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Co-movement of German Bond Market with European Bond Markets: An Application of Wavelet and Network Analysis

Abstract

This paper employs the wavelet method and network analysis method to investigate dynamic correlations between Germany's 10-year sovereign bond market and leading 10-year government bond markets of the UK, France, Italy, and Spain in Europe from June 2016 to May 2021. The results of wavelet analysis suggest a strong coherence between underlying pairs of government bonds markets on a high scale for the pandemic year 2020 and 2021. However, no such co-movement has been observed between the markets for the period before 2020. The network analysis results also substantiate these findings of wavelet analysis, which reveals that the sovereign bond markets of Germany and other European countries remain decoupled for most of the period except the short period affected by the Covid pandemic in 2020. Thus, the absence of regional interdependence between the government bond markets provides portfolio diversification opportunities to international investors for the normal period. However, for the crisis period, the investors should be wary of the influence of the German government bond market while managing investment portfolios.

Keywords: *Sovereign bond market, Germany, Europe, Co-movement, Contagion, Wavelet analysis.*

JEL Classification Code: G12, D40, B23

1. Introduction

Interdependence among the financial markets is a significant aspect of risk measurement and management. It is an important tool for understanding the impact and contagiousness of the financial crisis on the financial markets. The interdependence between the markets can be in the form of long-term relationships, short-term linkages, or sudden linkages due to reaction to some common macroeconomic factors. The co-movement of financial markets during an economic crisis has been defined as financial contagion in the literature (Corsetti, Pericoli, &

Sbracia, 2005; BenMim & BenSaïda, 2019; Cheng & Zhao, 2019). In more complex financial markets like fixed income securities, the interdependence among the markets can spread very swiftly throughout the global system with devastating consequences. Besides this, the size of government bond markets is enormously large compared to the equity markets. Therefore, the financial contagion among the bond markets during the financial crisis is likely to have more significant implications for the portfolio managers.

The co-movement of the markets does not offer the desired benefit of portfolio diversification to the portfolio managers, and their portfolios become more vulnerable to financial developments in other markets. Therefore, the study of financial contagion in the bond markets is vital for constructing a well-diversified portfolio and risk mitigation. It also helps in analysing whether diversification works during the period of crisis when it is most required.

Over the years, the sovereign bond markets have increased manifolds, and the increased interest in the sovereign bond markets has raised some critical questions. Variations in economic policies of the nations, governance system, national culture, and other aspects of the institutional framework in different countries may lead to different bond holding risk profiles and yield (Nguyen, 2012), yet the pandemic effect overrides all these differences. Empirical studies in the literature have held that financial, institutional, economic policy uncertainty, interventions by regulators affect the spread of sovereign bond yields and lead to financial contagion in different markets across the globe (Silvapulle et al., 2016; Ehrmann & Fratzscher, 2017; Youssef, Mokni & Ajmi, 2021; Karkowska & Urjasz, 2021; Singh, Roca & Li, 2021; Janus, 2021).

The extant literature on the connectedness between the European financial markets reflects that the connectedness became more profound since the unveiling of the European Monetary Union (EMU) in 1999. The introduction of the euro in 2002 further strengthened the volatility spillover in European markets, mainly for the EMU countries, and Global Financial Crisis (GFC) in 2008 also saw its impact (Christiansen, 2007; Cipollini et al., 2015). Financial integration is a mechanism to smooth shocks (Chen et al., 2018). The Covid pandemic offers an opportunity to test this cointegration premise. The study from Ehrmann et al., (2011) have reported substantial convergence in euro-area sovereign bond markets. However, (Claeys & Vašíček, 2014) opine that the underlying cause of the frequent surges in market co-movement is the shock of the crisis.

Therefore, through this research, we intend to find an answer to the following questions:

1. Are the European sovereign bond markets contagious to each other?
2. Are these markets more sensitive to the recent pandemic effect of 2020 and 2021?

The primary purpose of this study is to examine the co-movement of the German bond market with other major European bond markets. The inferences and the new knowledge have important implications for the participants of sovereign bond markets. In addition, analyzing the relationships between different bond markets also provides valuable information to the regulators about the critical international macroeconomic variables (Andersson, Krylova & Vähämaa, 2008). The present study has used a novel wavelet analysis approach to demonstrate that the German bond market along with France, Italy and Spain have high power on the medium-scale (32-64 days) and low power on a small scale (16-32 days). Surprisingly, the UK bond market is witnessed with high power on both medium and large scale during 2018 and 2020-21 but low power on a small scale. Additionally, the cross-wavelet transform reveals that there is an in-phase movement (i.e., former leading the later) between the pairs of markets for the 2020, at the end of medium-scale (32-64 days) and at the beginning of large scale (64-128 days). Wavelet coherency shows strong coherence in high scale (64-128 days) during 2020, indicating a greater degree of interdependence during that period. The result of network analysis encapsulates that there is no interdependence between German and other bond markets. Further, the co-movement between German and other European markets is temporary and is present for a short period which coincides with the period of the COVID-19 pandemic during 2020 and 2021. This paper provides new insights into the co-movement in the European sovereign bond markets during the COVID-19 pandemic, which is still evolving.

Our study makes important contribution to the existing literature in three ways. First, our paper employs wavelet analysis to examine the interdependence structure of European bond markets on several time scales, which is an important factor of financial integration. Second, it examines the relationship between these bond markets using a novel network analysis tool without dividing different time scales. Third, the majority of the studies exploring financial contagion focus on the dynamics in equity markets, and studies in the bond markets are insufficient (see BenSaïda, 2018; Sensoy et al., 2019). Finally, our analysis considers the impact of the COVID-19 global pandemic, which is a global event of recent origin characterized by high turbulence and uncertainty everywhere (Papadamou et al., 2021). The findings and contributions of this study, therefore, are beneficial for investors and portfolio managers. Investors Park their hard-earned money through safe investment alternatives. One of the critical factors for investment is risk mitigation. With the help of co-movement among various markets, one can easily identify whether there is a possibility of portfolio diversification or not.

The rest of the paper have been categorized as follows: Section 2 furnishes extensive literature related to co-movement from one capital market to another market. Section 3 provides data and econometric models followed by empirical analysis in section 4. Finally, the discussion is provided in section 5, while the conclusion and policy implication are presented in section 6.

2. Literature review

A large strand of empirical studies exploring the interdependencies of financial markets during the stress periods has emerged at the global level in the last decade (Mensi et al., 2016). Most of these studies examine the effect of GFC of 2008, Eurozone crisis on the connectedness across different asset classes (e.g., Claeys & Vašíček, 2014; Cronin, Flavin & Sheenan, 2016; Caporin et al., 2018; Mensi et al., 2016; Andrada-Félix, Fernandez-Perez & Sosvilla-Rivero, 2018; Bourie et al., 2021). They also demonstrate that the crises strengthen the cross-market linkages and affect asset allocation for portfolio diversification (Brière, Chapelle & Szafarz, 2012; Papadamou et al., 2021; Pang et al., 2021). In addition, several studies are evident on the connectedness structures of the sovereign bond market and European countries market (e.g., Longstaff, 2010; Syllignakis & Kouretas, 2011; Beetsma et al., 2013; Claeys & Vašíček 2014; Cipollini, & Lee, 2015; Broto & Perez-Quiros, 2015; Ehrmann & Fratzscher, 2017; Caporin et al., 2018; BenSaïda, 2018; Philippas & Siriopoulos, 2013; Alexakis & Pappas, 2018; Dewandaru, Masih & Masih, 2018; Kosmidou, Kousenidis, Ladas & Negkakis, 2019; Augustin et al., 2021).

The literature suggests that European bond markets are more vulnerable to regional risk factors than domestic and global factors (Abad, Chuliá, and Gómez-Puig, 2010; Christiansen, 2007; Deltuvaitė, 2015). Previous empirical analysis has also found structural dependence between the European bond markets (Philippas & Siriopoulos, 2013; Karkowska & Urjasz, 2021). Further, it is evident that the integration of government bond markets is stronger for EMU than non-EMU countries (Christiansen, 2014; Claeys & Vašíček, 2014; Ters & Urban, 2018). The asymmetric nature of interdependence in the bond markets in Europe is also reflected by the fact that bond markets of Central and Eastern Europe (CEE) are less connected than European Countries (EU) countries, which is attributed to the low credit rating of CEE countries. The financial integration of European bond markets is not perfect and regional integration is higher than global integration (Deltuvaitė, 2015; Karkowska & Urjasz, 2021). the impact of the global financial crisis (GFC) of 2008 and sovereign debt crisis of Europe (2009-2011) has not been uniform, and spillover in EMU is reported to be higher due to fiscal trouble and differences in bilateral linkages of the economies (Claeys & Vašíček, 2014; Ters & Urban, 2018). Caporin et al., 2018 analyzed the sovereign risk shift-contagion in bond markets for the major eurozone countries by employing quantile regressions. In their study, they find that the spread of shocks in the euro's bond yield spreads does not provide any evidence of shift-contagion during the financial crisis. The primary reason for risk spillover is the sovereign debt and fiscal conditions of the individual countries. In other study, Yang and Hamori (2014), while using copula-based models, find a higher degree of financial integration and dependence between the bond markets of Poland, the Czech Republic, Hungary, and Germany from 2000 to 2012. Still, surprisingly, the dependency between the bond markets decreased during the crisis period. Cronin et al., 2016, in their study exploring contagion in Eurozone sovereign bond markets, also find that evidence of contagion is insufficient, and interdependence is the more common determinant of market co-movements. The study Bayraci, Demiralay, & Gencer, (2018), while using wavelet coherence analysis, negated these results and found that interdependencies in the bond markets are more potent at lower frequencies and it rose during the period of GFC. Evidence of herding contagion, i.e., sharp and concurrent rise in the sovereign yield of European countries, has also been reported by Beirne & Fratzscher (2013). It has also been observed that effective government interventions reduce the uncertainty in the local sovereign bond markets (Cevik, & Öztürkkal, 2020; Zaremba, Kizys & Aharon, 2021). The co-movement between the returns of bond markets has been explored by employing different linear and non-linear time series techniques, VAR decomposition approaches, multivariate DCC-GARCH models, Markov regime-switching models, VMD copula, vine copula approach, MVMQ-CAViaR; network filtering methods and wavelet coherence analysis, etc. (e.g. Ramsey & Lampart, 1998; Nguyen, 2012; BenSaïda, 2018; Yang, Yang, Ho, & Hamori, 2020; Papadamou et al., 2021; Pang et al., 2021; Jareño, Escribano & Koczar, 2021).

From the analysis of the existing recent literature, it can be unarguably stated that the impact of the financial crisis has been concentrated in time and limited to a few markets only, and the underlying literature is still evolving. There are limited studies that have examined the interdependencies among the sovereign bond markets of Europe at different timescales. In our study, we bridge this vital gap in the existing knowledge by employing a novel wavelet coherence analysis technique to study the interdependencies of sovereign bond markets of Europe at different timescales for the COVID-19 pandemic period.

3. Data and Econometric Model

3.1. Data

Data for the study has been collected from the Bloomberg databases covering the period from June 2016 to May 2021. The daily closing values of the bond prices are converted into continuous compounded returns by taking the natural logarithmic differences of the daily prices: $R_t = ln\left(\frac{P_t}{P_{t-1}}\right)$ where R_t is the return on day 't'; $P_t \, and \, P_{t-1}$ are the prices on day t and day t-1, respectively. The primary motivation for selecting these markets is to investigate the presence of regional effects in Europe. The markets included in the study are the five largest economies of Europe, and our study examines the interdependence between the largest bond markets of Europe, i.e., Germany, with sovereign bond markets of the UK, France, Italy, and Spain. These markets have an established efficient bond market in Europe and represent the region effectively. The government bonds of Germany are sovereign bonds that are similar to treasuries in the United States. Further, government bonds referred to as "Gilts" in the UK are the investment vehicles that provide a fixed rate of return till their maturity. These bonds are in the form of a loan from the bondholder to the government. Similarly, the French government bonds (also called obligations assimilables du Trésor or fungible Treasury bonds) are used for the government's medium and long-term borrowing, with maturities ranging from two to fifty years. Italian bond market is represented by different state, municipal and Italian corporate bonds, which are issued for different maturity periods. Spanish government securities are represented by STRIPS, treasury bills (with the maturity of 3, 6, 9, or 12 months), medium-term bonds (interest-bearing securities with the maturity of 2-5 years), long-term bonds (interest-bearing securities with the maturity more than five years).

Table 1: Description of the German and select European bond market

Sovereign Bond Markets	Asset	Source
Germany	The 10-year yield of Government Bond of Germany	Bloomberg
United Kingdom (UK)	The 10-year yield of Government Bond of UK	Bloomberg
France	The 10-year yield of Government Bond of France	Bloomberg
Italy	The 10-year yield of Government Bond of Italy	Bloomberg
Spain	The 10-year yield of Government Bond of Spain	Bloomberg

Source: Authors' Construction

3.2. Econometric Model

The study employs wavelet and network analysis to investigate the relationship between the German bond market and other European bond markets. Wavelet analysis has been used extensively in the literature to determine the frequency connectedness of financial markets at different periods (Loh, 2013; Aguiar, 2014; Nasreen, Tiwari, Eizaguirre & Wohar, 2013; Sharif, Aloui & Yarovaya, 2020). Wavelet analysis has a distinct advantage as it can also be applied on a nonstationary or a locally stationary series (Yeh, Chiu & Chang, 2021). It represents graphical inspection through continuous wavelet, cross wavelet transforms, and wavelet coherency. Further, network analysis (Li, Gao & He, 2019; So, Chu & Chan, 2021) has been applied to check the connection in constituent series over the entire period of the study. The details of the models employed have been discussed below.

3.2.1. Wavelet Analysis

3.2.1.1 Continuous Wavelet Transformation (CWT)

CWT decomposes the real signal to elementary waveforms with the help of wavelet coefficients. It filters the signal through a dilated version of the mother wavelet, which represents the timescale of variables (Graps, 1995). This wavelet transformation considers some fundamental functions popularly known as daughter wavelets ψ_ι, s(t) out of a mother wavelet $\psi(t)$. The mother wavelet $\psi(t)$ provides a function of time and scale while the translation parameter τ is a function of time. In it, the scale is signified by a dilation parameter with an association of frequency-based information *t*. Mathematically, it is expressed as below:

$$w_t^{\varepsilon}(\Omega) = \sqrt{\frac{\Phi_t}{\Omega}} \sum_{t=1}^{n} X n \varepsilon \psi \theta \left[(\eta\varepsilon - n) \frac{\Phi t}{\Omega} \right] \quad (1)$$

In equation (1), n = 1,…, N, s is the scales, and Φ_t represents the time while the wavelet power $|Wt^{\varepsilon}(\Omega)|^2$ shows the local phase.

3.2.1.2 Cross Wavelet Transform (XWT)

XWT shows the criterion of comparison by recognizing the common power of one variable with another variable. It helps to detect cross-magnitude, phase difference, coherency, and non-stationarity. The XWT of two different time series, i.e., X_n and Y_n, is expressed as $W^{XY}=W^X W^Y*$, where W^{XY} denotes the local relative phase between X_n and Y_n in time-frequency space, * signifies complex conjugation (Torrence and Compo, 1998). The time-frequency of cross-wavelet provides the intensity of the interaction and degree of synergy between two-time series. The information is provided in the form of frequency as a function of time (the cross-wavelet). It can be presented through equation 2 given below:

$$D\left(\frac{|W_n^x(s) W_n^{y*}(s)|}{\sigma x \sigma y} < p\right) = \frac{Zv(p) *}{v} \sqrt{(p_k^x p_k^y)} \quad (2)$$

where the confidence level denoted by Zv(p) is concerned with the probability p for a probability distribution function in equation (2). As per the literature, the wavelet power spectra (WPS) are biased for low-frequency oscillations (Veleda, Montagne & Araujo, 2012). Liu, Liang & Weisberg (2007) mention that WPS fails to provide identical peaks in the form of similar amplitudes; this weakness has been overcome in cross wavelet transform. This paper applies wavelet tools propounded by Ng & Chan (2012), which corrects bias included in both WPS and wavelet cross-spectrum.

3.2.1.3 Wavelet Coherence (WC)

Wavelet Coherence (W.C.) is a tool to represent the association or relationship between two time series through frequency bands and time intervals. It can be computed as per the expression given in equation 3 stated below:

$$R_n^2(s) = \frac{|S(s^{-1}W_n^{XY}(s)|^2}{S(s^{-1}|W_n^X(s)|^2.S(s^{-1}|W_n^Y(s)|^2)} \quad (3)$$

In equation (3), W_n^{XY} is the continuous wavelet transformation, S is the smoothing operator normalizing time, and $R_n^2(s)$ ε [0,1] is the wavelet squared coherency. A value of wavelet squared coherence near 1 indicates a strong correlation, whereas a value near 0 shows a weak correlation between the two-time series. Further, the numerator and denominator are absolute values squared of the smoothed cross-wavelet spectrum and smoothed wavelet power spectra, respectively (Torrence & Webster, 1999). The wavelet coherence's graphical presentation helps ascertain the lead-lag relationships and provides information about positive and negative co-movements between two-time series (Bloomfield, McAteer, Lites, Judge, Mathioudakis & Keenan, 2004). In the graphical representation of wavelet coherence, arrows show the phase difference. If the arrows are up and right, it indicates that the variables are in-phase, i.e., the first series leads the second series, while if arrows are up and left, it signifies the antiphase where the second series leads the first one. A zero-phase shows that two variables move together.

3.2.2. Network Analysis

Network analysis is a visualization technique that examines the interconnectedness among entities (Sakiyama & Yamada, 2016) with the help of nodes and their connection. Nodes are vertices, and edges represent the link to examine the relationship in which densities help check the relative strength of connectedness. For displaying the network among constituent variables, the nodes and edges should be in such a manner that they represent the patterns of association. It can be analyzed at the individual or group level based on cross-sectional, time-series, and panel data. In a network structure, the edges are classified into two parts: directed edge and undirected edge. A directed edge is defined as the edge where nodes are connected through one head of the edge containing arrowhead. It shows a one-way effect, while the undirected edge is the edge in which nodes include connecting lines with some mutual association but with no arrowheads. For the present study, network structure, centrality indices, and accuracy of edge weights have been employed to validate the connectedness between German and selected European bond markets. Centrality indices furnish an insight into the importance of a node to the other nodes in the network (Borgatti, 2005). How strongly and directly nodes are connected among variables is based on the sum of the weighted number and their strength. Since the network analysis is employed on sample data, it is imperative to check for the accuracy of estimates. To check the edge weight, confidence intervals at 95% of the estimates are applied.

4. Empirical Results and Discussions

4.1 An evidence of Wavelet analysis

CWT results can be understood with the help of Figure 1, which presents the graph of the CWT of constituent bond markets for different scales and periods. We have used three different cycles like 16-32 days, 32-64 days, and 64-128 days containing monthly scale, monthly to quarterly scale, and quarterly to annual scale, respectively. In Figure 1, frequencies or scales have been shown on Y-axis while time has been shown on X-axis. The wavelet power is represented by the colour where blue is the region of low power, and red is the region of high power. Similarly, the significance level (5%) is represented by white contour. In CWT, the cone of influence is vital in checking the region affected by edge effects. In this entire CWT, there is no conical shape due to which edge effects is not found. As regards graphical representation shown in figure 1, the bond market of Germany has high power on the medium-scale (32-64 days) and low power on a small scale (16-32 days). Surprisingly, the UK bond market is witnessed with high power on both medium and large scale during 2018 and 2020-21 but low power on a small scale. Further, France, Italy, and Spain bond markets have high power on a large scale and low power on a small scale. We notice that high power is found on the medium and the large scale, but the timing is different. In the case of Germany, the UK, and Spain, bond markets have high power during 2020-2021, while power is scattered for France and Italy.

Insert Figure 1 here

Next, we apply XWT to investigate the co-movement from the German bond market to other European bond markets (UK, France, Italy, and Spain). In XWT diagram arrow indicates the phase difference (cyclical effects) among the variables. Referring the figure 2 for the cross wavelet transform from Germany to UK, we observe that there is no co-movement in any of the scales (short, medium, and large) as the presence of arrows from left to right or right to left is not found. XWT diagram for Germany and France suggests the presence of cyclical effects. The phase relationship indicates that German bond market returns are in the phase with France bond market returns during 2020 at the end of medium-scale (32-64 days) and at the beginning of large scale (64-128 days). The co-movement pattern between the German and Italy bond markets is concerted on a large scale corresponding to 2018 and 2020. In this scale, the arrows point right and up, indicating that the Italian bond market is lagging behind the German bond market. Considering the co-movement between the German and Spain bond market, we notice the variables are in the phase-only on a large scale (64-128 days) corresponding to 2018.

Insert Figure 2 here

Finally, we apply wavelet coherency to examine the relationship between German and other European bond markets encompassing frequency bands and time intervals. Figure 3 provides the wavelet coherency graph between constituent bond markets. Referring to the coherence between German and UK bond markets, there is strong coherence in medium and high scales as many of the islands of strong coherence are identified in these scales. During 2018-2020, the directions of the arrows are right-down, which signifies that the UK bond market is leading the German bond market. Regarding wavelet coherence between bond markets of Germany and France, the direction of the arrows can be pointed out in the direction, ensuring the cyclical effect. The coherence is strong in small and medium scales and even stronger at high scale. For these two bond markets for the year 2018, the arrows are right-up, which means the German bond market leads France bond market. By analysing the coherence between the German and Italy bond market, the strong coherence is identified in the high scale during 2018-2020 with Italy lagging Germany but in medium and low scales, variables have antiphase. It indicates that the bond markets of Germany and Italy have an anti-cyclical effect. In the end, the coherence between the German and Spain bond markets is similar as between German and Italy bond markets i.e., at higher scale Germany leads Spain. In contrast, at medium to small scale Spain leads Germany. Further, exploring the results of wavelet analysis, we notice that strong coherence is identified at a high scale during the year 2020, which incidentally is the period affected by COVID-19 pandemic. Thus, it can be deduced that financial co-movement between the markets tends to rise during the crisis period (COVID-19 pandemic). Therefore, it may be inferred that the crisis period has had a role in explaining bond markets co-movements (Bunda, Hamann, & Lall, 2005; Claeys, & Vašíček, 2014; Chang, Chia-Lin, McAleer & Wang, 2018; Živkov, D., 2019; Yeh, Chiu & Chang, 2021). These findings are similar to the behavior in equity markets where market declines are generally followed by rising correlations, reducing the diversification benefits precisely when most needed. However, these results are not in harmony with the empirical findings of (Gilmore, Lucey & Boscia, 2010; Christiansen, 2014; Vácha, Šmolík, & Baxa, 2019; Papadamou et al., 2021), which reported that co-movements between the markets subdued during the crisis period.

Insert Figure 3 here

4.2. Evidence of Network Analysis between German and European bond markets

Figure 4 encapsulates the overall distribution and a pairwise correlation of the return of German and select European bond markets. With reference to figure 4 highest correlation is observed between Germany & France followed by Spain & Germany. The negative correlation (-0.010) is found between return on bond market of UK & Germany, Italy & Germany (-0.107), France & UK (-0.020), Spain & France (-0.002), and Spain & Italy (-0.013). The correlation between Italy & Germany (-0.107) is the lowest. It is surprising to note that majorities of the bond markets have a negative correlation, indicating the investors' diversification opportunities.

Insert Figure 4 here

Further, we use network analysis containing network structure, centrality indices, and accuracy of edge weights to validate the relationship in the form of connectedness between German and select European bond markets. The network structure is shown in figure 5(a), which indicates that there is no network cluster in the constituent series. Since nodes are not connected even in a single series, we infer that these markets have a weak degree of association; the same has been confirmed from the unconditional correlation figure shown above. Thus, it can be deduced that there are suitable diversification opportunities, and by holding these bonds, one can mitigate the risk. Another vital component of network analysis is centrality indices which are encapsulated in 5(b). The strength of the relationship is represented in the horizontal axis, while different constituent series are represented on the vertical axis. Thus, it encompasses the relative importance of a node to the other nodes in the network (Borgatti, 2005; Hevey, 2018). Referring to the figure, we notice that the strength value of the German and European bond market is zero, which furnishes the portfolio diversification opportunity among these bonds. Finally, we employ bootstrapped confidence intervals to examine the robustness of the edge. It displays the visual representation of the estimates, which is shown in figure 5(c). The red line of the bootstrapped confidence interval represents the edge value, while grey bars encapsulate its width. From the figure, we notice that the estimation of each edge is zero except for Germany and France. By analysing the network structure, centrality indices, and bootstrapped confidence interval, we infer no connection between German and European bond markets based on full observation.

Insert Figure 5(a) here

Insert Figure 5(b) here

Insert Figure 5(c) here

5. Discussion

For the European market (EM), regional and local effects are most significant as these countries' bond markets are closer to perfectly integrated (Christiansen, 2007). The primary cause for the integration is the convergence of interest rates among bond markets. Hence, there may be a possibility of co-movement among European member countries. This paper investigates the frequency association of the German bond market with the European bond market (UK, France, Italy, and Spain) using daily observation. Through wavelet analysis, it is found that high power occurred on a medium and large scale, but the timing is different. In the case of Germany, the UK, and Spain, bond markets have high power during 2020-2021, while power is scattered for France and Italy. It encompasses that there is co-movement between German and other European markets temporarily for a short period that coincides with the period of the COVID-19 pandemic during 2020-2021.

Further, it indicates that the bond markets of Germany and Italy have an anti-cyclical effect. In the end, the coherence between the German and Spain bond market is similar as they are in the phase in high scale while they have antiphase in medium and small scale (see Figure 3). The network analysis reveals that the strength value of the German and European bond market is zero, which furnishes the portfolio diversification opportunity among these bonds.

Our study is just the opposite of the study carried out by Christansen (2007), who found that there is stronger co-movement among the bond markets of European bonds. The recent COVID-19 outbreak from 2020 spurred a new discussion, and we found the co-movement during this juncture; this is found in the case of all the sample bond markets examined in this study. Bayraci et al. (2018) found the interdependencies in the bond markets at lower frequencies, and it rose during the period of GFC. Evidence of herding contagion, i.e., sharp and concurrent rise in the sovereign yield of European countries, has also been reported by Beirne & Fratzscher (2013) in their study.

Contrary to our study, Caporin et al. (2018) found that spread of shocks in the euro's bond yield does not provide any evidence of shift-contagion during the financial crisis. Yang and Hamori (2014) found a higher degree of financial integration and dependence between the bond markets of Poland, the Czech Republic, and Hungary. Germany from 2000 to 2012 but surprisingly, the dependence between the bond markets decreased during the crisis period. Our study is similar to the study of Claeys & Vašíček (2014); Ters & Urban (2018), who found that the impact of the global financial crisis (GFC) of 2008 and the sovereign debt crisis of Europe (2009-2011) has not been uniform. The spillover in EMU is higher, which can be attributed to the fiscal trouble and differences in bilateral linkages.

6. Conclusion and Policy Implications

In contrast to the extant studies, our study has investigated the correlation of government bond markets between Germany and major economies of Europe such as the U.K, France, Italy, and Spain, drawing important economic implications thereof. The investigation of the dynamic relationship between these bond markets provides valuable information to the regulators about the critical international macroeconomic variables and portfolio diversification (Andersson et al., 2008). It is prudent to study the dynamics of inter-financial relations if the integration of the markets is higher as the contagious effect of an unexpected development beyond common shocks from one market to another shall also be higher. Conversely, for countries with a lower level of integration, the contagious effect shall be lower. The co-movement between these markets may provide more insights into the dynamics of cointegration caused by a severe epidemic disease. Therefore, it motivates to explore the co-movement between these bond markets. The study uses wavelet and network analysis methods for identifying dynamic co-movement of the bond markets. The study reports a few significant empirical results and implications thereof.

The results of CWT indicate that the German market has high power on medium-scale and low power on a small scale. UK market shows high power on both medium and large scale during 2018, 2020 but low power on a small scale. The bond markets of France, Italy, and Spain show high power on a large scale and low power on a small scale. The study infers a rise in the financial co-movement between the markets during the crisis period (COVID-19 pandemic). It means investors cannot diversify their portfolios during the crisis period. The results of XWT, W.C., and network analysis show significant positive correlations between the markets over the medium and high time scales during 2020 (i.e., COVID-19 pandemic period) revealing, synchronicity. It also indicates German bond markets play an important role in leading and guiding other government bonds. However, overall, no significant correlation has been observed between these markets, which signifies ample diversification and flight to quality opportunities for the investors for the non-crisis period. The findings alert international investors of the limited benefits of diversification on regional (European) bond investment portfolios and also prompt them to accord more attention to the impact of the German bond market when managing bond portfolios during the crisis period. Network analysis signifies the absence of the contagious effect among the bond markets of Germany and other selected European bond markets (UK, France, Italy, and Spain) during the entire period of analysis. Our results conform with the premise that interdependency between sovereign bond markets includes both contagion and divergence effects, wherein the contagion effect tends to increase during a crisis (Jaworski et al., 2017). From the perspective of investors, it is a good indicator for the sustenance of an international portfolio diversification strategy. The long-term bond investors can achieve arbitrage profits through portfolio diversification among these five European countries that offer heterogeneity in the investment opportunity.

The policymakers should continue to design appropriate stabilization policies with a focus on their macroeconomic parameters within the market. With specific reference to the countries in the European monetary union, who have already accorded integration of national monetary policy and exchange rates, the covid crisis provides an opportunity to debate over the case for a central fiscal policy to act as an additional European fiscal buffer to cushion economic downturns (European Stability Mechanism, 2021).

Our findings are subject to the limitations which provide scope for future studies. This study signifies the absence of the contagious effect among the bond markets of Germany and the rest of the selected European bond markets (UK, France, Italy, and Spain) during the entire period of analysis. The results of our research should be reinvestigated for a different sample and extended period of study before drawing any generalization. The USA, Japan, and Europe have been the biggest issuers in the government bond market. Future studies of the cointegration between these markets may provide more insights into the dynamics of cointegration caused by a severe epidemic disease. Further, our study can also be extended by studying the integration of bond markets with other asset classifications.

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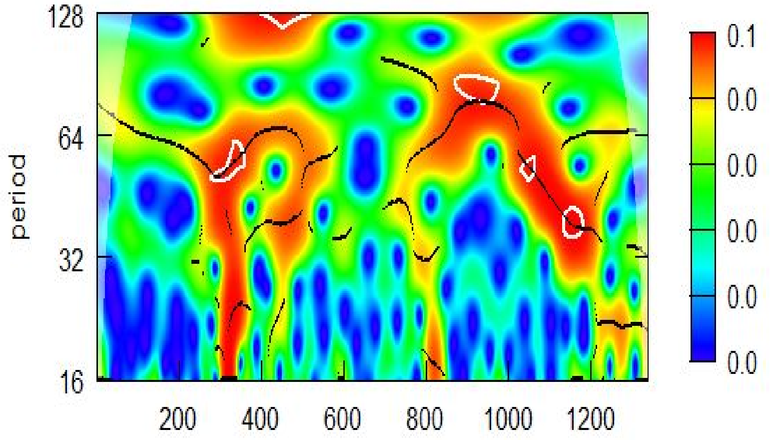
Table 1: Description of the German and select European bond market

Market	Asset	Source
German Bond Market	The 10-year yield of Government Bond of Germany	Bloomberg
European Bond Markets	The 10-year yield of Government Bond of UK	Bloomberg
	The 10-year yield of Government Bond of France	Bloomberg
	The 10-year yield of Government Bond of Italy	Bloomberg
	The 10-year yield of Government Bond of Spain	Bloomberg

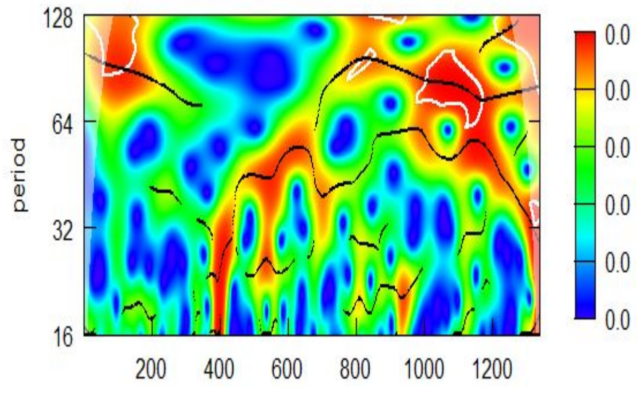
Source: Authors' construction and presentation

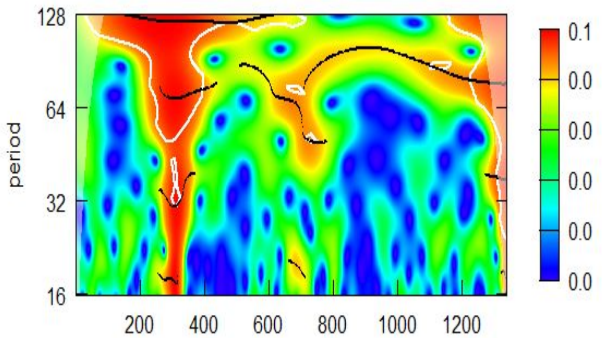
Figure 1: Continuous Wavelet Transform of Constituent bond markets



Daily observation	Time
200	2017-12-08
400	2018-09-03
600	2019-05-23
800	2020-02-17
1000	2020-11-16
1200	2021-05-28

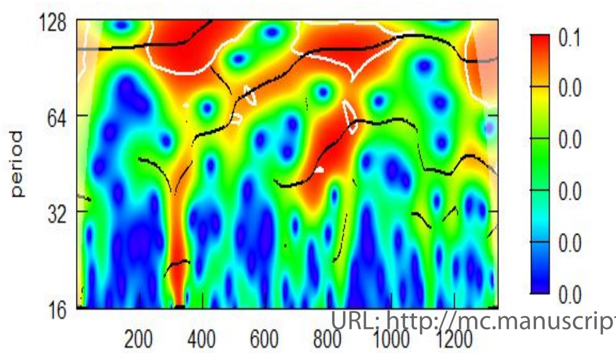
Contenuous wavelet of German bond market

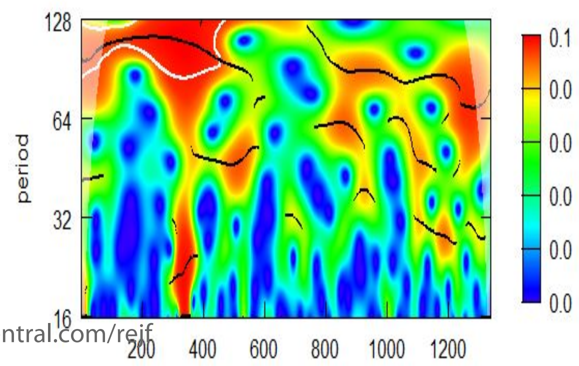




Contenuous wavelet of UK bond

market Contenuous wavelet of France bond market

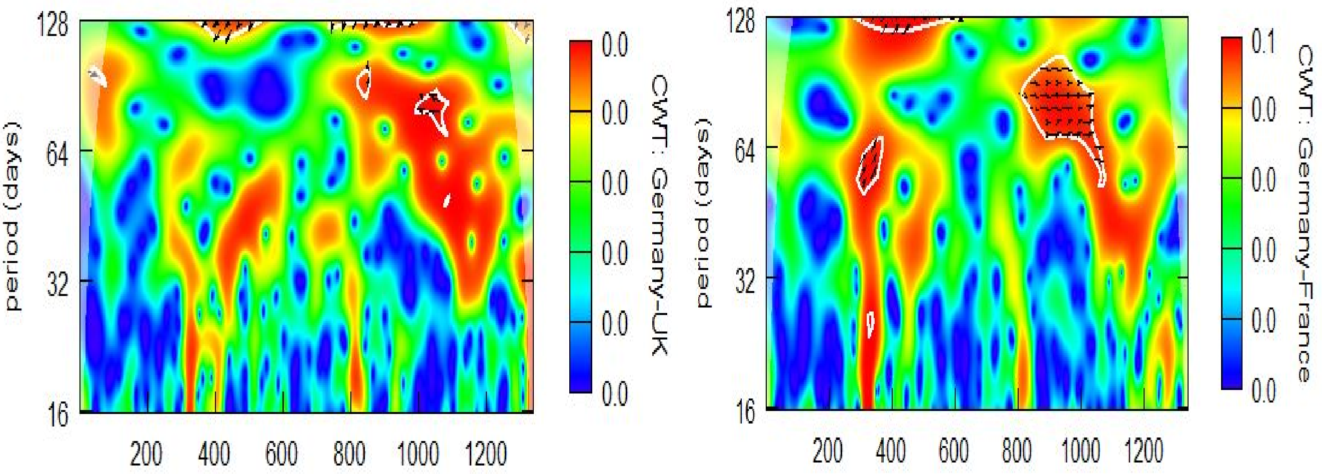




Contenuous wavelet of Spain bond market Contenuous wavelet of Italy bond market

Source : Authors' construction

Figure 2: Cross Wavelet Transform among constituent European bond markets



Source : Authors' construction

Figure 3: Wavelet Coherence among constituent European bond markets

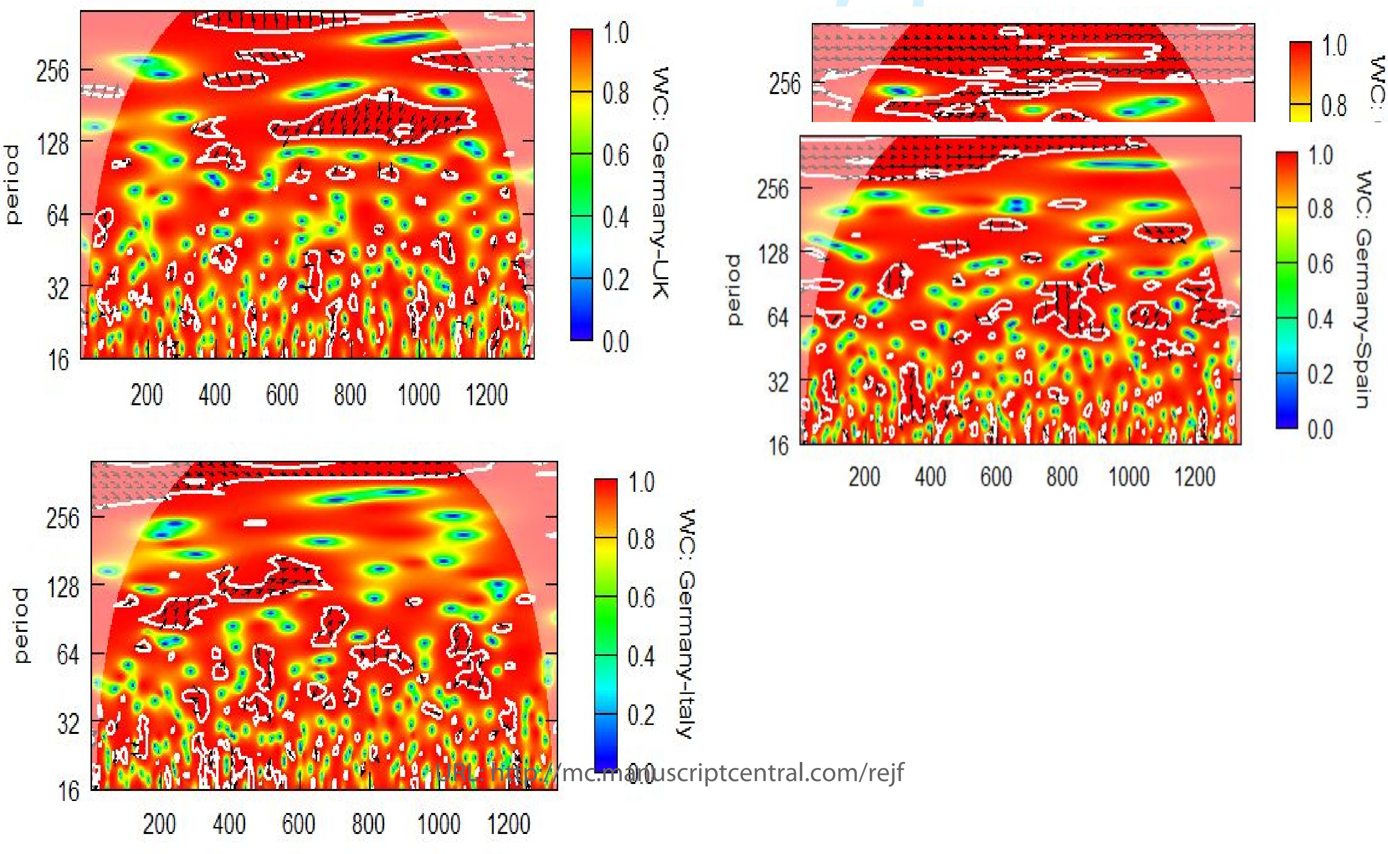
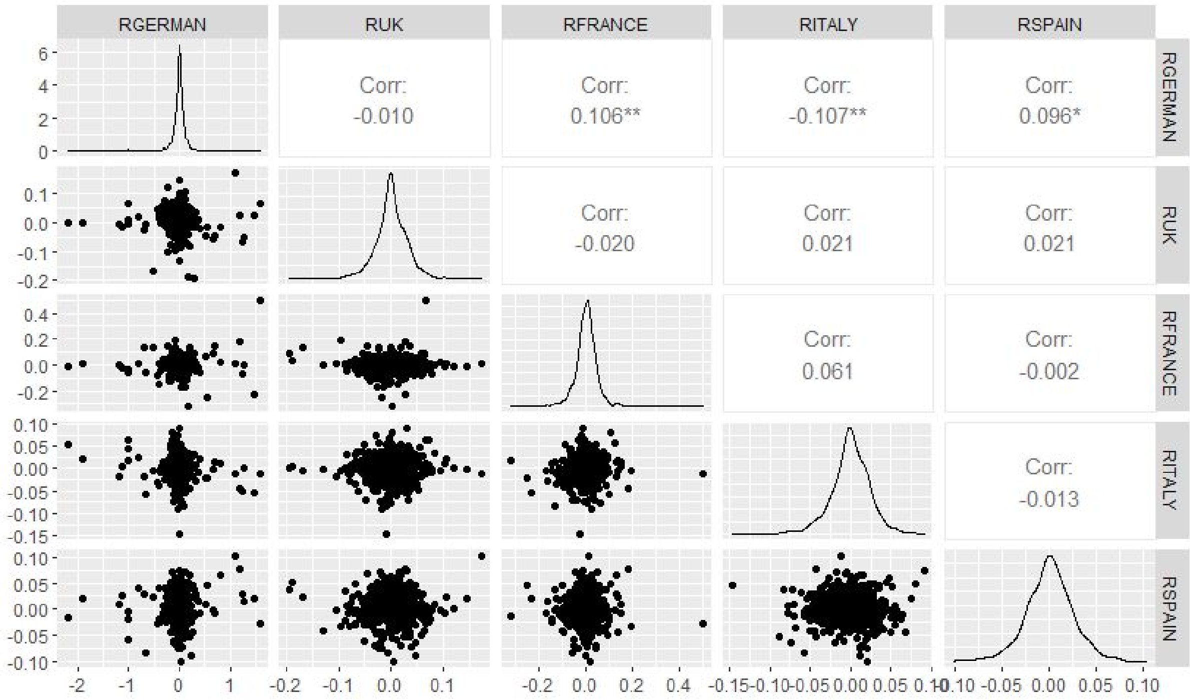


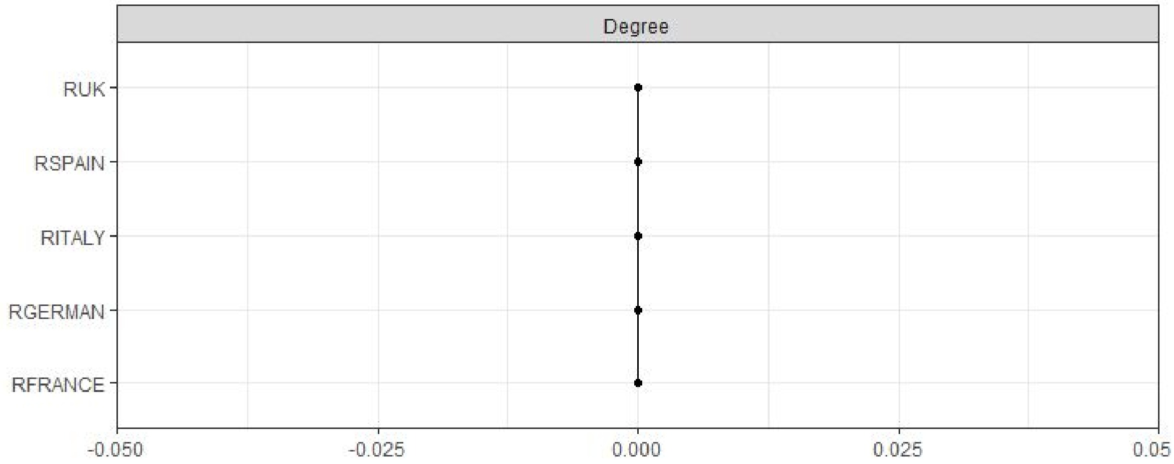
Figure 4: Correlation and distribution plot of constituent series



Source : Authors' construction

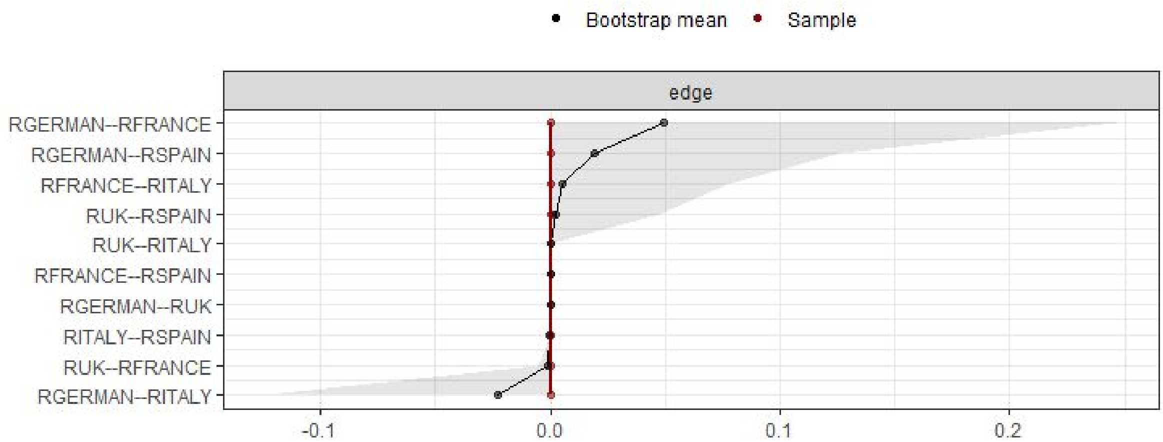
Figure 5(a): Network structure among constituent variables

Figure 5(b): Centrality indices among constituent series



Source : Authors' construction

Figure 5(c): Accuracy of the edge-weight estimates



Source : Authors' construction