Euro Area: Towards a European Common Bond? – Empirical Evidence from the sovereign debt markets

Nikolaos Stoupos[1] & Apostolos Kiohos[2]

Abstract

Despite the debt crisis of the period 2010-2015, the Eurozone did not manage to adopt an efficient policy for reinforcing the creation of a common bond among the members-states of the union. Under these circumstances, the research aim of this manuscript is to further explore the integration level of bond markets in the EMU after the end of the 2010 debt crisis and the potential creation of a Euro Area common bond. The empirical evidence we gathered is suggestive of a significant integration degree of bond markets in the Euro Area, whereas plenty of asymmetries exist among the member-states notwithstanding. The dominant role of France, the Netherlands, Germany, Italy, Ireland and Spain on the EA bond markets were unveiled. As a matter of fact, we propose that the EMU be conditionally prepared to issue a common Eurozone bond which will safeguard the financial stability in the monetary union.

Keywords: bond markets risk, FCVAR, Realized EGARCH, EMU unification, financial integration

JEL: C58, F15, F36, G15, G17

---

[1]Post-doc Research Fellow, Department of International and European Studies, University of Macedonia, Egnatias Street, 156, 54006, Thessaloniki, Greece, nikostoupos@gmail.com, (corresponding author)

[2]Associate Professor, Department of International and European Studies, University of Macedonia, Egnatia 156, 54006, Thessaloniki, Greece, akiohos@uom.gr, akiohos@otenet.gr

1. Introduction

Since the beginning of the creation of the Euro Area (EA) in 1999, the European financial markets have experienced three different and contrasting events; the circulation of euro in 2002, the 2008 global financial crisis and the 2010 sovereign debt crisis in EA periphery countries. The introduction of the euro facilitated the acceleration of the financial integration in the monetary union through a variety of channels. The common currency repealed the exchange rate barriers and therefore offered direct access to investors in the EA bond markets from different countries. The presence of a common central bank (ECB) assisted the member-countries to reap the benefits of low inflation and stable interest rates. Hence, investors faced higher similarity regarding the discounted rates of their future cash flows. Moreover, the markets evaluated that the default risk had been similar among the EA member-states despite continuous fiscal mismanagement and current accounts deficit. This incident subserved the most vulnerable EA economies by far to enjoy low borrowing cost and grant access to more funding sources. Nevertheless, plenty of researchers (Hafner and Jager, 2013, Chari et al. 2020) have discussed that this "illusion" of the financial markets was the cause of the 2010 sovereign debt crisis since the EMU does not meet the sharing system criterion of the optimal currency area (Mundell, 1961; McKinnon, 1963).

A risk sharing system could have been an automatic fiscal transfer mechanism to redistribute money to areas/sectors. This takes the form of a taxation redistribution to the less developed areas of a country/region. The EU Stability and Growth Pact does not allow fiscal transfers among the member-states. The only sustainable risk sharing system could have been the issue of a Eurobond where the EA member-states would issue common debt (Beetsma and Mavromatis, 2014) and enjoy uniform default risk.

The idea of Eurozone common bonds was initially proposed during the emergence of the sovereign debt crisis in 2010. The issuance of a single intergovernmental bond by the European monetary union (EMU) reached an ardent conflict point of lengthy debates at that period. In 2020, the spread of COVID-19 pandemic forced every EA member-state to put their economies on lockdown which provoked an asymmetric economic shock across the monetary union (Celi et al. 2020). Countries that suffered the most due to the pandemic (France, Spain, and Italy) re-proposed the issue of Eurobonds as a recovery solution. However, the resistance of the Netherlands, Finland

and Germany was intense due to the problem of moral hazard and debt mutualisation (Esteves and Tunçer, 2016).

Nowadays, each member-state persists to issue its own government bonds and enjoy different borrowing costs. Essentially, international financial markets lend to each EA member-state with differentiated interest rates by considering their creditability, the ratio of public debt to GDP, the economic growth, and other macroeconomic or political factors. The role of emergency funding has been primarily placed on the European Stability Mechanism (ESM) and auxiliary of the European Commission. The task of regular funding has been assigned to the Central governments of each member state by issuing government bonds and Treasury bills.

In the light of all this political and economic background, it becomes understood that a research lacuna exists which concerns the evolution of the financial integration of the monetary union and more particularly, the bond markets. So far (2021), the Eurozone has been integrated only with regard to monetary, economic (common currency and central bank) and banking terms (European Banking Union). Contrary, a decelerated integrated level took place in the EA financial markets during the 2010 sovereign debt crisis (Abad et al. 2014).

Christiansen (2014), Deltuvaite (2015), Lorenzo and Wolswijk (2015) have endorsed on the imperfect integration of EA bond markets before and during the 2010 sovereign debt crisis. This research was motivated from these studies in order to explore further the degree of bond markets integration in the Eurozone after the end of the sovereign debt crisis in July 2015 (Baldwin and Giavazzi, 2015). Specifically, this paper examines the level of Eurozone bond markets synchronization in three distinct countries clusters (core, periphery and east). Lastly, it presents significant findings concerning the consideration and the establishment of a Eurozone common state bond.

To answer this research query, we are based on the theory of financial integration and on its direct type. Baele et al. (2004) classified the financial integration among the categories of total, direct and indirect. Direct financial integration, which is also called as financial markets integration, is expressed in deviations from the law of one price for financial securities (Codogno et al. 2003). Under perfect direct financial integration, an investor can expect the same return on investments with similar lending costs from different markets considering risk adjustment. If the differential in expected risk-adjusted returns is greater than zero but less than or the same as the transaction cost, we mention that markets are disintegrated but are nonetheless efficient (Stavarek et al.,

2011). Liebscher et al. (2006) show that direct financial integration can take many forms and present various aspects, such as that of monetary unions. The supporters of financial markets integration indicate that this type of integration could offer more opportunities for risk sharing and risk diversification, better allocation of capital among investment opportunities and potential for higher economic development (Colacito and Croce, 2010). On the other hand, the contrarians support that bond markets integration would create misallocation of capital flows in the integrated region, risks of entry by foreign banks and pro-cyclicality of short-term capital flows (Allen and Gale, 1997).
Recent report (March 2020) of the ECB expresses that a continuous and an increasing level of financial integration has been taking place in the Euro Area the last five years (ECB, 2020). It has been estimated that the EMU presented a satisfactory level of financial integration which is continuously becoming more improved and unified.
The results of this research present a significant difference on the level of integration of the bond markets among the European Central-West (EA core), the European South (EA periphery) and the European East (EA Baltic and Slavic countries). The empirical evidence of this paper reveals that the Eurozone be conditionally apt to issue a common interstate bond.
The present research has been organized into several sections. Section 2 briefly outlines the literature review. Section 3 includes the dataset analysis, and Section 4 presents the methodology. Section 5 describes the empirical results of the methodology and Section 6 concludes the paper.

2. Literature Review

Since the establishment of the EMU, academic interest arose regarding its synchronization in monetary (Angeloni et al. 2007), business (Asimakopoulos et al. 2018, Casu et al. 2016), macroeconomic (Apergis et al. 2019) and financial terms (Seghal et al. 2017, Lindman et al. 2020). Other researchers focused on the integration level of private sector (Harm, 2001) and sovereign debt government bonds (Barr and Priestley, 2004; Panchenko and Wu, 2009; Abad et al. 2014) in the Eurozone. The relevant finance literature is quite disparate revealing different degrees of integration in the EA bond markets throughout a variety of periods. According to Georgoutsos and Migiakis (2013), an increasing level of bond markets integration occurred in the EU after the sign of Maastricht Treaty. Askari and Chatterjee (2005) provided findings regarding the financial integration and the instrumental role of euro. On the contrary, other researchers demonstrate that the 2008 financial crisis (Pozzi and Wolswijk, 2012) and the 2010 sovereign debt crisis decelerated the level of bonds markets synchronization in the monetary union (Boubakri et al. 2012; Ehrmann and Fratzscher, 2017; Grauwe and Ji, 2019). Konig and Ohr (2013) state the heterogeneities of the European economic integration. Furthermore, some researchers concentrated on the financial integration asymmetries among the Eurozone member-states. For instance, Christiansen (2014) discovered a disparately integrated level in the bond market between the old EA countries and the new EA countries. Similar evidence proposed by Deltuvaite (2015) and Lorenzo and Wolswijk (2015). Gabor and Ban (2015) suggest that the weakest EA economies be vulnerable to pro-cyclicality and collateral crises. On the other hand, other researchers present significant evidence regarding the symmetrical effects of bond markets in the Eurozone, indicating higher financial integration (Abad et al. 2010; Berben and Jansen 2009; Simovic *et al.* 2016). Eichengreen (2012) highlighted that the EMU financial disintegration occurred due to the lack of supervision and regulation of the banking and financial systems, and the domestic political and economic factors in developing bailout mechanisms. Recently, Inaba (2021) proposed that the EMU bond markets faced high degree of integration due to the free capital movements in the EU.

Nevertheless, no research addresses the level of EMU bond markets synchronization after the end of the sovereign crisis in financial terms (exploiting the commonality of bond price) by using realized data. To fill this lacuna in the literature, this manuscript attempts to introduce new evidence regarding the next stage of integration/unification in the Eurozone by transforming its form from monetary to financial.

3. Dataset Analysis

This research uses the 10-year government bond yields of eighteen EA members-states[3]. Estonia has not been included in the sample, since this EMU country has not historically issued any long-term government bonds. Particularly, three different clusters (EA core, periphery and east) are created and multivariate FCVAR and realized EGARCH models are implemented across the groups in order to examine the long-term

[3] Austria, Belgium, Luxemburg, Greece, Germany, Finland, Cyprus, Malta, France, the Netherlands, Portugal, Spain, Italy, Ireland, Latvia, Lithuania, Slovenia, and Slovakia

realized volatility and dynamic impacts on the borrowing cost of the Eurozone countries.

The dataset intraday frequency is equal to 60 minutes from 00:00 GMT 01 August 2015 to 23:00 GMT 28 February 2020. No more recent data has been included due to the outbreak of Covid-19 pandemic crisis in the beginning of March 2020. Covid-19 pandemic created higher instability and uncertainty to the financial markets. Hence, more recent data will deform the validity of the results. Realized frequency data extensively aids the exploration of the actual trading condition among the 10-year government bond yields in the EMU. The choice of dataset start point has been realized because the economic and political stability eventually returned into the monetary union, especially after the sign of the 3rd Memorandum of Understanding to Greece (mid-July 2015). The dataset of 10-year bond yields has been extracted from the Thomson Reuters Database ®.

Important milestones for the construction of the intra-day time series are the following:

- Non-trading hours: Excluded trading from the dataset from Friday 21:00:01 GMT to Sunday 20:59:59 GMT.
- Holidays: Not included bank holidays in the dataset where the trading activity is extremely low. The following bank holidays are removed; Christmas, Boxing Day, New Years' Eve, Catholic Good Friday, Catholic Easter Monday, International Workers' Day and Thanksgiving Day.
- Common sample: Selected the trading days where the state bonds are traded in order to have a common sample across each time series.
- Time zone: Greenwich Mean Time (GMT) is the time-zone in order to construct and weight the dataset.

4. Methodology

4.1 Realized Volatility (RV)

We consider the observed dependent variable (state yields) log-price at trading day t and j intraday point as $\log(P_{tj})$. For $j=1,\ldots,\tau$ equidistant intervals at each trading 60 min-intervals. Andersen and Bollerselv (1998) proposed a procedure in order to estimate the daily realized volatility which is calculated as the sum of squared intraday returns:

$$DRV_t^{(\tau)} = \sqrt{\sum_{j=1}^{\tau} \left(\log P_{t_j} - \log P_{t_{j-1}}\right)^2} \ (1)$$

The realized volatility assembles in probability to the integrated volatility, $IV_t \equiv \int \sigma^2(t)dt$, as the number of sub-intervals tend to infinity, $\tau \to \infty$. Nevertheless, the microstructure frictions add more noise to the estimated volatility when the sampling frequency converges on zero. Thus, it takes place a trade-off between the bias that is embed in the realized volatility measure and its precision.

4.2 Fractional unit root test

Fractional processes with the order of integration d>0.5 are non-stationary. Standard unit root tests often reject the null hypothesis when the true process is fractionally integrated with $d \in (0.5, 1)$. This can lead to the misleading conclusion that the process is stationary.

We used the fractional unit root test of Chang and Perron (2017) by assuming deterministic time trend without structural change in mean. We consider the time series of our variables y_t, as consisting of a deterministic component (f_t) and fractionally integrated errors. The data-generating process is specified as:

$$y_t = f_t + u_t \ (2)$$

Where $ft \ = \mu + \psi * t$

μ is the constant, ψ represents the coefficient on a time trend (t) and $u_t = \Delta^{-1}\eta_t 1_{t\geq 1}, t = 0, \pm 1, \pm 2, \ldots,$ η_t is a short-memory zero mean covariance stationary process.

The short-memory zero-mean covariance stationary process η_t is assumed to be independent and identically distributed (i.i.d.) with zero mean and finite. Under this assumption, the Lagrange Multiplier test LM_t defined by:

$$LM_T = \sqrt{T}\sqrt{\frac{6}{\pi^2}}\frac{\left(\sum_{t=1}^{T}((-log\Delta\widetilde{\Delta y_t})\widetilde{\Delta y_t}\right)}{\sum_{t=1}^{T}\left(\widetilde{\Delta y_t}\right)^2} \ (3)$$

$With\ T \to +\infty, LM_t \overset{d}{\to} N(0,1)$

According to Chang and Perron (2017), the fractional unit root test shows the following advantages:

(i) it imposes a symmetric treatment on the nature of the deterministic trend under both the null and the alternative hypotheses.
(ii) distinguishing long memory from structural change is not required.
(iii) the power of fractional unit root tests can be substantially improved when a break is actually present.

4.3 Fractional Co-integration

A process is integrated of order d, denoted by I(d), if its k^{th} difference has a spectral density:

$$\boldsymbol{f(\lambda) \sim C|\lambda|^{-2(d-k)}, \lambda \to 0, (4)}$$

Where C >0, and k is a non-negative integer such that $d-k<1/2$. Here, d is the memory parameter. An I(d) process without deterministic trends is weakly stationary if d <1/2 and nonstationary otherwise. We mention that {Xt}and{Yt}are fractionally cointegrated if both processes are I(d) where a linear combination exists there Ut=Yt−βXt, such that{Ut} is I(dU), with $d_U< d$. Fractional cointegration is a generalization of standard cointegration, where d=1 and $d_U= 0$. Both fractional and standard cointegration were originally defined simultaneously in Engle and Granger (1987). Standard cointegration allows only integer values for the memory parameter while tests for the existence of cointegration rely on unit root theory. The fractional cointegration framework is more general since it allows the memory parameter to take fractional values and $d-d_U$ to be any positive real number (Dolatabadi et al. 2015). Fractional cointegration analysis often focuses on the reduction of the memory parameter from $d\geq1/2$ to $d_U<1/2$, since cointegration is commonly considered as a stationary relationship between non-stationary variables; but cases, where d <1/2 are also of interest, particularly if one wishes to study fractional cointegration in volatility. Robinson (1994) noted that for 0<d<1/2, the ordinary least square estimator will in general be inconsistent in the presence of correlation between {Xt},{Ut}, and he counterproposed a narrow-band least squares estimator (NBLSE) of β in the frequency domain.

4.4 Fractionally Cointegrated Vector Autoregression (FCVAR)

Johansen (2008) introduced the FCVAR model to check for multivariate fractional cointegration. This model was firstly utilized by Johansen and Nielsen (2010; 2012; 2016) and its benefits are emphasized by Caporin *et al.* (2013). A recent implementation was actualized by Gil-Alana and Carcel (2020).

The FCVAR model permits long memory (fractional integration) in the equilibrium errors. It enables the existence of long-run backwardation or contango in the equilibrium as well, i.e. a non-unit cointegration coefficient (Figuerola-Ferretti and Gonzalo, 2010).

FCVAR is relied on the Cointegrating VAR (CVAR) model of Johansen (1995) which allows for fractional processes of order d that cointegrate to order d-b. Letting Y_t, t=1,…T be a k-dimensional I(1) time series, the CVAR model is:

$$\Delta \boldsymbol{Y_t} = \boldsymbol{\alpha\beta' L Y_t} + \sum_{i=1}^{k} \boldsymbol{\Gamma_i} \Delta \boldsymbol{L^i Y_t} + \boldsymbol{\varepsilon_t} \quad (5)$$

By replacing the difference and lag operator Δ and L in (5) with their fractional counterparts Δ^b and $L_b = 1 - \Delta^b$, respectively (Johansen 2008). We attain:

$$\Delta^b \boldsymbol{Y_t} = \boldsymbol{\alpha\beta' L_b Y_t} + \sum_{i=1}^{k} \boldsymbol{\Gamma_i} \Delta^b \boldsymbol{L_b^i Y_t} + \boldsymbol{\varepsilon_t} \quad (6)$$

And with $Y_t = \Delta^{d-b} x_t$, equation (6) becomes:

$$\Delta^d \boldsymbol{X_t} = \boldsymbol{\alpha\beta' L_b} \Delta^{d-b} \boldsymbol{X_t} + \sum_{i=1}^{k} \boldsymbol{\Gamma_i} \Delta^b \boldsymbol{L_b^i Y_t} + \boldsymbol{\varepsilon_t} \quad (7)$$

Where α and β kxr matrices with rank r, where 0 ≤ r ≤ k. The elements of $\beta' x_t$ are the cointegrating relationships in the system, where r represents the number of long-run equilibrium relationships, i.e. the cointegration or co-fractional rank. The parameters Γi govern the short-run dynamics. The coefficients in matrix α shows the speed of adjustment towards equilibrium for each of the variables in response to shocks. Δ^d the fractional operator, and L_b is the fractional lag operator defined as above. The fractional parameter d is the order of integration of the individual time series and d - b (with b < 0) is the degree of fractional cointegration, the fractional integration order of $\beta' X_t$ which is lower compared to that of itself. Alternatively, fractional cointegration hypothesizes the presence of a common stochastic trend which is integrated of order d, and the short-term departures from the long-run equilibrium being integrated of order d-b (Johansen and Nielsen 2012).

The model presents cointegration and adjustment towards equilibrium. However, it is more general, as it incorporates fractional integration and cointegration. X_t are integrated of d order, and b is the strength of the cointegrating relations (a higher means less persistence in the cointegrating relations; can also be named the cointegration gap).

4.5 The Exponential Realized GARCH model (R-EGARCH)

According to Hansen and Huang (2012), an Exponential Realized GARCH is structurally more improved than the Realized GARCH (Hansen *et al.* 2012). This happens because the model shows three advantages:

- Shares the simple structure of GARCH while simultaneously keeping some characteristics (leverage effect, skewness and kurtosis) of the stochastic volatility (SV) models.
- Improves the empirical fit of data and provides better forecasting performance in comparison with the GARCH models.
- Enables observation insights on the properties (accuracy, bias, variance) of different realized measures.

According to Hansen and Huang (2012), a Realized EGARCH with N realized measures is given by the following equations:

$$\log(h_t) = \omega + \theta \log(h_{t-1}) + r(z_{t-1}) + \zeta u_{t-1} \quad (8)$$

$$\log(x_{n,t}) = \xi_n + \varphi \log(h_t) + \delta_n(z_t) + u_{n,t}, n = 1, \ldots, N \quad (9)$$

Where, θ is the persistence parameter, $\delta(z_t)$ is the leverage effect and $r(z_{t-1}) + \zeta u_{t-1}$ captures the volatility shock. φ parameter has the restriction to be close to unity.

5. Empirical Evidence

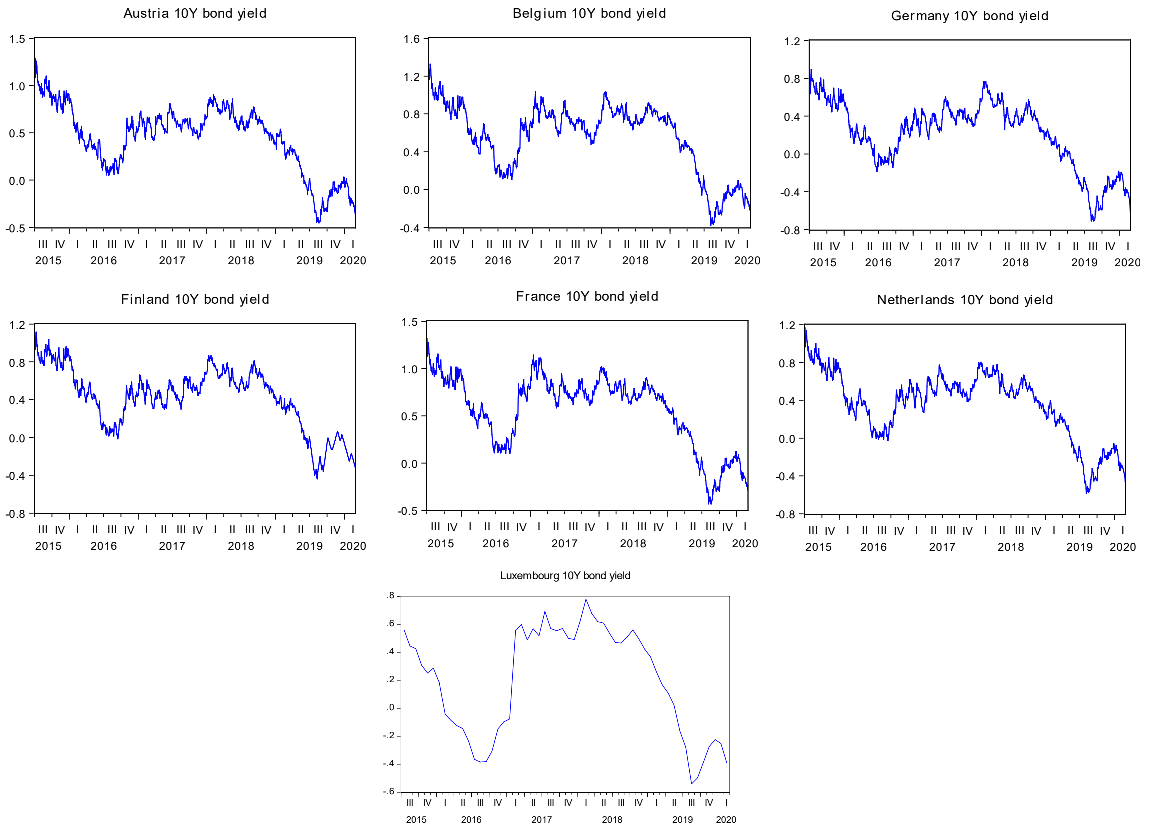
Firstly, the historical tendency of the government 10-year bond yield for every EA country is displayed. Secondly, the empirical evidence of preliminary diagnostics tests (fractional unit root test, Chang and Perron, 2017), the implementation of FCVAR (Johansen, 2008) and the realized EGARCH (Hansen and Huang, 2012) ensue.

The FCVAR multivariate model incorporates the short-term and long-term dynamic relationships between the independent and dependent variables and their equilibria. The estimation of the long-term linkages shows the level of integration in the long-run, which is an important parameter in order to answer the research aims. This model allows the investigation of the interdependence of different bond markets in a single unified model. The use of realized EGARCH examines the persistence level and the asymmetrical effect of the realized long-term volatility among the variables. Realized volatility is the actual movement that occurs in a given underlying over a defined past period (Degiannakis and Floros, 2015).

FCVAR is used as a mean equation and the realized EGARCH as a conditional variance equation, respectively (Stoupos and Kiohos, 2021). This model provides with the opportunity to isolate the realized long-term volatility (Clements and Hendry, 2011) which also constitutes a necessary interest of our research. Realized long-term volatility can express the reaction and the impact of the independent variables on the dependent variable in the long-run, from the realized volatility aspect of view. The use of errors in the mean equation offers information about the realized volatility persistence and causality of volatility asymmetry (leverage effect) in the long-run (Degiannakis and Floros, 2015).

Three different groups were created by considering similar characteristics of the EMU member-states. The first group (core) includes the strongest economies of the monetary union (Germany, France, Austria, Belgium, Finland, the Netherlands, and Luxembourg). Typically, the core states are characterized as the most resistant EA economies against the external financial shocks. The latter occurs because these countries traditionally show sound fiscal administration. The second group (periphery) contains the peripheral EA countries (Cyprus, Greece, Ireland, Italy, Malta, Portugal, and Spain) which are economically more vulnerable than the core once.

Figure 1: Timeline of EA core 10Y bond yields[4]



Source: Thomson Reuters Database ®

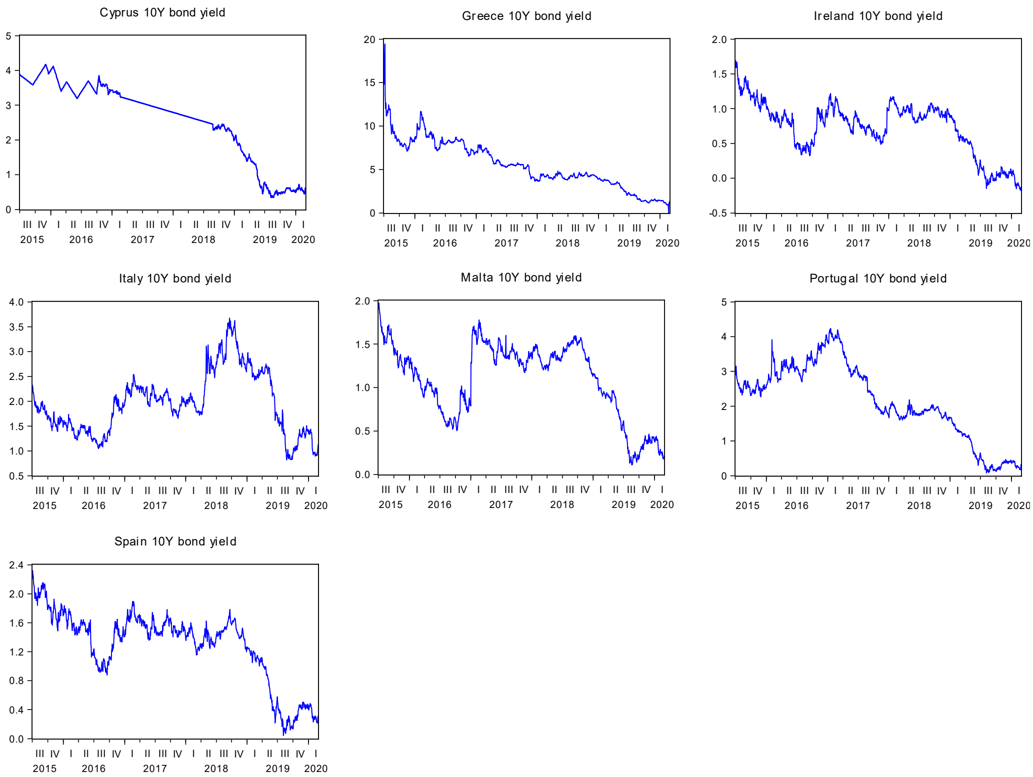
The susceptibility of their economies was revealed during the period of 2010 sovereign debt crisis. The most of these countries, except Italy and Malta, had signed memoranda of understanding in order to shake out their economies. The third group consists of EA eastern countries (Lithuania, Latvia, Slovenia, and Slovakia). These EA countries have started to follow Keynesian economics after their independence in 1990/1991. These states are the only new EU member-countries that successfully met the fiscal convergence criteria (low public debt and deficit) of Maastricht Treaty for a long period.

Figure 1,2 and 3 present the historical tendency of EA 10-year government bond yields from 01/08/2015 to 28/02/2020. The EA core state bond yields seem to be synchronized by following the same tendency. The EA periphery and east 10Y government bond yields are partially synchronized. Spanish and Irish 10Y borrowing cost seems to follow

[4] Differences at figure line of Luxembourg occur due to low trading volume.

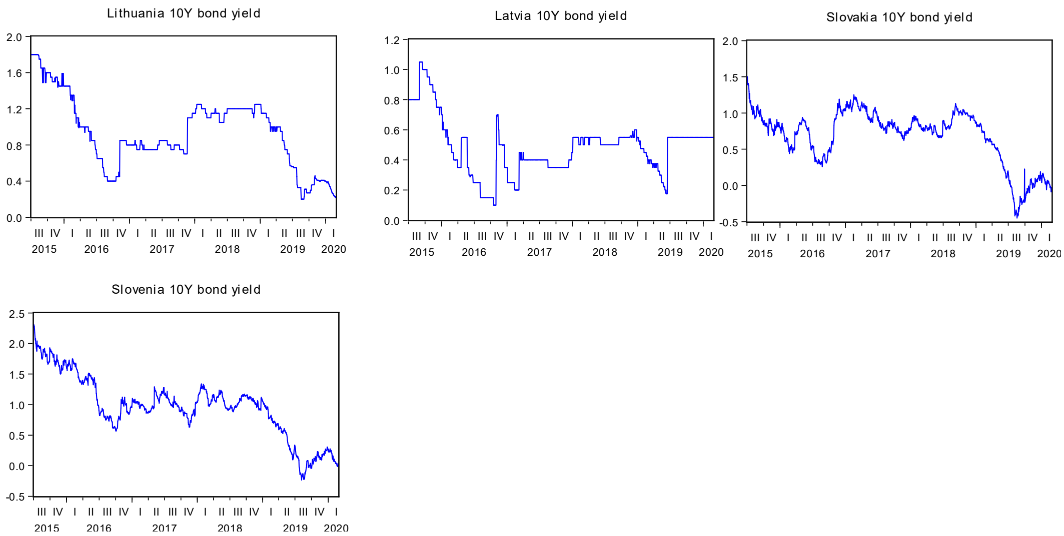
similar trend. Latvia presents a quite different behavior. However, this may be related to the low trading volume of Latvian government bond at the bond markets.

Figure 2: Timeline of EA periphery 10Y bond yields[5]



Source: Thomson Reuters Database ®

Figure 3: Timeline of EA eastern countries 10Y bond yields[6]



Source: Thomson Reuters Database ®

---

[5] Differences at figure line of Cyprus occur due to low trading volume.
[6] Differences at figure line of Lithuania and Latvia occur due to low trading volume.

5.1 Fractional unit root and co-integration test results

The results of fractional unit root test (Chang and Perron, 2017) show that the time series of the variables are non-stationary (statistically significance a=0.01) according to the value of the Lagrange Multiplier test.

Table 1: Chang and Perron fractional unit root test results			
Countries	**Variables**	**Order of integration (d)**	**LM_T***
Austria	AT10Y	**1.049**	12.98
Belgium	BE10Y	**1.034**	15.69
Luxemburg	LU10Y	**0.999**	24.22
France	FR10Y	**1.018**	22.31
Italy	IT10Y	**0.949**	9.91
Spain	ES10Y	**1.022**	10.63
Greece	GR10Y	**0.988**	21.10
Cyprus	CY10Y	**0.971**	27.78
Finland	FI10Y	**1.009**	32.13
Malta	MT10Y	**1.031**	23.74
Slovakia	SK10Y	**0.984**	17.71
Slovenia	SI10Y	**1.009**	9.69
Portugal	PT10Y	**0.931**	25.52
Netherlands	NL10Y	**1.005**	29.38
Ireland	IE10Y	**1.048**	35.37
Latvia	LV10Y	**1.028**	14.16
Lithuania	LT10Y	**0.953**	9.88
Germany	DE10Y	**1.002**	27.53

Notes: *level of significance, a=0.01 (test critical value $LMt_c = 9.49$)

Firstly, we should determine lag, k, and rank of the multivariate FCVAR systems (7 variables in core, 7 variables in periphery and 4 variables in east). A general-to-specific testing strategy of lag length in Table 2 unveils that the null hypothesis of zero lag was failed to accept until k=2 was reached according to Akaike criterion (AIC). The likelihood ratio (LR) test statistic for each k with a p-value supports that for k=2, the p values are below 5% (p_1=0.023, p_2=0.014, p_3=0.035). The parameter d for k=2 is 1.015 for EA core FCVAR model, 0.998 for EA periphery FCVAR model and 0.951 for EA east FCVAR model.

Table 2: Lag-selection in the FCVAR models						
Clusters	**k**	**r**	**d**	**LR**	**P-value***	**AIC**
EA Core	3	7	0.975	176.45	0.381	-794.09
	2	7	1.015	329.98	0.023	*-862.41*
	1	7	1.042	512.32	0.000	-777.84

	0	7	1.121	0.00	0.000	-819.22
	k	**r**	**d**	**LR**	**P-value***	**AIC**
EA Periphery	3	7	0.882	219.33	0.399	-764.38
	2	7	0.998	384.09	0.014	*-877.37*
	1	7	1.013	555.76	0.000	-826.10
	0	7	1.067	0.00	0.000	-855.98
	k	**r**	**d**	**LR**	**P-value***	**AIC**
	3	4	0.642	164.88	0.446	-687.11
EA East	2	4	0.951	327.85	0.035	*-747.98*
	1	4	0.987	497.72	0.000	-711.24
	0	4	1.029	0.00	0.000	-735.85

Notes: *level of significance, a=0.05

Before implementing the cointegration rank determination by Johansen and Nielsen (2010) of the FCVAR model, it would be interesting the compare the results of Cointegrated VAR (CVAR) (Johansen, 1995). The CVAR was executed assuming linear deterministic trend (intercept and trend in co-integration equations and no intercept in VAR).

Table 3: CVAR Johansen (1995) results					
	Rank	**Eigenvalue**	**Trace statistic**	**Critical Value**	**P-value***
EA Core	**0**	0.074107	266.8410	139.2753	0.0000
	1	0.049164	173.3669	107.3466	0.0000
	2	0.034856	112.1653	79.34145	0.0000
	3	0.025477	69.09560	55.24578	0.0019
	4	0.019053	39.76617	35.01090	0.0047
	5	0.009061	19.41217	18.39771	0.0667
	6	0.002765	3.261439	3.841466	0.1653
EA Periphery	**Rank**	**Eigenvalue**	**Trace statistic**	**Critical Value**	**P-value***
	0	0.057563	183.6445	139.2753	0.0000
	1	0.030857	111.6118	107.3466	0.0055
	2	0.019336	84.52978	79.34145	0.0065
	3	0.015744	56.80700	55.24578	0.0083
	4	0.012433	35.52642	35.01090	0.0095
	5	0.009709	16.52520	18.39771	0.0625
	6	0.002852	3.270648	3.841466	0.1279
EA East	**Rank**	**Eigenvalue**	**Trace statistic**	**Critical Value**	**P-value***
	0	0.027513	72.12127	55.24578	0.0008
	1	0.021136	38.25302	35.01090	0.0017
	2	0.007237	16.31945	18.39771	0.0613
	3	0.002880	3.101586	3.841466	0.2860

Note: Number of lags =2. We reject the null hypothesis that Rank=0 for every group according to the Trace Statistic (TRS). Level of significance, a=0.01.

Table 3 presents the estimation of the cointegrated VAR model. This model suggests that there are five (5) co-integrated vectors in EA core and periphery group, and two (2) co-integrated vectors in EA east at a level of significance a=0.01, according to the trace statistic.

Table 4: Cointegration rank determination by Johansen and Nielsen (2010)				
	Rank	**d**	**LR statistic**	**P-value***
EA Core	**0**	0.881	198.17	0.000
	1	0.793	177.41	0.000
	2	0.712	148.88	0.000
	3	0.684	126.54	0.000
	4	0.641	99.32	0.000
	5	0.627	76.86	0.001
	6	0.603	51.71	0.023
	7	0.582	33.87	0.089
EA Periphery	**Rank**	**d**	**LR statistic**	**P-value***
	0	0.814	172.43	0.000
	1	0.793	143.29	0.000
	2	0.732	107.30	0.000
	3	0.685	96.99	0.000
	4	0.636	77.85	0.000
	5	0.611	47.90	0.039
	6	0.598	31.68	0.097
	7	0.571	20.17	0.289
EA East	**Rank**	**d**	**LR statistic**	**P-value***
	0	0.778	100.52	0.000
	1	0.714	78.93	0.000
	2	0.686	53.08	0.001
	3	0.628	28.62	0.105
	4	0.581	16.38	0.458

Note: Number of lags =2. We reject the null hypothesis that Rank=0 for every group according to the Likelihood Ratio (LR). Level of significance, a=0.01.

Table 4 unveils that the null hypothesis of rank 0 against rank r (r=7 for EA core, r=7 for EA periphery and r=4 for EA east). In terms of the selection of ranks, a series of likelihood ratio (LR) tests were conducted. The results of cointegration rank test (Johansen and Nielsen, 2010) supports that there are six (6) cointegrated vectors at EA core[7], five (5) cointegrated vectors at EA periphery[8] and two (2) cointegrated vectors at EA East group[9] for a level of significance a=0.01. The FCVAR and CVAR estimation shows similar findings, except EA core (one more co-integrated vector).

[7] EA core time series datasets move together, fluctuating around a long-run equilibrium (co-integration), except Luxemburg.

[8] Similar findings exist for EA periphery time series, except Greece and Portugal.

[9] Similar findings exist for EA east time series, except Lithuania and Latvia.

The FCVAR model presents better estimation of the co-integrated vectors than the typical CVAR. According to Johansen and Nielsen (2018), the FCVAR model shows plenty of advantages when estimating a system of fractional time series variables that are potentially cointegrated. The flexibility of the model permits one to determine the cointegrating rank, or number of equilibrium relations, via statistical tests and to jointly estimate the adjustment coefficients and the cointegrating relations, while accounting for the short-run dynamics. Therefore, we consider the estimation of cointegration rank test (Johansen and Nielsen, 2010) in order to implement the multivariate FCVAR models and search for co-integration dynamics.

5.2 FCVAR results[10]

This part presents the multivariate FCVAR empirical evidence of three examined groups (EA core, periphery and east). The results are displayed in clusters. FCVAR models of each group include only the co-integrated vectors. In each step, we check the residuals for serial correlation using a multivariate Ljung-Box Q-test, $Q_{\varepsilon}(h)$, with h = 24 lags because our realized data has hourly frequency (24 hours per day). The estimated value of the fractional cointegration order d demonstrating the existence of long-memory in the variables system. It indicates that while there exists a long-run relationship in the system, the equilibrium errors induced by occurred shocks to the target variables exhibit slow reversion to zero, i.e. error corrections towards the equilibrium are slow and thus deviations from equilibrium are highly persistent over time featured by long-memory. This means that the effect of a shock to the EA core/periphery/east bond yields potential from the rest EA bond yields of each relevant group does not transmit instantly but rather is highly persistent, which might be caused by the delay in the behavior investors at the EA bond markets.

Table 5 displays the results of FCVAR models for EA core. The estimation results for k = 2 and r = 6 are shown in (10,12,14,16,18,20) with the corresponding equilibrium relations in (11,13,15,17,19,21). Also, it is presented the d estimate for each model with the equivalent standard error in parenthesis. The residuals appear well-behaved with no evidence of serial correlation; the Ljung- Box Q-test of each model has a significant high P value (over 5%) (reported in brackets).

[10] The calculation of FCVAR estimations was executed according to Matlab program user's guide for the FCVAR (Nielsen and Popiel, 2018).

Table 5: FCVAR models for EA Core

$$FCVAR\ Austria: \Delta^d \begin{bmatrix} Austria_t \\ Belgium_t \\ Germany_t \\ France_t \\ Finland_t \\ Netherlands_t \end{bmatrix} - \begin{bmatrix} 1.249 \\ 1.122 \\ 0.797 \\ 0.977 \\ 0.868 \\ 0.821 \end{bmatrix} = L_d \begin{bmatrix} -0.0547 \\ -0.0634 \\ -0.0103 \\ -0.0133 \\ -0.0349 \\ -0.1009 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t \ (10)$$

$$d = 0.607, \quad Q_\varepsilon(24) = 120.263\ , logL = 297.106$$

(0.085) [0.682]

Equilibrium relation:

$$Austria_t = -0.0051 - 0.0075 * Belgium_t + 0.1827 * Germany_t + 0.1285 * France_t + 0.013 * Finland_t + 0.083 * Netherlands_t + v_t \ (11)$$

(0.0012) (0.026) (0.047) (0.028) (0.037) (0.018)

$$FCVAR\ Belgium: \Delta^d \begin{bmatrix} Belgium_t \\ Austria_t \\ Germany_t \\ France_t \\ Finland_t \\ Netherlands_t \end{bmatrix} - \begin{bmatrix} 1.031 \\ 0.931 \\ 0.629 \\ 0.966 \\ 0.817 \\ 0.738 \end{bmatrix} = L_d \begin{bmatrix} -0.0352 \\ -0.0229 \\ -0.0126 \\ -0.0149 \\ -0.0446 \\ -0.0147 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t \ (12)$$

$$d = 0.675, \quad Q_\varepsilon(24) = 126.459\ , \quad logL = 240.054$$

(0.123) [0.466]

Equilibrium relation:

$$Belgium_t = -0.0054 + 0.0267 * Austria_t + 0.1251 * Germany_t + 0.1163 * France_t - 0.007 * Finland_t + 0.0626 * Netherlands_t + v_t (13)$$

(0.0019) (0.0029) (0.045) (0.032) (0.059) (0.0078)

$$FCVAR\ Germany: \Delta^d \begin{bmatrix} Germany_t \\ Austria_t \\ Belgium_t \\ France_t \\ Finland_t \\ Netherlands_t \end{bmatrix} - \begin{bmatrix} 0.523 \\ 0.852 \\ 0.908 \\ 0.703 \\ 0.781 \\ 0.744 \end{bmatrix} = L_d \begin{bmatrix} -0.0499 \\ -0.0763 \\ -0.0716 \\ -0.0184 \\ -0.0288 \\ -0.0060 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t \ (14)$$
$d = 0.549$, $Q_\varepsilon(24) = 124.653$, $logL = 265.567$
(0.074) [0.751]
Equilibrium relation:
$Germany_t = 0.00208 + 0.0083 * Austria_t + 0.0027 * Belgium_t + 0.0632 * France_t + 0.0477 * Finland_t + 0.0530 * Netherlands_t + v_t \ (15)$
(0.00159) (0.0024) (0.007) (0.018) (0.047) (0.0067)
$$FCVAR\ France: \Delta^d \begin{bmatrix} France_t \\ Austria_t \\ Belgium_t \\ Germany_t \\ Finland_t \\ Netherlands_t \end{bmatrix} - \begin{bmatrix} 1.021 \\ 0.869 \\ 0.974 \\ 0.604 \\ 0.865 \\ 0.775 \end{bmatrix} = L_d \begin{bmatrix} -0.0847 \\ -0.1039 \\ -0.0074 \\ -0.0732 \\ -0.0347 \\ -0.0091 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t \ (16)$$
$d = 0.711$, $Q_\varepsilon(24) = 122.405$, $logL = 266.685$
(0.131) [0.555]
Equilibrium relation:
$France_t = 0.00243 - 0.0105 * Austria_t + 0.0306 * Belgium_t + 0.0688 * Germany_t + 0.0674 * Finland_t + 0.0667 * Netherlands_t + v_t \ (17)$
(0.00158) (0.0236) (0.0334) (0.0256) (0.0479) (0.0232)

$$\boldsymbol{FCVAR\ Finland}: \Delta^d \left(\begin{bmatrix} Finland_t \\ Austria_t \\ Belgium_t \\ Germany_t \\ France_t \\ Netherlands_t \end{bmatrix} - \begin{bmatrix} 0.721 \\ 0.825 \\ 0.861 \\ 0.543 \\ 0.925 \\ 0.735 \end{bmatrix} \right) = L_d \begin{bmatrix} -0.0648 \\ -0.0871 \\ -0.0091 \\ -0.0291 \\ -0.0058 \\ -0.0129 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t \quad (18)$$
$d = 0.554$, $Q_\varepsilon(24) = 127.255$, $logL = 280.583$
(0.091) **[0.836]**
Equilibrium relation:
$$Finland_t = -0.00546 + 0.0135 * Austria_t - 0.007 * Belgium_t + 0.1399 * Germany_t + 0.0865 * France_t + 0.0531 * Netherlands_t + v_t \quad (19)$$
(0.0014) (0.0022) (0.0243) (0.0541) (0.0229) (0.0056)
$$\boldsymbol{FCVAR\ Netherlands}: \Delta^d \left(\begin{bmatrix} Netherlands_t \\ Austria_t \\ Belgium_t \\ Germany_t \\ France_t \\ Finland_t \end{bmatrix} - \begin{bmatrix} 0.794 \\ 0.899 \\ 0.974 \\ 0.635 \\ 0.991 \\ 0.844 \end{bmatrix} \right) = L_d \begin{bmatrix} -0.0475 \\ -0.1062 \\ -0.0061 \\ -0.0449 \\ -0.0313 \\ -0.0765 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t \quad (20)$$
$d = 0.518$, $Q_\varepsilon(24) = 122.428$, $logL = 274.455$
(0.076) **[0.631]**
Equilibrium relation:
$$Netherlands_t = -0.00086 - 0.0037 * Austria_t + 0.0285 * Belgium_t + 0.1332 * Germany_t + 0.0560 * France_t + 0.0033 * Finland_t + v_t \quad (21)$$
(0.0007) (0.0221) (0.0029) (0.0468) (0.0211) (0.0045)

Notes: The table shows FCVAR estimation results for EA core countries, including only the cointegrated vectors. Standard errors in parentheses below every parameter and P values are in brackets below Q_ε, Level of significance a=0.01. Luxembourg is not included at the models (no co-integration).

In the left-hand-side of (10,12,14,16,18,20), the numbers in the vector describe the level parameter (mu) of the FCVAR models. In the right-hand-side, the estimated adjustment coefficients α are shown in the vector preceding v_t, which is the stationary long-run equilibrium. The coefficients that characterize the long-run equilibrium are normalized with respect to each dependent variable (EA core country bond yield) and presented in (11,13,15,17,19,21) respectively, with the constant term. This relation suggests that especially the bond yields of Germany, France, Austria and Netherlands show a positive impact on the bond yields of each EA core country. The effect of German and French bond yields seems to be higher than the yields of the rest core countries. Finally, the impact of Belgian and Finnish bond yields seems to be quite minor and partial. The estimates of Γi are suppressed since it is concerned only with long-run dynamics. The estimation results show a significant level of integration at the bond markets in the EA core.

Table 6 presents the results of FCVAR models for EA periphery. The estimation results for k = 2 and r = 5 are shown in (22,24,26,28,30) with the corresponding equilibrium relation in (23,25,27,29,31). The residuals appear well-behaved with no evidence of serial correlation; the Ljung- Box Q-test of each model has a significant high P value (over 5%).

Table 6: FCVAR models for EA Periphery
$$\boldsymbol{FCVAR\ Cyprus}: \Delta^d \begin{bmatrix} Cyprus_t \\ Ireland_t \\ Italy_t \\ Malta_t \\ Spain_t \end{bmatrix} - \begin{bmatrix} 2.771 \\ 1.108 \\ 1.891 \\ 2.438 \\ 1.356 \end{bmatrix} = L_d \begin{bmatrix} -0.0015 \\ -0.0049 \\ -0.0046 \\ -0.0042 \\ -0.0015 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (22)$$
$d = 0.718$, $Q_\varepsilon(24) = 127.818$, $logL = 290.794$
(0.200) **[0.651]**
Equilibrium relation:
$Cyprus_t = -0.0023 + 0.0455 * Ireland_t + 0.121 * Italy_t - 0.0003 * Malta_t + 0.0191 * Spain_t + v_t$ (23)

(0.0006) (0.017) (0.0118) (0.0201) (0.0024)
$FCVAR\ Ireland: \Delta^d \begin{bmatrix} Ireland_t \\ Cyprus_t \\ Italy_t \\ Malta_t \\ Spain_t \end{bmatrix} - \begin{bmatrix} 1.172 \\ 2.717 \\ 1.874 \\ 1.292 \\ 1.332 \end{bmatrix} = L_d \begin{bmatrix} -0.0139 \\ -0.0252 \\ -0.0044 \\ -0.0053 \\ -0.0052 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (24)$
$d = 0.551, \quad Q_\varepsilon(24) = 125.949, \quad logL = 240.055$
(0.101) [0.540]
Equilibrium relation:
$Ireland_t = -0.0018 + 0.0053 * Cyprus_t + 0.0849 * Italy_t + 0.0206 * Malta_t + 0.0233 * Spain_t + v_t\ (25)$
(0.0010) (0.0015) (0.0178) (0.0323) (0.0036)
$FCVAR\ Italy: \Delta^d \begin{bmatrix} Italy_t \\ Cyprus_t \\ Ireland_t \\ Malta_t \\ Spain_t \end{bmatrix} - \begin{bmatrix} 2.313 \\ 3.349 \\ 1.070 \\ 1.732 \\ 1.877 \end{bmatrix} = L_d \begin{bmatrix} -0.0224 \\ -0.0217 \\ -0.0177 \\ -0.0010 \\ -0.0019 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (26)$
$d = 0.946, \quad Q_\varepsilon(24) = 134.820, \quad logL = 174.314$
(0.175) [0.771]
Equilibrium relation:
$Italy_t = -0.0011 + 0.0191 * Cyprus_t + 0.0221 * Ireland_t + 0.0582 * Malta_t + 0.1097 * Spain_t + v_t\ (27)$
(0.00168) (0.0029) (0.004) (0.0534) (0.0299)
$FCVAR\ Malta: \Delta^d \begin{bmatrix} Malta_t \\ Cyprus_t \\ Italy_t \\ Ireland_t \\ Spain_t \end{bmatrix} - \begin{bmatrix} 1.286 \\ 2.885 \\ 1.776 \\ 0.697 \\ 1.599 \end{bmatrix} = L_d \begin{bmatrix} -0.0023 \\ -0.0145 \\ -0.0018 \\ -0.0228 \\ -0.0027 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (28)$

$d = 0.833,\qquad Q_{\varepsilon}(24) = 141.076\,,\qquad logL = 264.349$
(0.074) **[0.884]**
Equilibrium relation:
$Malta_t = -0.0009 - 0.0264 * Cyprus_t + 0.0919 * Italy_t + 0.0889 * Ireland_t + 0.0768 * Spain_t + v_t\ (29)$
(0.0008) **(0.0036)** **(0.0144)** **(0.0147)** **(0.0295)**
$FCVAR\ Spain{:}\ \Delta^d \begin{bmatrix} Spain_t \\ Cyprus_t \\ Ireland_t \\ Italy_t \\ Malta_t \end{bmatrix} - \begin{bmatrix} 1.145 \\ 1.556 \\ 0.832 \\ 1.342 \\ 0.878 \end{bmatrix} = L_d \begin{bmatrix} -0.0144 \\ -0.0008 \\ -0.0002 \\ -0.0244 \\ -0.0026 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (30)$
$d = 0.719,\qquad Q_{\varepsilon}(24) = 134.177\,,\qquad logL = 230.625$
(0.051) **[0.773]**
Equilibrium relation:
$Spain_t = -0.0021 + 0.0461 * Cyprus_t + 0.0671 * Ireland_t + 0.0718 * Italy_t - 0.0107 * Malta_t + v_t\ (31)$
(0.0011) **(0.0489)** **(0.0275)** **(0.0193)** **(0.0329)**

Notes: The table shows FCVAR estimation results for EA periphery countries, including only the cointegrated vectors. Standard errors in parentheses below every parameter and P values are in brackets below Q_{ε}. Level of significance a=0.01. Greece and Portugal are not included at the models (no co-integration).

In the right-hand-side of (22,24,26,28,30), the estimated adjustment coefficients α are shown in the vector preceding v_t. The coefficients that characterize the long-run equilibrium are normalized with respect to each dependent variable (EA periphery country bond yield) and presented in (23,25,27,29,31) respectively. This relation suggests that especially the bond yields of Italy, Ireland, Spain and partially Cyprus show a positive impact on the bond yields of each EA periphery country. The impact of Italian bond yields seems to be higher than the yields of the rest periphery countries. The effect of Maltese bond yields seems to be quite minor and limited. The estimates of Γi are suppressed since we are concerned only with long-run dynamics. The estimation findings show a satisfied level of integration at the bond markets in the EA periphery.

Table 7 shows the results of FCVAR models for EA east. The estimation results for k = 2 and r = 2 are shown in (32 and 34) with the corresponding equilibrium relation in (33 and 35). The residuals appear well-behaved with no evidence of serial correlation; the Ljung- Box Q-test of each model has a significant high P value (over 5%).

Table 7: FCVAR models for EA East
$\boldsymbol{FCVAR\ Slovenia}: \Delta^d \begin{bmatrix} Slovenia_t \\ Slovakia_t \end{bmatrix} - \begin{bmatrix} 1.928 \\ 1.118 \end{bmatrix} = L_d \begin{bmatrix} -0.0176 \\ -0.0261 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (32)$
$d = 0.435,\quad Q_\varepsilon(24) = 135.140,\quad logL = 241.415$
(0.032) **[0.917]**
Equilibrium relation:
$Slovenia_t = -0.0018 + 0.0641 * Slovakia_t + v_t\ (33)$
(0.0010) **(0.0266)**
$\boldsymbol{FCVAR\ Slovakia}: \Delta^d \begin{bmatrix} Slovakia_t \\ Slovenia_t \end{bmatrix} - \begin{bmatrix} 1.555 \\ 0.757 \end{bmatrix} = L_d \begin{bmatrix} -0.0012 \\ -0.0002 \end{bmatrix} v_t + \sum_{i=1}^{2} \Gamma_t \Delta^d L_d^i (X_t - \mu) + \varepsilon_t (34)$
$d = 0.560,\quad Q_\varepsilon(24) = 181.472,\quad logL = 231.716$
(0.023) **[0.996]**
Equilibrium relation:

$\boldsymbol{Slovakia_t = -0.0015 + 0.0397 * Slovenia_t + v_t}$ **(35)**
(0.0011) (0.012)

Notes: The table shows FCVAR estimation results for EA Eastern countries, including only the cointegrated vectors. Standard errors in parentheses below every parameter and P values are in brackets below Q_ε. Level of significance a=0.01. Latvia and Lithuania are not included at the models (no co-integration).

In the right-hand-side of (32 and 34), the estimated adjustment coefficients α are shown in the vector preceding ν_t. The coefficients that characterize the long-run equilibrium are normalized with respect to each dependent variable (EA east country bond yield) and presented in (33 and 35) respectively. This relation suggests that especially the bond yields of Slovenia and Slovakia show an equivalent and positive impact on the bond yields of each EA east country. The estimates of Γi are suppressed since we are concerned only with long-run dynamics.

5.3 Realized EGARCH results

The realized EGARCH model is more suitable for realized data (Hansen and Huang, 2012). Furthermore, it produces more precise results in juxtaposition to the original EGARCH model (Nelson and Cao, 1992). The following table (8) presents the empirical findings of the realized EGARCH emphasizing on the realized volatility shock, volatility persistence and leverage effect. The errors of the FCVAR models were used at the realized EGARCH in order to explore the features of the long-term realized volatility. No co-integrated EA countries were not included at this analysis. The results of the Realized EGARCH highlights that the φ coefficient value be high and close to unity for each EA core government bond. This indicates high volatility yields persistence against the shocks of the EA core bond yields in the bond markets. The volatility persistence of each EA periphery state bond is high for the majority of member-states, except for Italy. This demonstrates medium-to-low volatility persistence of Italian bonds against the shocks of the EA periphery bond yields. The volatility shock effect (r+ζ) is positive for each EA country.

Table 8: Realized EGARCH model estimation results Euro Area (with no ω constant term)						
Group	**Parameters**	**Volatility Shock effect (r+ζ)**	**Persistence parameter (φ)**	**Constant (ξ)**	**Restriction parameter (θ)**	**Leverage effect (δ)**
EA Core	**Austria**	0.611 (49.25)*	0.981 (38.09)*	-0.526 (-2.68)*	0.856 (12.02)*	-0.342 (-23.91)*
	Belgium	1.352 (50.75)*	0.904 (50.12)*	-1.127 (-80.77)*	0.895 (15.80)*	-0.815 (-34.23)*
	Finland	0.419 (26.26)*	0.965 (37.39)*	-0.455 (-26.89)*	0.922 (10.31)*	-0.306 (-25.59)*
	France	0.468 (25.54)*	0.999 (110.07)*	-0.303 (-35.04)*	0.954 (14.12)*	-0.259 (-15.07)*
	Germany	0.650 (63.17)*	1.00 (167.33)*	-0.325 (-55.65)*	0.981 (22.34)*	-0.226 (-27.94)*
	Netherlands	1.415 (80.14)*	0.924 (44.40)*	-1.025 (-78.50)*	0.987 (6.38)*	-0.418 (-32.16)*
EA Periphery	**Cyprus**	0.274 (12.42)*	0.995 (77.69)*	-0.239 (-10.55)*	0.911 (2.31)*	-0.089 (-8.58)*
	Ireland	0.149 (7.66)*	0.971 (122.33)*	-0.315 (-4.92)*	0.942 (6.22)*	-0.002 (-2.25)*
	Italy	1.619 (86.62)*	0.729 (213.06)*	-1.743 (-14.84)*	0.918 (3.37)*	-1.658 (-90.79)*
	Malta	0.144 (14.72)*	0.999 (121.23)*	-0.098 (-11.33)*	0.970 (3.31)*	-0.072 (-9.57)*
	Spain	0.294 (12.77)*	0.969 (239.37)*	-0.432 (-10.60)*	0.926 (6.75)*	-0.115 (-7.91)*
EA East	**Slovakia**	0.106 (20.19)*	0.999 (61.52)*	-0.026 (-7.31)*	0.950 (3.81)*	-0.162 (-34.97)*
	Slovenia	0.466 (31.23)*	0.979 (62.66)*	-0.388 (-21.64)*	0.993 (9.11)*	-0.183 (-19.53)*

Notes: *statistically significant at 0.05 level

This signifies that, once the asymmetric impact of innovations is accounted for, the absolute size of the innovation also becomes important. The leverage effect (δ) is negative for each EA country implying that positive shocks suggest a higher next period conditional variance than the negative shocks of the same sign. For instance, the good news of the EA periphery bond yields (yields increase) shows an approximately 166% greater impact than the bad news of the EA periphery bond yields (yields fall) on the Italian government bond yields. The restriction parameter (θ) is close to unity producing the conclusion that a realized EGARCH can be applicable.

Figure 4: Realized Volatility Response of EA core 10Y government bonds

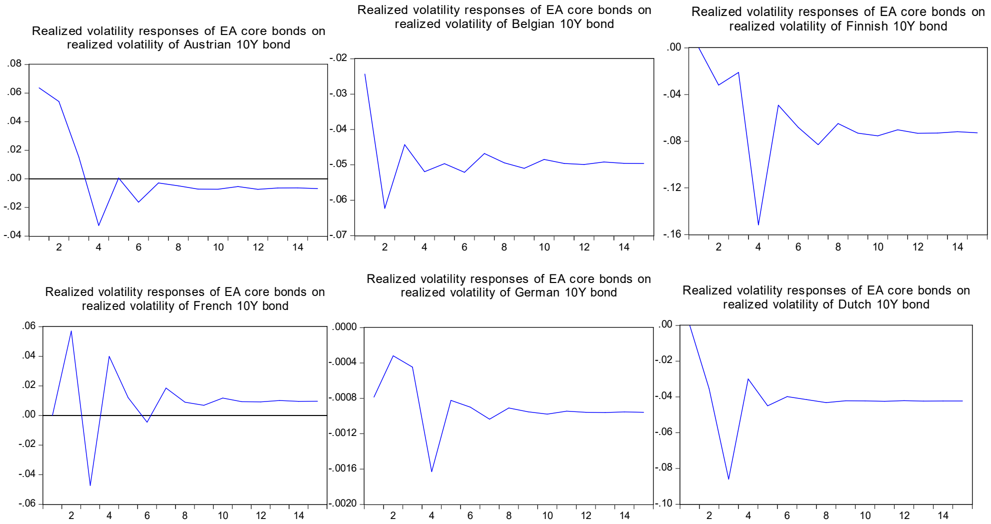
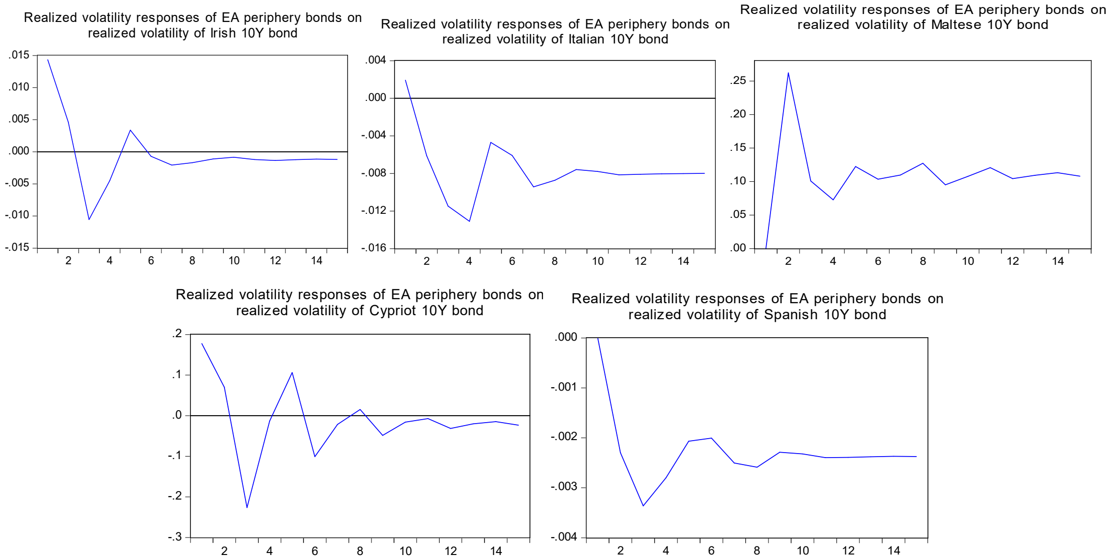


Figure 4, 5 and 6 show the realized volatility responses of the co-integrated EA bond yields on the realized volatility of each EA member-state bond yields. Realized volatility impact of 15 continuous periods indicating that one period is equal to 1 trading hour. EA core bonds realized volatility impact is negative for each EA core country. The signal of the EA core bonds responses fades for each EA core country after 6 trading hours. For instance, the realized volatility of German government bond yields is anemically influenced by the volatility of the rest EA core bond yields.

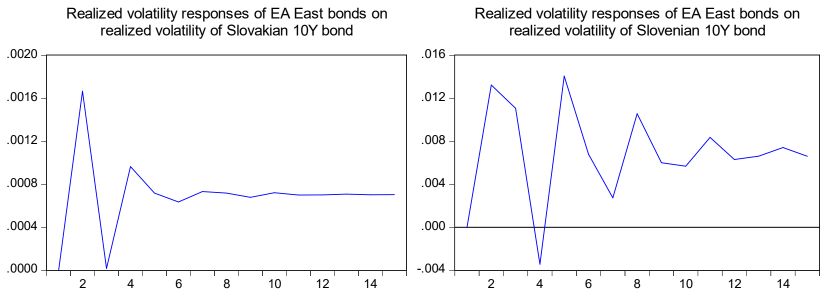
EA periphery bonds realized volatility impact is positive for each EA periphery country. The signal of the EA periphery responses is different across each EA periphery member (It fades after 8 hours for Ireland, after 10 hours for Spain and Italy, after 12 hours for Malta and Cyprus). The impact of the EA periphery bonds yields on the Cypriot bond yield is 10 times stronger than the effect on the Maltese bonds and 100 stronger than the impact on the Irish, Italian, or Spanish bonds.

Figure 5: Realized Volatility Response of EA periphery 10Y state bonds



Lastly, EA east bond realized volatility effect is positive for Slovenia and Slovakia. The signal of the EA east bonds responses fades after approximately 6 trading hours, except Slovenia (14 hours). The effect of the EA east bonds yields on the Slovakian bond yield is 10 times weaker than the effect on the Slovenian bond yields.

Figure 6: Realized Volatility Response of EA east 10Y government bonds



Firstly, this paper finds out that the EA core displays sounder degree of integration in the bond markets. Luxemburgish bond market is not integrated with the rest of EA core. This outcome is justified since Luxembourg is an international financial center with a special tax status. The trading volume of Luxembourg bonds are lower than the rest EA core countries due to the low national debt that was issued. Therefore, it is quite reasonable to assume that its bond market is more globally integrated than the European once (Nardo et al., 2017). Another finding is the leading role of France, Germany, Austria and the Netherlands regarding the integration degree of EA core bond markets.

Secondly, it is observed that the EA periphery level of integration is varied. Greek and Portuguese bond markets show no degree of synchronization with the rest EA peripheral countries. This may happen because investors appraise that the long-term default risk of this country be higher than the one of the rests of the EA peripheral countries. The credit ratings of Greece (BB- or B1)[11] and Portugal (BBB or Baaa3)[11] also play an instrumental role. Hence, the bond yields will be vulnerable against the changes of the EA periphery bond yield. For instance, an increase on the EA periphery borrowing cost will significantly raise the Greek or the Portuguese borrowing cost as the retention of these bonds are riskier. Consequently, investors will either rebalance their bond portfolio towards a direction of less risk EA state bonds or will demand higher compensations (yields) in order to keep the state bonds of the most vulnerable EA economies on hold. Additionally, the absence of integration in the Greek and Portuguese bond markets may happen because these countries suffered the most austerity measures in the EA periphery for a long period during the previous decade. However, the results show the leading role of Spain, Ireland and especially Italy in the integration of EA periphery bond markets.

Thirdly, the bond markets of Lithuania and Latvia are not integrated with the rest EA east. This might occur since these countries are the most recent members of the Eurozone[12]. These countries typically show low trading volume at the bond markets due to their low national debt. Consequently, their bond markets did not have sufficient time to get integrated with rest EA east states. One minor observation is that there is no evidence for a leading country on the EA east bond markets. Thus, it is assumed that the EA periphery and east bond markets have potentials for further integration in the next mid-term period.

Regarding the realized volatility, the government yields of the periphery are more vulnerable to the bond yields shocks of the cluster that they belong to. Consequently, the long-term volatility of the borrowing cost will be higher due to the bonds trading activity in primary and secondary financial markets. The realized volatility responses of the EA core state bond yields communicate an almost neutral impact on the German and French bond yields. This occurs since investors characterize the state bonds of these countries as the safest bond investment in the Eurozone.

---

[11] According to credit ratings of S&P, Fitch Ratings and Moody's

[12] Lithuania joined the Eurozone on 1 January 2015. Latvia adopted the euro on 1 January 2014.

6. Conclusion

The purpose of this research is to explore the level of integration of the bond markets in the Eurozone after the end of the 2010 sovereign debt crisis. The empirical results clearly acknowledge that the Eurozone bond markets show a significant degree of integration but plenty of asymmetries can also be observed across the examined groups (core, periphery, east). The EA core government bond yields are more solid and integrated, in terms of realized dynamics and volatility, in comparison to the bond yields of the EA periphery and east countries. It was revealed the leading role of Germany, France and the Netherlands in the EA core. The EA periphery and east bond markets seem to be partially synchronized. Italy, Spain and Ireland possess a principal role in the EA periphery bond markets. Also, Slovenia and Slovakia are financially integrated. Overall, from a predominantly financial perspective, we suggest that the EA countries are conditionally apt to issue a common EMU bond. This paper proposes that their level of integration is steadily accelerated, comparing with the findings of previous studies (Christiansen 2014; Deltuvaite 2015; Lorenzo and Wolswijk 2015). Lastly, a Eurozone mutual bond would strengthen the cohesion of the monetary union and would assist the financial stability of the Euro Area leading to the next stage of its integration.

Acknowledgements

We are particularly grateful to the two anonymous referees and the editors of *Journal of Common Market Studies* for their beneficial comments which highly improved the quality of our research. In addition, we would like to thank Prof. Christos Nikas (University of Macedonia, Greece) for his guidance during the first revision of this manuscript. Finally, we acknowledge Prof. Morten Ørregaard Nielsen (Queen's University, Canada) for his valuable discussion on the FCVAR methodology.

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Reinforcement of Postdoctoral Researchers - 2nd Cycle" (MIS-5033021), implemented by the State Scholarships Foundation (IKY).

Ευρωπαϊκή Ένωση
European Social Fund

Operational Programme
Human Resources Development, Education and Lifelong Learning
Co-financed by Greece and the European Union

ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη

References

- Abad, P., Chulia, H. & Gomez-Puig M. (2010). EMU and European government bond market integration. *Journal of Banking and Finance*, 34(12), 2851-2860.
- Abad, P., Chulia, H. & Gomez-Puig M. (2014). Time-varying integration in European government bond markets. *European Financial Management*, 20(2), 270-290.
- Allen, F. & Gale, D. (1997). Financial Markets, Intermediaries and Intertemporal Smoothing, *Journal of Political Economy*, 105, 523-546.
- Andersen, T.G., & Bollerslev, T. (1998). Answering the Skeptics: Yes, Standard Volatility Models Do Provide Accurate Forecasts. *International Economic Review*, 39 (4), 885-905.
- Angeloni, I., Flad, M. & Mongelli, F.P. (2007). Monetary Integration of the New EU Member States: What Sets the Pace of Euro Adoption?. *Journal of Common Market Studies.* 45(2), 367-409.
- Apergis, E., Apergis, I. & Apergis, N. (2019). A new macro stress testing approach for financial realignment in the Eurozone. *Journal of International Financial Markets, Institutions and Money*, 61, 52-80.
- Asimakopoulos, G., Chortareas, G. & Xanthopoulos, M. (2018). The eurozone financial crisis and bank efficiency asymmetries: Peripheral versus core economies. *Journal of Economic Asymmetries*, 18, e00099.
- Askari, H. & Chatterjee, J. (2005). The euro and financial market integration. *Journal of Common Market Studies*. 43(1), 1-11.
- Baele, L., Ferrando A., Hördahl P., Krylova E. & Monnet C. (2004). Measuring Financial Integration in the Euro Area. *Oxford Review of Economic Policy*, 20(4), 509-530.
- Baldwin, R & Giavazzi, F. (2015). *Eurozone Crisis: A Consensus View of the Causes and a Few Possible Solutions*. Centre for Economic Policy Research Press: London.
- Barr, D. & Priestley, R. (2004). Expected returns, risk and the integration of international bond markets. *Journal of International Money and Finance*. 23 (1), 71-97.
- Berben, R.P. & Jansen, W.J. (2009). Bond market and stock market integration in Europe: a smooth transition approach. *Applied Economics*, 41 (24), 3067-3080.
- Beetsma, R.& Mavromatis, K. (2014). An analysis of eurobonds. *Journal of International Money and Finance*, 45, 91-111.
- Boubakri, S., Couharde, C. & Guillaumin, C. (2012). Assessing the financial integration of Central and Eastern European countries with the euro area: Evidence from panel data cointegration tests. *International Economics*, 131, 105-120.

- Caporin, M., Ranaldo, A. & Santucci de Magistris, P. (2013). On the predictability of stock prices: a case for high and low prices. *Journal of Banking and Finance*, 37(12), 5132–5146.
- Casu, B., Ferrari, A., Girardone, C. & Wilson, J. (2016). Integration, productivity and technological spillovers: Evidence for eurozone banking industries. *European Journal of Operational Research*, 255(3), 971-983.
- Celi, G., Guarascio, D. & Simonazzi, A. (2020). A fragile and divided European Union meets Covid-19: further disintegration or 'Hamiltonian moment'?. *Journal of Industrial and Business Economics*, 47, 411-424.
- Chang, S.Y. & Perron, P. (2017). Fractional Unit Root Tests Allowing for a Structural Change in Trend under Both the Null and Alternative Hypotheses, *Econometrics, MDPI, Open Access Journal*, 5(1), 1-26.
- Chari, V.V., Dovis, A. & Kehoe, P. (2020). Rethinking Optimal Currency Areas. *Journal of Monetary Economics*. 111, 80-94.
- Christiansen, C. (2014). Integration of European bond markets. *Journal of Banking and Finance*, 42, 191-198.
- Clements, M. & Hendry, D. (2011). *The Oxford Handbook of Economic Forecasting*. Oxford: Oxford University Press.
- Codogno, L., Favero, C. & Missale, A. (2003). Yield spreads on EMU government bonds, *Economic Policy*, 18(37), 503–532.
- Colacito, R., & Croce, M. (2010). The Short and Long Run Benefits of Financial Integration. *American Economic Review*, 100 (2), 527-31.
- Degiannakis, S., & Floros, C. (2015). *Modelling and forecasting high frequency financial data*. London: Palgrave MacMillan.
- Deltuvaite, V. (2015). Investigation of Global Integration of the Central and Eastern European Countries Sovereign Bond Markets. *Procedia Economics and Finance*, 24, 182-191.
- Dolatabadi, S., Nielsen, M., & Xu, K. (2016). A fractionally cointegrated VAR model with deterministic trends and application to commodity futures markets. *Journal of Empirical Finance*, 38B, 623-639.
- Ehrmann, M. & Fratzscher, M. (2017). Euro area government bonds – Fragmentation and contagion during the sovereign debt crisis. *Journal of International Money and Finance,* 70, 26-44.
- Eichengreen, B. (2012). European monetary integration with benefit of hindsight. *Journal of Common Market Studies*, 50(S1), 123-136.
- Engle, R. & Granger C. (1987). Co-integration and error correction: Representation, estimation and testing. *Econometrica*, 55(2), 251-276.
- Esteves R. P. & Tunçer A. C. (2016). Eurobonds Past and Present: A Comparative Review on Debt Mutualization in Europe. *Review of Law & Economics*, De Gruyter, 12(3), 659-688.
- European Central Bank. (2020). *ECB Financial Integration and Financial Structures Report.* Published online on 03 March 2020.

https://www.ecb.europa.eu/pub/fie/html/ecb.fie202003~197074785e.en.html#toc1

- Figuerola-Ferretti, I. & Gonzalo J. (2010). Modelling and measuring price discovery in commodity markets. *Journal of Econometrics*, 158, 95–107.
- Gabor, D. & Ban, C. (2015). Banking on Bonds: The New Links Between States and Markets. *Journal of Common Market Studies.* 54 (3), 617-635.
- Gil-Alana, L.A. & Carcel, H. (2020). A fractional cointegration var analysis of exchange rate dynamics. *North American Journal of Economics and Finance*, 51, 100848.
- Georgoutsos, D. & Migiakis, P. (2013). European sovereign bond spreads: financial integration and market conditions. *Journal of Applied Financial Economics*, 23(20), 1609-1621.
- Grauwe, P. & Ji, Y. (2019). Making the Eurozone Sustainable by Financial Engineering or Political Union?. *Journal of Common Market Studies,* 57 (S1) 40-48.
- Hafner, K. & Jager, J. (2013). The Optimum Currency Area Theory and the EMU. *Intereconomics*, 48 (5), 315-322.
- Harm, C. (2001). European financial market integration: the case of private sector bonds and syndicate loans. *Journal of International Financial Markets, Institutions and Money*, 11 (3-4), 245-263.
- Hansen, P.R., & Huang, Z. (2012). Exponential GARCH Modeling With Realized Measures of Volatility. *Journal of Business & Economic Statistics, 34*(2), 269-287.
- Hansen, P. R., Huang, Z., & Shek, H. H. (2012). Realized GARCH: a joint model for returns and realized measures of volatility. *Journal of Applied Econometrics, 27*(6), 877-906.
- Inaba, K.I. (2021). An empirical illustration of the integration of sovereign bond markets. *Journal of Multinational Financial Management*. In press.
- Johansen, S. (1995). *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. New York: Oxford University Press.
- Johansen, S. (2008). A representation theory for a class of vector autoregressive models for fractional processes. *Econometric Theory*, 24, 651-676.
- Johansen, S. & Nielsen, M.O. (2010). Likelihood inference for a nonstationary fractional autoregressive model. *Journal of Econometrics*, 158, 51-66.
- Johansen, S. & Nielsen, M.O. (2012). Likelihood inference for a fractionally cointegrated vector autoregressive model. *Econometrica*, 80, 2667-2732.
- Johansen, S. & Nielsen, M.O. (2016). The role of initial values in conditional sum-of-squares estimation of nonstationary fractional time series models. *Econometric Theory*, 32 (5), 1095-1139.
- Johansen, S. & Nielsen, M.O. (2018). Testing the CVAR in the Fractional CVAR model. *Journal of Time Series Analysis*, 39(6), 836-849.

- Jones, M., Nielsen, M.O. & Popiel, M.K. (2014). A fractionally cointegrated VAR analysis of economic voting and political support. *Canadian Journal of Economics*, 47(4), 1079-1130.
- Konig J. & Ohr, R. (2013). Different efforts in European Economic Integration: Implications of the EU Index. *Journal of Common Market Studies,* 51(6), 1074-1090.
- Liebscher, K., Christl, J., Peter Mooslechner, P. & Ritzberger-Grünwald, D. (2006). *Financial development, integration and stability: evidence from Central, Eastern and South-Eastern Europe, Cheltenham*: Edward Elgar Publishing.
- Lindman, S., Tuvhag, T., Jayasekera, R., Uddin, G.S. & Troster, V. (2020). Market Impact on financial market integration: Cross-quantilogram analysis of the global impact of the euro. *Journal of Empirical Finance*, 56, 42-73.
- McKinnon, R. (1963). Optimum Currency Areas. *The American Economic Review , 53*(4), 717-725.
- Mundell, R. (1961). A Theory of Optimum Currency Areas. *American Economic Review*, 657-665.
- Nardo, M., Ndacyayisenga, N., Papanagiotou, E., Rossi, E. & Ossala, E. (2017). Measures and drives of financial integration in Europe. JRC Science for Policy Report – European Commission. 1-97. ISSN 1831-9424.
- Nielsen, M. & Popiel, M.K. (2018). "A Matlab Program and User's Guide For The Fractionally Cointegrated Var Model," Working Paper 1330, Economics Department, Queen's University, Canada.
- Panchenko, V. & Wu, E. (2009). Time-varying market integration and stock and bond return concordance in emerging markets. *Journal of Banking and Finance*, 33 (6), 1014-1021.
- Pozzi, L. & Wolswijk, G. (2012). The time-varying integration of euro area government bond markets. *European Economic Review*, 56 (1), 36-53.
- Robinson, P.M. (1994). Efficient tests of nonstationary hypotheses. *Journal of American Statistical Association*, 89, 1420-1437.
- Seghal, S., Gupta, P. & Deisting, F. (2017). Assessing time-varying stock market integration in Economic and Monetary Union for normal and crisis periods. *The European Journal of Finance.* 23(11), 1025-1058.
- Simovic, P., Tkalec, M., Vizek, M. & Lee, J. (2016). Time-varying integration of the sovereign bond markets in European post-transition economies. *Journal of Empirical Finance*, 36, 30-40.
- Stavarek, D., Repkova, I. & Gajdosova, K. (2011). *Theory of financial integration and achievements in the European Union*. MPRA Paper 34393, University Library of Munich, Germany.
- Stoupos, N. & Kiohos, A. (2021). BREXIT referendum's impact on the financial markets in the UK. *Review of World Economics*, 157, 1-19.