Silvapulle *et al.*, 2016), Bayesian regressions (Caporin *et al.*, 2018), vector error correction approach (Ters & Urban, 2018), network methodology (Chen *et al.*, 2020). Empirically, this paper uses the Diebold and Yilmaz (2012, 2014, 2015) framework to explore cross-country volatility propagation. A similar approach is taken by Karkowska & Urjasz (2020). This paper is in fact an attempt to replicate the Karkowska & Urjasz (2020) study, including all relevant EU countries for the sample. The choice of methodology is motivated by the high degree of simplicity for measuring spillover effects in a generalized vector autoregressive framework. The benefits of using this methodology are presented in section 4.

The results of this research attempt to highlight the transmitting states of the spillover effects, as well as the receiving states in the European network, providing insights on future research directions. Only one general and common conclusion can be drawn from the results: peripheral countries are receivers of spillover effects, while central countries transmit spillover effects.

This paper is organized as follows: Section 2 reviews the literature attempting to explore the policy applicability of the direction and magnitude of spillover effects. Section 3 describes the data and attempts to explore the differences between euro area and non-EU countries. Section 4 presents the inter-connectivity estimation methodology. Section 5 presents the results. Section 6 concludes by formulating future research directions.

2. Literature review

The academic literature on bond market contagion explores the determinants of contagion as well as the effects of this phenomenon. Regarding the determinants, studies have shown that government bond spreads are driven by fundamental macroeconomic and fiscal indicators, specific news, exchange rate movements, rating changes or stock market returns (Silvapulle *et al.*, 2016; Gomez-Puig *et al.*, 2014; Haugh & Turner, 2009; Afonso *et al.*, 2012; Reboredo & Ugolini, 2015; Favero, 2013; Beetsma *et al.,* 2013). Regarding contagion effects in bond markets, studies have focused on bank and sovereign default risk (De Bruyckere *et al.*, 2013; Angeloni and Wolff, 2012; Arezki *et al.*, 2011; Brown and Dinc, 2011) or on the impact of sovereign yield margins on stock returns (Bhanot, K., *et al.,*2014).

Looking at the inter-connectivity of sovereign bond markets as measured by volatility spillovers, the literature is limited. Market interdependence or inter-connectivity is addressed, as described above, in cause-and-effect studies. It can be mentioned that inter-connectivity is a concept that remains undefined completely and can be measured by several tools.

At the European level, most studies on the inter-connectivity of sovereign bond markets focus on countries within the European Monetary Union (Fernández-Rodríguez *et al.*, 2015; Caporin *et al.*, 2018; Frijns and Zwinkels, 2020; Gomez-Puig and Sosvilla-Rivero, 2014; Martin and Zhang, 2017). For example, using the Diebold and Yilmaz (2012, 2014, 2015) framework, Fernández-Rodríguez *et al*. (2015) show that in the pre-crisis period, most of the triggers of spillover effects came from core countries, while during the crisis, peripheral countries became the dominant transmitters. Similar results were also identified by Gomez-Puig and Sosvilla-Rivero (2014) who demonstrate that causal relationships originating from EMU peripheral countries show an important increase during the crisis period. In contrast, Caporin *et al.* (2018) show that the propagation of euro bond shocks shows almost no change implying that contagion has so far remained low.

The study of CEE sovereign bond markets is even more limited as this market is relatively new. Moreover, the study of this region presents some disadvantages because not all states are part of the Monetary Union, which makes it difficult to control some of the factors that influence yield spreads, including exchange rate movements, exchange rate risk, inflation, or credit risk premiums. However, the studies related to this field focus on the dynamics of the financial integration of the CEE in the euro area. For example, Christiansen (2014) shows that the integration of government bond markets is stronger for UM than for non-UM member states and stronger for old UM member states than new UM member states. The article by Yang and Hamori (2015) discusses the interdependence between the bond markets of the CEC-3 (Poland, the Czech Republic and Hungary) and Germany, finding that there was contagion in these markets during the global financial crisis and the sovereign debt crisis at different degrees and directions. Even though the focus should be on CEE bond markets, this study considers roughly all EU markets. Since the general interest is market convergence, future research should analyse specific markets and the use of econometric models of convergence is necessary. Furthermore, exploring the dynamics of convergence will provide insights into what type of policy instruments are needed for financial markets and what type of policy instruments are best suited for convergence. For example, some studies demonstrate the divergence of bond

yields and support the static criterion of the Maastricht Treaty for long-term bond yields that does not favor financial stability for euro candidate countries (Gabrisch and Orlowski, 2009).

In general, the interconnection between bond markets in the European Union is important. Inter-connections indicate a high or low degree of market integration. As government bonds are influenced by interest rate movements in other economies and are integrated into EU bond markets, understanding these links leads to further implications for monetary policy actions. Monetary policy instruments could be limited to some extent by spillover effects. Furthermore, for investors, understanding these inter-connections could lead to different investment diversification strategies, especially during a crisis.

3. Data

The data used in this study were taken from Thomson Reuters Eikon and represent daily closing values of 10-year government bond yields, denominated in Euro to ensure comparability. The geographic area of the data includes 19 European countries (all members of the European Union), except for Slovakia, Croatia, and Slovenia, which were removed due to the lack of data available for the periods leading up to the EU accession negotiations. The data set comprises 4137 observations for each time series between April 1, 2005, and January 29, 2020.

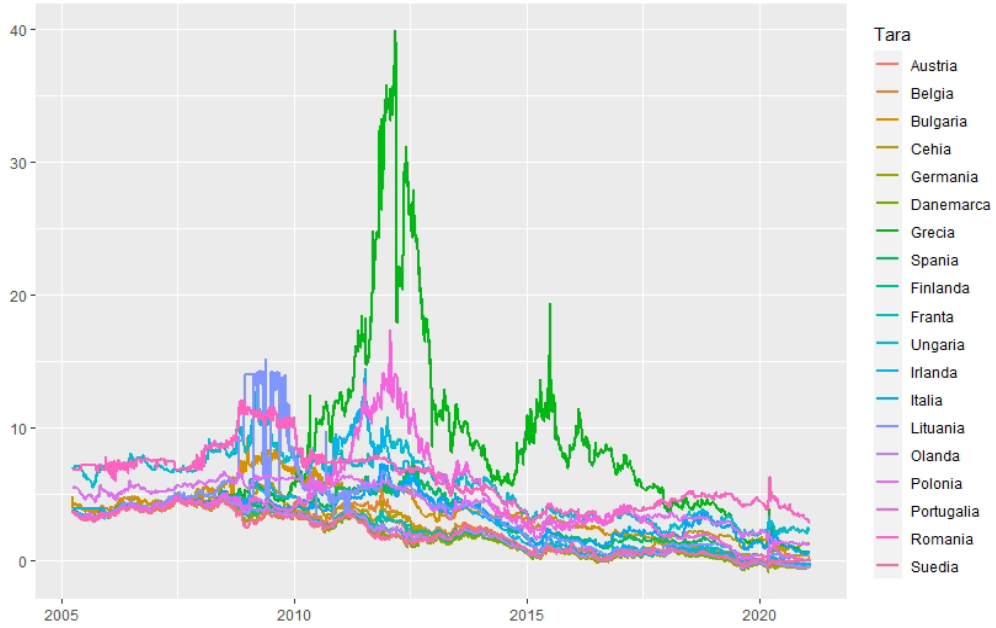

Figure 1. Daily 10-year government bond yields (% per year)

Figure 1 shows the evolution of sovereign bond yields from 2005 to 2020 in each country. The figure depicts a similar trend indicating a decline in all 19 bond markets. Significant changes are observed over three sub-periods corresponding to major crisis events: the 2007-2009 Global Financial Crisis (GFC), the peak of the 2012 sovereign debt crisis, and the 2020 Covid-19 pandemic.

For clarity, figure 2 shows the evolution of the bond markets for the euro area and for the non-member states of the UM, the states geographically located in Eastern Europe (Bulgaria, the Czech Republic, Hungary, Poland, and Romania). The figure shows the same trend over time, but the degree of volatility is much lower outside the UM.

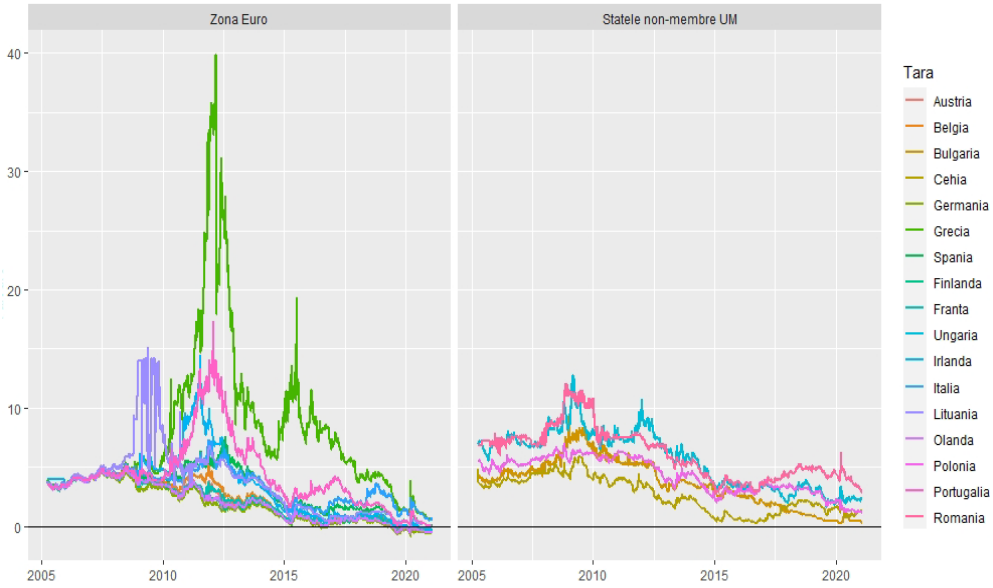

Figure 2. Daily 10-year government bond yields (% per annum) - comparison between the Eurozone and non-member states of the Monetary Union

Table 1 presents preliminary statistics for 10-year government bond yields, as well as the results of the Jarque-Bera test for normality. Series of mean returns are either positive or negative. France, Denmark, Austria, the Czech Republic, and Greece have the highest average returns, while Germany, Portugal, Sweden, Belgium, and the Netherlands have the lowest average returns. France is characterized by the highest degree of volatility, resulting from the standard deviation. It is followed by Ireland, Sweden, and Germany. The least volatile countries in our sample are Poland, Hungary, Romania, and Italy.

The results of the skewness, kurtosis and Jaque-Berra tests indicate that the return series do not follow the normal distribution. Thus, based on these results, we justify our decision to apply a different measurement of profitability, but also the application of the Diebold and Yilmaz (2012, 2014) framework.

4. Methdology

The first step to construct measures of connectivity (spillover effects of contagion), consisted of measuring daily returns by calculating the changes that occur from the previous day to the current day, as follows:

$$Return = \frac{Bond\ yield_t - Bond\ yield_{t-1}}{Bond\ yield_{t-1}} \quad 1$$

Based on the descriptive statistics of the data set, our choice of measurement of the spillover effect, a measure of contagion, was driven by its simplicity. For future research, other methods of calculating volatility could be applied: the ADDC-GARCH model that estimates a measure of volatility based on the performance of daily returns or the Garman & Klass (1980) model that estimates weekly return volatilities using the highest daily prices, lowest prices, closing prices and opening prices.

The second step of our analysis is to apply the Diebold Yilmaz (2012, 2014, 2015) framework that uses a generalized VAR (GVAR) and a generalized variance decomposition that allows us to explore the connectedness in bond markets. This methodology allows us to examine the relative importance of information both within a market and across markets in explaining contagion movements. First, it allows us to examine net directional spillover effects that provide information about how much one market contributes to contagion to other markets. Second, it allows us to assess the total volatility losses in the markets. In addition, we use a network mapping approach to graph volatility dynamics.

The methodology of the Diebold-Yilmaz Connectedness Index (DYCI) relies on generalized variance decompositions within a vector autoregressive (VAR) model framework. By incorporating network graphical display, DYCI effectively visualizes spillover effects across countries, bridging forecast error variance decompositions matrices with network edge weights to provide a robust representation of interconnectedness. The measure reveals how much SCDS i's variable future uncertainty results from shocks in variable j. DYCI methodology starts with the implementation of a covariance-stationary VAR model with N variables is defined as follows:

$$Y_t = \sum_{i=1}^{p} \emptyset_i\, x_{t-i} + \varepsilon_t$$

with $\varepsilon_t \sim (0, \Sigma)$. The moving average representation of VAR takes the following form:

$$Y_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}$$

where *N*N* is a coefficient matrix. Ai follows recursive pattern as $A_i = \emptyset_1\, A_{i-1} + \emptyset_2\, A_{i2} + \ldots + \emptyset_p\, A_{i-p}$. A_0 is an identity matrix and $A_j = 0$ for $i<0$. We calculate the decomposition of the variance of the forecast error at h steps ahead:

$$\varphi_{ij}(H) = \frac{\gamma_{jj}^{-1}\Sigma_{h=0}^{H-1}\left(e_i' A_h \Sigma e_j\right)^2}{\Sigma_{h=0}^{H-1}(e_i' A_h \Sigma A_h' e_i)}$$

The decomposition records how much variance of the forecast error of SCDS idiosyncratic or returns measures at h steps ahead is due to the shocks in another variable included in the VAR model. Each matrix element is normalized by summing the row so that the decomposition including shocks in each market equals the total decomposition of all variables sums to N:

$$\tilde{\varphi}_{ij}(H) = \frac{\varphi_{ij}(H)}{\Sigma_{j=1}^{N}\varphi_{ij}(H)}$$

These measures denote the spillover level received or transmitted by variable *i* within the system. Finally, the total spillover index is calculated as:

$$S(H) = \frac{\Sigma_{i,j=1,i\neq j}^{N}\tilde{\varphi}_{ij}(H)}{N}\ x\ 100$$

denoting the overall spillover significance that originates in other countries on the determination of SCDS measures. This measure is called “system-wide connectedness” or “dynamic connectedness index”.

5. Results and discussion

As depicted in Table 2, the degree of total inter-connectivity among states in our sample is 14.73%. On the one hand, the markets that transmit most of the contagion are Italy, Lithuania, Portugal, Spain, and the Netherlands. Italy has the most significant result in measuring contagion (1.89%), followed by Lithuania (1.64%). Thus, the bond markets of Italy and Lithuania are the two most connected markets in terms of contagion.

On the other hand, the receiving bond markets are: Lithuania (1.77%), Portugal (1.67%), Italy (1.66%), Denmark (1.12%) and Spain (1.12%) . The states that receive the least contagion effects are Germany (0.11%), Bulgaria (0.26%), Romania (0.29%), Austria (0.33%) and Belgium (0.39 %).

As mentioned, within the European Union, Italy is the strongest transmitter of volatility. However, the bond markets of Germany, Bulgaria, France, and Romania are the least affected by the Italian bond market, while the bond markets of Lithuania, Poland, Spain, and the Netherlands are the most influenced.

Overall, the analysis shows that, to some extent, these countries exhibit a high degree of two-way spillovers, suggesting financial market integration. As expected, this degree of integration is more persistent among the member states of the Monetary Union.

Table 1. Descriptive statistics

	Austria	Belgium	Germany	Denmark	Greece	Spain	Finland	France	Ireland	Italy	Lithuania	Netherlands	Portugal	Sweden
Mean	0.0036	-0.0061	-0.0138	0.0071	0.0001	-0.0009	-0.0015	0.0329	-0.0038	-0.0001	-0.0005	-0.0044	-0.0119	-0.0110
Standard deviation	0.6440	0.4430	0.9405	0.2940	0.0300	0.0979	0.3653	2.0394	1.3662	0.0276	0.2044	0.6420	0.9015	1.0998
Min	-32	-12.5	-54.3333	-5	-0.5110	-3.8	-9.1429	-15.7692	-62	-0.2709	-8	-27.5	-56	-37
Max	18	14.5	10	13.5	0.4109	1.1818	10	125.6667	44	0.5978	5.4	23	7	26.5
Kurtosis	-22.5584	-2.5672	-47.2225	25.6530	-0.5949	-19.5782	-0.7614	56.7853	-15.0707	2.9656	-11.9636	-10.0400	-58.0660	-7.4279
Skewness	1647.9843	566.5107	2705.4884	1163.1911	65.4522	754.2191	318.0210	3483.1638	1331.7200	65.3469	805.2604	1252.6298	3598.1867	508.1455
Jarque-Bera test	388.6308*	418.4935*	346.0478*	344.3913*	8701.5955*	213.6975*	361.5985*	359.6592*	512.9511*	141.6182*	2972.3985*	357.1527	1826.1305	337.9856

	Bulgaria	Czechia	Hungary	Poland	Romania
Mean	-0.0000004	0.0001	-0.0001	-0.0003	4.76E-05
Standard deviation	0.0382	0.0301	0.0196	0.0165	0.0224
Min	-0.4375	-0.2846	-0.1741	-0.1990	-0.224
Max	1.2286	0.26	0.2613	0.1636	0.1903
Kurtosis	7.9196	0.9923	0.8210	-0.0137	0.2117
Skewness	274.1038	18.5700	18.3356	19.5680	14.8856
Jarque-Bera test	113.0774*	276.2342*	207.7915*	283.6493*	241.5051*

**** Notes: The Jarque-Bera test measures whether the sample data have a skewness index and a flattening index that fit a normal distribution.*

Table 2. Total connectivity of volatilities, Diebold & Yilmaz method (2012), 10-year sovereign bond markets

	Austria	Belgium	Bulgaria	Czechia	Germany	Denmark	Greece	Spain	Finland	France	Hungary	Ireland	Italy	Lithuania	Netherlands	Poland	Portugal	Romania	Sweden	FROM
Austria	93.55	0.91	0.63	0.68	0.01	0.09	0.23	0.19	1.72	0.51	0.58	0.05	0.06	0.02	0.09	0.30	0.01	0.02	0.36	0.34
Belgium	0.36	92.47	0.14	0.09	0.01	0.11	0.20	0.33	1.80	1.93	0.81	0.22	0.48	0.05	0.43	0.26	0.01	0.05	0.24	0.40
Bulgaria	1.14	0.09	95.04	0.01	0.07	0.04	0.09	0.01	2.99	0.01	0.01	0.01	0.01	0.01	0.08	0.14	0.00	0.09	0.15	0.26
Czechia	0.33	0.23	0.01	90.23	0.07	0.74	0.03	0.42	0.22	0.05	2.33	0.24	1.16	0.03	0.94	2.48	0.02	0.37	0.11	0.51
Germany	0.02	0.02	0.07	0.53	97.83	0.58	0.08	0.03	0.04	0.00	0.06	0.01	0.17	0.01	0.25	0.24	0.00	0.07	0.00	0.11
Denmark	0.09	0.11	0.03	0.51	0.60	78.56	0.26	0.09	2.04	0.03	0.09	0.04	0.12	0.02	17.17	0.03	0.01	0.12	0.07	1.13
Greece	0.25	0.36	0.08	0.03	0.05	0.15	81.19	2.03	0.19	0.23	1.12	0.30	12.11	0.05	0.08	0.06	0.08	1.33	0.33	0.99
Spain	0.11	0.13	0.01	0.27	0.02	0.03	1.82	78.59	0.13	0.14	1.36	0.49	12.36	1.28	0.04	1.41	1.43	0.14	0.22	1.13
Finland	2.02	2.23	2.29	0.26	0.11	0.91	0.09	0.15	86.84	0.59	0.17	0.58	0.16	0.04	2.29	0.16	0.01	0.19	0.93	0.69
France	2.01	0.52	0.06	0.03	0.00	0.05	0.12	0.34	3.24	91.62	0.29	0.81	0.55	0.04	0.09	0.10	0.02	0.04	0.05	0.44
Hungary	0.41	0.79	0.01	2.07	0.05	0.03	1.10	1.40	0.26	0.08	80.20	0.55	2.77	0.03	0.04	8.80	0.04	0.98	0.38	1.04
Ireland	0.02	5.96	0.01	0.35	0.00	0.01	0.25	0.82	0.14	0.11	0.09	91.30	0.60	0.05	0.03	0.14	0.03	0.04	0.05	0.46
Italy	0.15	0.46	0.01	0.87	0.17	0.29	10.19	11.13	0.18	0.21	2.36	1.03	68.45	0.23	0.24	2.33	0.86	0.75	0.12	1.66
Lithuania	0.01	0.02	0.01	0.03	0.01	0.00	0.07	5.54	0.01	0.02	0.09	0.07	0.12	66.32	0.00	0.10	26.20	0.00	1.39	1.77
Netherlands	0.04	0.07	0.12	1.67	1.68	1.92	0.20	0.04	1.38	0.04	0.29	0.03	0.41	0.01	91.56	0.24	0.00	0.27	0.03	0.44
Poland	0.44	0.68	0.12	2.23	0.19	0.03	0.05	1.48	0.40	0.07	8.89	0.32	2.78	0.06	0.16	81.68	0.08	0.21	0.12	0.96
Portugal	0.00	0.02	0.00	0.01	0.00	0.00	0.31	1.46	0.00	0.00	0.07	0.01	0.67	28.62	0.00	0.04	68.23	0.01	0.54	1.67
Romania	0.02	0.11	0.12	0.39	0.05	0.11	1.52	0.19	0.10	0.07	1.14	0.09	1.00	0.02	0.44	0.24	0.04	94.31	0.05	0.30
Sweden	0.12	0.70	0.18	0.12	0.01	0.09	0.31	2.69	0.29	0.04	0.83	0.23	0.46	0.66	0.06	0.71	0.12	0.31	92.06	0.42
TO	0.40	0.71	0.21	0.53	0.16	0.27	0.89	1.49	0.80	0.22	1.08	0.27	1.89	1.64	1.18	0.94	1.52	0.26	0.27	**14.73**

Furthermore, from Table 2 measures of net connectivity can be calculated. Directional connection in network pairs can take the form of a positive (sender) or negative (receiver) value. As can be seen, the number of states transmitting contagion effects is slightly higher than the number of recipient states. The Dutch bond market is the largest transmitter of spillovers, followed by Spain, Belgium, and Italy. On the other hand, Denmark, France, Ireland, and Portugal are characterized as recipient states.

Table 3. Transmission/reception of volatility propagation effects

Country	Net Sender/ Net Receiver	Net Degree of Connectivity – Diebold & Yilmaz (2012)
Austria	Net transmitter	0.057
Belgium	Net transmitter	0.309
Bulgaria	Net receiver	-0.055
Czech Republic	Net transmitter	0.021
Germany	Net transmitter	0.050
Denmark	Net receiver	-0.856
Greece	Net receiver	-0.100
Spain	Net transmitter	0.364
Finland	Net transmitter	0.103
France	Net receiver	-0.223
Hungary	Net transmitter	0.041
Ireland	Net receiver	-0.191
Italy	Net transmitter	0.233
Lithuania	Net receiver	-0.128
Netherlands	Net transmitter	0.736
Poland	Net receiver	-0.028
Portugal	Net receiver	-0.148
Romania	Net receiver	-0.037
Sweden	Net receiver	-0.148

Table 3 graphically presents the pair-wise directional connection between the analysed bond markets. Also, Figure 3 represents the graphical confirmation of the results presented in table 3. A general conclusion is related to the geographical distribution of the countries receiving spillover effects: most of them are peripheral countries (Romania, Portugal, Lithuania, Ireland). However, Germany does not follow the same pattern.

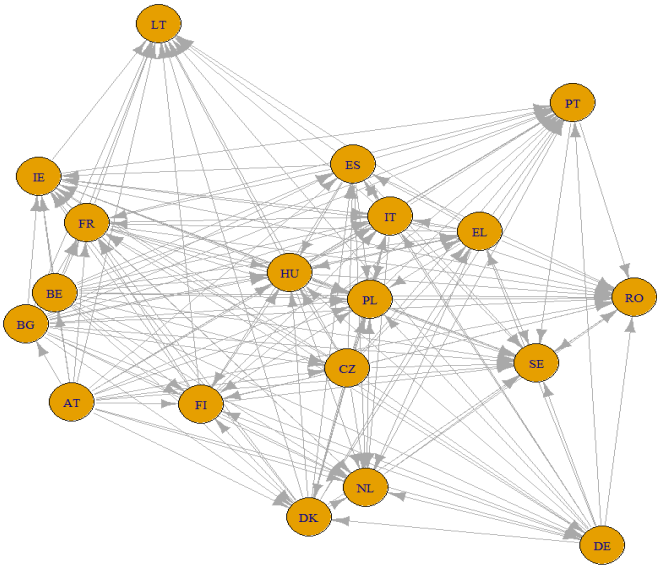

Figure 3. The degree of directional net connectivity by country pairs over the entire period studied

Figure 4 shows the global propagation effects of the contagion for the entire analysed period. Three periods of contagion can be identified. The first period between 2007-2008 corresponding to the GFC, the transmission of spillover effects reached its highest point in early 2009. Between 2009-2012, the intensity dropped considerably from 70% to about 40%. However, in early 2013, we identify a second period of uncertainty culminating in the highest value between 2016-2017.

Figure 4. Global spillover effects of contagion

Furthermore, the third and most interesting period starts with a sharp increase in 2017 with a level of spillover effects that fluctuates for the next two years until it reaches the first highest point in 2019. After a sharp decline, 2019 characterized by a second peak and a sudden drop from 90% to about 30%. The Covid-19 crisis has also raised the level of contagion effects, but the increase is not significantly higher compared to the immediate previous level (from less than 30% to 40%).

However, describing contagion interconnectivity only based on the Diebold & Yilmaz framework, which only considers the static connectivity index, requires the application of a new method that considers price jumps and volatility caused by global events such as the Referendum Brexit. For example, Karkowska & Urjasz (2021) tried to apply the methodology of Bai & Perron (1998, 2003) to discover the data of structural changes caused by political events or international market conditions. However, their analysis did not distinguish a single event, with each market affected by multiple structural changes. To solve this problem, they applied a rolling window analysis for each market and described the developments in the CEE market.

6. Conclusions, implications for economic policy and future research

In the current context described by the increase in public budget deficits and public debt, the results of this study indicate some aspects of interest for economic governance such as tax policy, as the Netherlands, Spain, Italy, and Belgium send the highest degree of contagion to other EU countries, it is worth paying attention to the potential implications of the determinants of sovereign risk. Fiscal performance, as well as other macroeconomic fundamentals, are key determinants of sovereign bond yield movements (Gómez-Puig *et al.*, 2014; Haugh *et al.*, 2009; Bae, K.H., 2012; Caporin *et al.*, 2018). The GIIPS countries, including Italy and Spain, are of particular interest as their public deficits and debts are expected to rise above the limits set by the Maastricht Treaty. As described by Afonso *et al.* (2012) in the run-up to the GFC crisis, fiscal performance was not significant in explaining spreads, but during the crisis, fiscal performance began to explain these movements, with financial markets setting the size, liquidity, and maturity of debt issuance. Moreover, the increase in investors' risk aversion driven by sovereign ratings has significant effects, especially for EMU peripheral countries (Gómez-Puig *et al.*, 2014). In addition, more attention should be paid to the interconnection between private and public debt. During the GFC, studies have observed that an increase in sovereign risk is driven by an increase in the level of bank debt as well as foreign bank claims on the public sector. Mitigating sovereign risk through appropriate policy must consider specific national contexts. Governments are under pressure to decide whether to implement contractionary fiscal policy or expansionary fiscal policy. Which type of expansionary policies (additional spending or tax cuts) are appropriate remains to be decided given particular national contexts.

Another aspect of interest is the prudential policy. Regarding the possibility of avoiding contagion effects, governments must evaluate effective measures to reduce their intensity. Banks with a weak funding structure, weak capital depreciation and less traditional banking activities are vulnerable to contagion effects (Arezki et al. 2011). Appropriate policy measures aimed at reducing the intensity of contagion should consider the temporal dimension, as direct capital injections are the most effective instruments. For this reason, future research should look at time periods. Studies have

found that when governments face high budget deficits, they are less likely to close or take over a failing bank, especially if the banking system is weak. This effect, referred to in the literature as "too many to fail" leaves governments with limited options, but specific contexts determine whether capital, credit or liquidity are the appropriate tools.

Future research should explore, in turn, specific time periods and specific events that differentiate between pre-crisis and early crisis periods. Similar studies have been carried out by (Fernández-Rodríguez *et al.*, 2015; Gomez-Puig and Sosvilla-Rivero, 2014) which argue that, in the pre-crisis period, most of the contagion triggers came from the core countries. However, during a crisis, peripheral countries have become dominant transmitters. Furthermore, Antonakakis and Vergos (2013) highlight that during the debt crisis, destabilizing shocks mainly come from peripheral euro area countries and in a smaller measure of the eurozone core. Another research direction is suggested by the increasing importance of sovereign ratings, which are perceived as one of the key determinants of bond yield volatility (Silvapulle *et al.*, 2016; Afonso *et al.*, 2012; Frijns and Zwinkels, 2020). In addition, the paper does not influence the US bond market in European markets. Other studies have quantified this influence (Davidson, 2020; Karkowska and Urjasz, 2021). The methodological steps required for future research were described in section 5.

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Appendix A: Abbreviations and explanatory notions

CEE	Member States of the European Union in Eastern Europe
CEC-3	Member States of the European Union in Central Europe (Poland, Czech Republic and Hungary)
GFC	Global Financial Crisis
UE	European Union
UM	Monetary Union
VAR	Vector Autoregression Model
EMU	European Monetary Union

Term/Notion	**Explanation/ definition**
Net connectivity	Table 3. Transmission/reception of volatility propagation effects shows the degree of net connectivity. This degree is calculated as the difference between the total connectivity transmitted / country and the total connectivity received from Table 2. This difference can be negative (case in which the state is a net receiver of spillover effects) or positive (case in which the state is a transmitter of spillover effects propagation). The values in table 3 are not approximate.
VAR Model (Vector Autoregression Model)	Vector autoregression model is a statistical model used to highlight the relationship between multiple quantities as they change over time. Models of this type generalize the univariate autoregressive model using multivariate time series. Generally, a VAR model includes lags for previous time periods. For example, for a variable y_t (e.g. bond yield, bond yield) with only one previous time period, the model is: $$y_t = a_1 y_{t-1} + \epsilon_t$$ where y_t, a_1, ϵ_t are matrices.

Appendix B: Conclusions drawn from specialized literature

Reference	Items researched	Conclusions
Bond market contagion units articles		
Silvapulle P., Fenech, J.P., Thomas, A., Brooks, R. (2016) "Determinants of sovereign bond yield spreads and contagion in the peripheral EU countries", Economic Modelling, vol. 58, 83-92.	• Significant determinants of daily bond yield spreads and their volatilities. • The presence of financial contagion effects among the peripheral countries of the EMU.	The German stock index return, the Euro interbank offer rate, stock index returns in these countries, S&P 500 returns, VIX and sovereign debt ratings have had a significant impact on bond yields and/or volatilities, particularly in the post-crisis period.
Gómez-Puig, M., Sosvilla-Rivero, S., & Ramos-Herrera, M.d.C. (2014) "An update on EMU sovereign yield spread drivers in times of crisis: a panel data analysis", The North American Journal of Economics and Finance, vol. 30, 133-153. Gonzalo, J., & Olmo, J., (2005).	• Potential drivers of EMU sovereign bond yields.	The increase in sovereign risk in core countries during the crisis can be explained by the behaviour of regional macroeconomic fundamentals and the local, regional, and global market climate. In addition, the increase in sovereign risk could be explained by the interconnection between private debt and public debt, as during the crisis there was an increase in the importance of the bank level of indebtedness and the claims of foreign banks in the public sector (mainly in peripheral countries). The results also indicate that global market climate and investors' risk aversion increase their marginal effects after the onset of the sovereign crisis, especially in peripheral EMU countries.
Haugh, D., Ollivaud, P., & Turner, D. (2009) "What Drives Sovereign Risk Premiums? An Analysis of Recent Evidence from the Euro Area", OECD Economics Department Working Paper, No. 718, Paris.	• The evolution of the yield of sovereign bonds between Germany and other countries in the euro area.	Fiscal performance (measured by the ratio of debt service to fiscal receipts and expected fiscal deficits) is a key determinant of the evolution of the sovereign bond yield spread. There is evidence to suggest that such effects are non-linear, such that incremental deteriorations in fiscal performance can lead to increasingly large increases in the spread. Thus, financial market reaction could become an increasingly important constraint on fiscal policy for some countries.
Afonso, A., Arghyrou, M., & Kontonikas, A. (2012) "The Determinants of Sovereign Bond Yield Spreads in the EMU", Working Papers 2012_14.	• Determinants of long-term sovereign bond yields	The drivers of government bond spreads in the euro area have changed significantly over time. In the pre-crisis period, macro and fiscal fundamentals are generally not

Reference	Items researched	Conclusions
Business School – Economics, University of Glasgow.		significant in explaining spreads. Instead, since the summer of 2007, movements in macro and fiscal fundamentals explain movements in spreads. During the crisis, the size, liquidity, and maturity of debt securities issues were valued by the markets. The results also show that sovereign credit ratings are statistically significant in explaining spreads, but relative to macro and fiscal fundamentals, their role was quite limited.
Reboredo, J. C., & Ugolini, A. (2015). Systemic risk in European sovereign debt markets: A CoVaR-copula approach. Journal of International Money and Finance, 51, 214–244.	• Systemic risk in European sovereign debt markets before and after the Greek debt crisis, considering conditional value at risk (CoVaR)	The article calculates systemic risk by considering country-specific stock market returns. The results indicate a separation between peripheral and core EU countries. The results indicate that European debt markets were highly developed in the period before the onset of the debt crisis and that systemic risk trends were similar across markets. European decoupled debt and GIIPS markets were negatively correlated with the EMU index and exhibited lower tail dependence. As a result, the systemic risk changed dramatically and the CoVaR value increased. In contrast, for non-crisis countries, cooperation has not changed substantially, even though systemic risk has increased.
Favero, C. A. (2013) "Modelling and forecasting government bond spreads in the euro area: A GVAR model", Journal of Econometrics, vol. 177, no. 2: 343-356. (Diebold and Yilmaz, 2009, 2011)	• Determinants of sovereign bond yields	The article proposes an econometric model that captures not only local fiscal fundamentals and global market appetite for risk, but also expected exchange rate devaluations.
Beetsma, R., Giuliodori, M., de Jong, F., & Widijanto, D. (2013) "Spread the news: the impact of news on the European sovereign bond markets during the crisis", Journal of International Money and Finance, vol. 34, 83-101.	• Determinants of sovereign bond yields	The results find that more news, on average, raised the domestic interest spread of GIIPS countries since September 2009. The magnitude of this effect is related to cross-border bank holdings. A breakdown of the news into bad and good news shows that the upward pressure on domestic and foreign interest rates is being driven by the bad news.

Reference	Items researched	Conclusions
		We also find bad news spillovers from GIIPS countries to non-GIIPS countries. However, the magnitude of these spillover effects is substantially lower than that of other GIIPS countries.
Articles on bond market contagion effects		
De Bruyckere, V., Gerhardt, M., Schepens, G., Vennet, R. V. (2013)" Bank/sovereign risk spillovers in the European debt crisis", Journal of Banking & Finance, vol. 37, no. 12: 4793-4809.	• Contagion between bank default risk and sovereign default risk • Determinants of contagion	The articles present empirical evidence of the existence of three contagion channels: a collateral channel, an asset holding channel, and a collateral channel. They believe that banks with a weak capital buffer, a weak funding structure and less traditional banking activities are particularly vulnerable to contagion risks. At the country level, the debt ratio is the most important driver of contagion. Furthermore, the impact of government interventions on contagion depends on the type of intervention, with capital injections simply being the most effective measure to reduce contagion intensity.
Angeloni, C., & Wolff, G. (2012) "Are banks affected by their holdings of government debt?", Bruegel Working Paper 07.	• Banks' sovereign exposure to GIIPS countries has effects on stock market values.	The article finds that bank market performance in July-October 2011 was affected by Greek debt holdings and, in October-December 2011, by Italian and Irish sovereign exposures. The Spanish exposure did not appear to have an impact on the banks' stock values. The second transmission channel is a collateral channel. Sovereign risk can spread to banks when the value of collateral that banks hold in the form of sovereign debt is reduced.
Arezki, R., Candelon, B., & Sy, A. (2011) "Sovereign rating news and financial markets spillovers: evidence from the European debt crisis", IMF Working Paper 68	• The effects of the weak fiscal position on the financial sector	The article shows that sovereign rating downgrades cause significant spillovers, both across markets and across countries. Finally, the guaranteed channel is linked to the too-big-to-fail status of some large banks. When sovereigns' fiscal position is weakened, implicit and explicit government guarantees could lose value, which could make it harder for the financial sector to reap the benefits of such guarantees.

Reference	Items researched	Conclusions
Brown, C., & Dinc, I. (2011) " Too many to fail? Evidence of regulatory forbearance when the banking sector is weak", Review of Financial Studies, vol. 24, no. 4: 1378-1405.	• Collapse of banks	A country's ability to support its financial sector, as reflected in the government deficit, affects the treatment of troubled banks: a government is less likely to take over or close a troubled bank if the banking system is weak. This *too-many-to-fail* effect is robust to controlling for macroeconomic factors, financial crises, the *too-big-to-fail* effect, domestic financial development, and concerns about systemic risk and information leakage. The article also shows that the *too-many-to-fail* effect is stronger for larger banks and when there is a large budget deficit.
Bhanot, K., Burns, N., Hunter, D., & Williams M. (2014) "News spillovers from the Greek debt crisis: impact on the Eurozone financial sector", Journal of Banking & Finance, vol. 38, 51-63.	• The relationship between Greece's sovereign yield spreads and financial sector stock returns	The article finds evidence of spillover effects. For example, news announcements (rating downgrades and other news) about Greece lead to negative and significant abnormal returns of financial stocks in Portugal, Italy, and Spain. No evidence of spillover effects was found for financial firms in other European countries: Austria, Belgium, France, and the Netherlands. The spillover effect is amplified for countries with higher yield spreads. Collectively, the results point to the role of information (news announcements) as a transmission channel during the crisis.
Bae, K.H. (2012) " Determinants of local currency bonds and foreign holdings: Implications for bond market development", People's Republic of China ADB working paper series on regional economic integration.	• Macroeconomic, institutional, and capital importance in explaining bond market development.	In government bond markets, the fiscal balance is the variable that strongly affects the value of outstanding bonds. A one standard deviation increase in the budget deficit is associated with a 10-percentage point increase in outstanding government bonds as a percentage of GDP. In financial bond markets, no variable is strongly related to the value of outstanding bonds except GDP per capita. In corporate bond markets, low interest rates, a large banking sector

Reference	Items researched	Conclusions
		and well-developed government bond markets are conducive to market development. Variables measuring a country's institutional quality do not explain cross-country variation in bond market development, whether it is government, financial, or corporate bond markets.
Definition of connection within Diebold and Yilmaz		
Acemoglu, D., Ozdaglar, A., & Tahbaz-Salehi, A. (2015) "Systemic risk and stability in financial networks", American Economic Review, vol. 105, no. 2: 564-608.	• Financial contagion	The article shows that a more densely connected financial network (corresponding to a more diversified pattern of interbank liabilities) improves financial stability if the magnitude of negative shocks is small enough. However, beyond a certain point, dense interconnections serve as a mechanism for propagating shocks, leading to a more fragile financial system: contagion will be strengthened and manifested as connectivity increases, only if excess liquidity is insufficient to cover capital losses.
Karkowska, R. & Urjasz, S. (2021) "Connectedness structures of sovereign bond markets in Central and Eastern Europe", International Review of Financial Analysis, vol. 74.	• Financial connectivity through volatility effects of CEE and developed markets sovereign bond markets	CEE countries are more interconnected with each other than global markets: EM bond markets can be contagious with each other creating the regional center of volatility transmission. Poland, Hungary, and the Czech Republic have the highest share of influence over other countries + similar two-way transmission, suggesting that they are strongly interconnected. In advanced countries (USA) government bond markets turn out to be the most connected in terms of volatility. The integration of government bond markets is stronger for EMU members compared to non-EMU countries, as well as stronger for old EU member states than for new ones.

Reference	Items researched	Conclusions
Davidson, S. N., (2020) "Interdependence or contagion: A model switching approach with a focus on Latin America", Economic Modelling, vol 85 (May 2019), 166-197.	• New econometric strategy proposal in which the nature of interdependencies, the extent of interdependencies, and the selected transmission channels change over time	The results generally indicate interdependence, not contagion, during the currency crises of the 1990s and the Argentine crisis of 1998-2002. During the global financial crisis, the results show sudden contagion from the US to Argentina and Brazil. Mexico, however, experiences contagion through existing interdependencies with the US. The results also show that macroeconomic and uncertainty channels play a role during various crises, not just financial channels.
Studies on the EU		
EMU		
Fernández-Rodríguez F., Gómez-Puig, M., & Sosvilla-Rivero, S. (2015) " Volatility spillovers in EMU sovereign bond markets", International Review of Economics and Finance, vol. 39, 337-352.	• Spillover effects on EMU sovereign bond market volatility and the determinants of net directional spillover effects on detected pairs (macroeconomic fundamentals and investor sentiment)	Slightly more than half of the total variation in forecast errors is explained by cross-country shocks rather than idiosyncratic shocks, implications: in the pre-crisis period, most volatility triggers were core countries – peripheral countries imported credibility from them, while during the crisis peripheral countries became the dominant transmitters. [*see also Antonakakis and Vergos (2013)*]
Caporin, M., Pelizzon, L., Ravazzolo, F. & Rigobon, R. (2018) " Measuring sovereign contagion in Europe", Journal of Financial Stability, vol. 34, 150-181.	• Transfer of sovereign risk-contagion	The article finds that the propagation of shocks in euro bond yield spreads indicates almost no presence of sovereign risk transfer-contagion in the sample periods considered. Shock transmission is no different on days with large spread changes and small changes. This is the case even though a significant number of countries in our sample have been severely affected by their sovereign debt and fiscal situation. The risk of spreading between these countries is not a affected by the size or sign of the shock, implying that contagion has thus far remained subdued. However, the US crisis does not generate a change in the intensity of

Reference	Items researched	Conclusions
		shock propagation in the euro area between the pre-crisis period 2003-2006 and November 2008-November 2011 post-Lehman one, but the coefficients actually go down, not up.
Frijns, B., & Zwinkels, R. C. J. (2020) "Absence of speculation in the European sovereign debt markets", Journal of Economic Behavior and Organization, vol.169, 245-265	• The determinants of extreme dynamics in the bond market and the CDS market	The article finds that bond markets are driven 80% by liquidity trading, 13% by credit news, and only 5.4% by speculation. The CDS market is 49% driven by credit news, 45% by liquidity trading, and 5.5% by speculation. The relative importance of different types of agents varies over time.
Gomez-Puig, M., & Sosvilla-Rivero, S. (2014) "Causality and contagion in EMU sovereign debt markets", International Review of Economics and Finance, vol. 33, 12-27.	• Contagion after the current euro debt crisis	The article concludes that, during the crisis period, not only some new patterns of causality can be observed, but also an intensification of the causal link in 70% of cases, which means that these links may be purely crisis contingent. Causality in peripheral EMU countries shows an important increase in the crisis period: not only causality in peripheral countries, but also causality running from peripheral EMU to core EMU countries. This suggests that problems in peripheral countries may spill over not only to other peripheral countries but also to core EMU countries, as some of these banks (especially German and French banks) are highly exposed to peripheral debt.
Martin, F., & Zhang, J. (2017) "Modelling European sovereign bond yields with international portfolio effects", Economic Modelling, vol. 64 (December 2016), 178-200.	• A two-country portfolio choice model to assess the specific role of volatility and co-volatility risks in the formation of long-term European interest rates in crisis and post-crisis periods, with an active role of the European Central Bank	This shows that the decline in long-term rates in Germany and France since March 2011 is partly due to the decline in both risk premia and covariances with the peripheral countries. These decreases amplify the flight-to-quality mechanisms. Finally, a lower volatility and co-volatility risk sensitivity during the crisis lends credence to the hypothesis of an occasional fragmentation of European sovereign bond markets.

Reference	Items researched	Conclusions
CEE		
Cappiello, L., Engle, R. F., & Sheppard, K. (2006) "Asymmetric dynamics in the correlations of global equity and bond returns", Journal of Financial Econometrics, vol. 4, no. 4: 537-572.	• Conditional asymmetries in volatilities and correlations for a collection of global equity and bond indices	While equity returns show strong evidence of asymmetries in conditional volatility, little has been found for bond returns. However, both stocks and bonds show asymmetries in conditional correlations, with stocks responding more strongly than bonds to common bad news. The introduction of a fixed exchange rate regime leads to an almost perfect correlation between bond yields within European Monetary Union (EMU) countries, which is not surprising when monetary policy harmonization is considered. However, the increase in return correlation is not limited to bond yields in EMU countries: the correlation of equity returns, both within and outside EMU, is also increasing.
Christiansen, C., (2014) "Integration of European bond markets", *Journal of Banking and Finance,* vol. 42, no. 1: 191-198.	• Variation over time in the integration of EU government bond markets	The article shows that the integration of government bond markets is stronger for EMU than non-EMU members and stronger for old EU members than new ones. For EMU countries, integration is weaker the lower the credit rating. In recent crisis periods, integration is weaker, especially for EMU countries.
Ters K. & Urban (2018), Intraday dynamics of euro area sovereign CDS and bonds, BIS Working Papers No 423	• Which market (the CSD market or the bond market) is more important in terms of sovereign credit risk pricing?	The pricing of sovereign credit risk in the bond and CDS market converges over time, deviations between the two market segments do not persist for long. A key result is that the CDS market dominates the bond market in terms of price discovery in many cases which were examined: CDS premiums, in many cases, adjust faster to reflect new information than bond spreads.
Yang, L., & Hamori, S. (2015) "Interdependence between the bond markets of CEEC-3 and Germany: A wavelet coherence analysis",	• Interdependence between bond markets in CEEC-3 (Poland, Czech Republic, and Hungary) and Germany	The article finds that, first, contagion occurred in these markets during the global financial crisis and the European debt crisis, to varying degrees and in different directions.

Reference	Items researched	Conclusions
The North American Journal of Economics and Finance, vol. 32 (April 2015), 124-138		Second, it shows that the degree of bond market integration was relatively high before 2004 for Poland and Hungary and very high for the Czech Republic during the sample period. Finally, the panel notes that interest rate developments in Poland and the Czech Republic have mirrored those in Germany.