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Abstract

In this paper we investigate the dynamics of European government bond market integration during the financial crisis and, subsequently, during the European sovereign debt crisis. Based on the approach developed by Bae *et al.* (2003), we adopt an intuitive measure of integration: the higher the number of joint extreme price rises or falls (coexceedances), the higher the degree of integration. We also analyse the underlying determinants of the dynamics of integration using a binomial logistic regression. Our results reveal that the level of integration of European government bond markets with the euro area has changed over time, with notable differences between the financial and the European sovereign debt crises. We find that the Euribor, unexpected monetary policy announcements from the ECB and both regional and international volatility play an important role in determining the level of integration, and that, in general, the relevance of these factors does not change between the financial and the sovereign debt crises.

Keywords: Financial integration; European government bond markets; coexceedances; extreme returns; logistic regression.

JEL Classifications: C25; F36; G15

1. Introduction

The extent to which European government bond markets are integrated is a key question for policymakers and market participants. Policymakers are particularly keen to understand the mechanisms that link these markets in order to be able to make effective monetary policy decisions and to maintain financial stability. Likewise, an understanding of bond market linkages can help market participants formulate appropriate risk management strategies and investment decisions. This interest becomes even greater in years of turmoil when financial markets are hit by extreme shocks.

In the financial literature, a wide variety of frameworks have been employed for the empirical examination of the integration of European government bond markets. The central focus of early papers was on the role that the European Monetary Union (EMU) played in the process of financial integration of the EU-15 bond markets. In this line of research, some studies have assessed the relative importance of systemic and idiosyncratic risk in EMU sovereign yield spreads. Geyer *et al.* (2004) and Pagano and von Thadden (2004) find that yield differentials under EMU are driven mainly by a common risk (default) factor and suggest that liquidity differences play, at best, only a minor role in the time series behaviour of yield spreads. Gomez-Puig (2009a and 2009b) presents evidence to the effect that it was domestic, rather than international, risk factors that were the primary drivers of ten-year yield spread differentials over Germany in all EMU countries in the seven years following the initiation of monetary integration. A different perspective is provided by Christiansen (2007) who conducts a volatility-spillover analysis to show that the bond markets of EMU countries are more integrated than those of non-EMU countries and that these markets became more integrated following the introduction of the euro. A more recent study by Beber *et al.* (2009) finds that the bulk of sovereign yield spreads can be explained by differences in credit quality, though liquidity plays a non-trivial role. Finally, Abad *et al.* (2010) find that euro area countries are only partially integrated and present differences in their market liquidity and default risk. They also find that the markets of countries sharing a monetary policy are more vulnerable to regional risk factors and that the countries that opted to stay out of the Monetary Union are more vulnerable to global risk factors.

Another line of empirical research of European government bond market integration incorporates the new EU members into the analysis.[1] Drawing on a set of complementary techniques, including dynamic cointegration and time-varying correlations, Kim *et al.* (2005) find that the degree of integration of the new members with the German bond market is weak and stable, with little evidence of any further strengthening despite increased political integration. Within the framework of a factor model for market returns, Cappiello *et al.* (2006) only document an increase in integration for the Czech Republic's bond market versus Germany's.

Finally, a new line of research investigates the impact of the financial crisis on European government bond market integration. Von Hagen *et al.* (2011) find that the larger spreads observed during the financial crisis are the result of a higher penalty imposed by the markets on fiscal imbalances and of greater international risk aversion, i.e. a higher common risk factor in the spreads. Pozzi and Wolswijk (2012) and Abad *et al.* (2014) exploit the implications of asset pricing models to analyse the effects of the financial crisis. The results of Pozzi and Wolswijk (2012) suggest that the idiosyncratic factors were almost eliminated in all countries by 2006 but subsequently reappeared as a consequence of the financial crisis. Abad *et al.* (2014) show that, from the onset of the financial market tensions in August 2007, markets moved towards higher segmentation, and the differentiation of country risk factors increased substantially across countries. Christiansen (2014), who measures the integration of European government bond markets employing the explanatory power of factor models, concludes that the integration of EMU members has not been so great during the recent crisis.

This study assesses the integration of a selected number of European government bond markets with the euro area during periods of turbulence, when investors and policymakers have a particularly strong interest in whether and how shocks propagate to other countries. Following the launch of the euro in January 1999, the markets priced the debt of the European member states as being virtually identical. In the period 2003-2007, spreads remained very small and did not reflect differences in the fiscal positions of the countries.[2] As such, the period was characterised by a significant underpricing of risk, leaving investors to search for yield in an environment of abundant global liquidity. This progress towards

[1] The new members included are usually the Czech Republic, Hungary and Poland given that they are the only ones with sufficiently developed bond markets.

[2] Cassola and Morana (2012) also point out that a peculiar feature of the pre-crisis euro area money market was the virtual absence of EURIBOR-Overnight Index Swaps spreads.

financial integration was interrupted and reversed, however, by the global financial crisis and, more recently, by the European sovereign debt crisis, in which sovereign bond markets have been dominated by sharp differentiation, especially across borders.

Based on the approach developed by Bae *et al.* (2003), we measure the integration of each European government's bond market with the euro area by examining how often extreme returns on each bond market and the euro area occur simultaneously. This analysis provides helpful information on the dynamics leading to joint extreme price rises or falls and allows us to adopt an intuitive measure of integration: the higher the number of coexceedances with the euro area, the higher the degree of integration. Bae *et al.* (2003) capture the coincidence of extreme return shocks across countries within a broader region and also across regions. They define contagion within regions as the fraction of coexceedances that cannot be explained by fundamentals and contagion across regions as the fraction of coexceedances unexplained by fundamentals that is explained by the exceedances from other countries.[3] This approach is used by Christiansen and Ranaldo (2009) to analyse the financial integration of the stock markets in the ten new EU member states from the former Communist countries of Eastern and Central Europe as well as the integration of two groups of countries, namely, new and old member states. In this paper, we are interested in analysing the integration of a selected number of European government bond markets with the euro area and in testing whether there are differences across countries with respect to the underlying determinants of the level of integration. To this end, in a first step, we carry out a hierarchical cluster analysis that allows us to group countries in terms of their level of integration over the sample period. In a second step, we use a logistic regression model to determine the underlying determinants of the observed dynamics of integration.

We address two basic sets of questions. First, how closely are the European government bond markets associated with the euro area? And, has the level of integration of these markets changed during the recent years of turmoil? It is intuitive that financial market integration changes with economic conditions. Second, which factors are associated with an increase (decrease) in the probability of observing extreme returns across markets? Have the effects of these factors changed during the financial crisis and, subsequently, during the

[3] Their approach possesses two advantages. First, contrary to standard correlation measures, it is robust to time-varying volatility and departure from normality. Second, the correlation coefficient is a linear measure, which is inappropriate for analysing nonlinear phenomena, as financial market integration potentially might be (see Baur and Schulze, 2005; Dungey and Martin, 2007).

European sovereign debt crisis? And is the level of integration of European government bond markets driven by global (US) or regional (EMU) factors?

The main results of this paper can be summarized as follows. First, we find that the level of integration of European government bond markets with the euro area has changed over time and that the bond markets analysed group differently over the sample period in terms of integration. Second, our analysis of the factors affecting the integration of European government bond markets shows that: (i) there is a substitution effect between the bond market and money market instruments that leads to a decrease in the level of integration, (ii) integration increases in highly volatile periods in both regional and international stock markets, (iii) unexpected news releases from the ECB increase uncertainty and decrease the level of integration of European government bond markets, (iv) in general, the relevance of these factors does not change during the financial and the sovereign debt crises and, (v) the new members are those that behave most differently in terms of the factors associated with the level of integration.

The rest of this paper is organized as follows. In Section 2 we present our data. In Section 3 we investigate the evolution of the integration of European government bond markets with the euro area. In Section 4 we examine the determining factors of European government bond market integration. Finally, we conclude in Section 5.

2. Data

The data consist of the ten-year JPMorgan Government Global Bond Index (JPMGBI), expressed in terms of a common currency, the euro, and the sample includes 16 European countries. Our study focuses on ten EMU EU-15 countries (Austria, Belgium, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain)[4] and six non-EMU countries (Denmark, the Czech Republic, Hungary, Poland, Sweden and the UK). As a proxy for the entire euro area we use the JP Morgan EMU Government Index. These bond market indices are transformed into returns by taking the first difference of the natural log of each bond price index. All data have been collected from Thomson Datastream.

We use daily data for the period January 2005 through December 2013, thus our sample covers the recent years of turmoil (initially the financial crisis and, subsequently, the

4 Finland is not included in the study due to a lack of available data.

European sovereign debt crisis). We define the starting point of the financial crisis as August 2007, when equity markets initially fell and central banks started intervening to provide liquidity to financial markets. For our analysis, we match the end of the financial crisis with the beginning of the European sovereign debt crisis. As pointed out by Christiansen (2014), dating the European sovereign debt crisis is not a straightforward task as no official dates are available. Generally, it is considered to have begun in late 2009 and is still running its course. Therefore, we define the starting point of the sovereign crisis as January 2010 and it runs till the end of our dataset in December 2013.

Following Bae *et al.* (2003), we define an extreme return, or exceedance, as one that lies either below (above) the 5th (95th) quantile of the marginal return distribution. Similarly, we define a coexceedance as the occurrence of extreme returns in one European government bond market and in the euro area simultaneously on a given day; thus, the higher the number of coexceedances with the euro area, the higher the degree of integration. We treat positive extreme returns separately from negative extreme returns as some authors suggest an asymmetric effect of explanatory variables on the tails of the return distribution (see Bae *et al.,* 2003 and Cristiansen and Ranaldo, 2009). Therefore, for each European government bond market we distinguish between three events: negative coexceedance with the euro area for a given day, positive coexceedance with the euro area for a given day and no coexceedance with the euro area for a given day.

Table 1 shows the relative frequency of the joint occurrences of extreme returns between each European government bond market and the euro area on a particular day. We compute the number of coexceedances for the entire sample, for the "tranquil period" (from 1 January 2005 to 6 August 2007), the financial crisis (from 7 August 2007 to 31 December 2009) and, the European sovereign crisis (from 1 January 2010 to 15 December 2013). As is standard in the literature, we have divided the European countries into four groups: (1) EMU EU-15 central countries, (2) EMU EU-15 peripheral countries, (3) Non-EMU new EU countries, and (4) non-EMU EU-15 countries. In our study, these groups are composed of the following countries: EMU EU-15 central (Austria, Belgium, France, Germany and the Netherlands), EMU EU-15 peripheral (Greece, Ireland, Italy, Portugal and Spain), Non-EMU new EU (the Czech Republic, Hungary and Poland), and non-EMU EU-15 (Denmark, Sweden and the UK). The number of coexceedances of central and peripheral bond markets with the euro area is lower during the tranquil period than during the crisis periods and, within the crisis periods, it is higher during the financial crisis. The

ANOVA test, reported in Table 2, in general confirms the statistical significance of these differences in the number of coexceedances suggesting that the level of integration of these bond markets with the euro area, measured by the number of coexceedances, differs across the three sub-samples.[5] The distribution of negative and positive coexceedances is largely symmetrical. In general, there are no great differences in the number of coexceedances across the central bond markets; however, in the case of peripheral bond markets, Italy is the most frequent participant in coexceedance events in the three sub-samples, together with Spain during the periods of crisis, indicating that these are the most highly integrated peripheral bond markets with the euro area. Likewise, Greece is the country with the lowest number of coexceedances with the euro area during the sovereign debt crisis, suggesting that this is the least integrated of the peripheral bond markets during this period.

The picture is somewhat different when we look at the new members. When we distinguish between positive and negative coexceedances, the ANOVA test does not reject the null hypothesis that the number of coexceedances is equal in the three sub-samples and in the two crisis periods considered, indicating that their level of integration with the euro area has not changed over the sample period. As with the central and peripheral bond markets, the distribution of coexceedances is mostly symmetrical but, in general, the number of coexceedances of the new members' bond markets and the euro area is lower, suggesting that the new members are less integrated with the euro area than are the central and peripheral bond markets.[6] Finally, in terms of the number of coexceedances over the sample period, Denmark, Sweden and the UK present a similar behaviour to that of the central and peripheral bond markets. The ANOVA test indicates that the number of coexceedances of Denmark and Sweden with the euro area is significantly higher during the financial crisis than during the sovereign debt crisis.

2.1. Explanatory variables

We examine four main hypotheses relating market conditions to the likelihood of coexceedances and, to this end, we use a large set of explanatory variables. First, several arguments such as the flight-to-quality proposed by Caballero and Krishnamurthy (2008) and the liquidity spirals proposed by Brunnermeier and Pedersen (2009) suggest a substitution effect between equities, money market instruments and bonds in turbulent

[5] To test the equality in the number of coexceedances across the tranquil, financial crisis and European sovereign debt crisis periods, we carry out the ANOVA test with the null hypothesis that the number of coexceedances is equal in the three sub-samples and in the two crisis periods considered.
[6] Christiansen and Ranaldo (2009) come to the same conclusion for European stock markets.

periods. Capital flows towards other markets might weaken the integration of European government bond markets. To test this hypothesis we include daily returns of the European stock market (Eurostoxx50), the relevant index for each local market[7] and the three-month interbank interest rate (Euribor).[8]

Second, according to Cristiansen and Ranaldo (2009) integration or the propagation of shocks is more likely in a highly volatile environment. Thus, the hypothesis to be tested is whether integration is strengthened when volatility is pervasively high in the financial markets. As a proxy of European financial market volatility we use the European stock market volatility.[9] As is standard in the literature, we compute volatility as the square root of the conditional variance estimated using an AR(1)-GARCH(1,1) model.

Third, as pointed out by Manganelli and Wolswijk (2009), the greater integration of European government bond markets mainly reflects the progressive elimination of uncertainty in the euro area. Similarly, as suggested by Abad and Chuliá (2013), unexpected monetary policy announcements from the European Central Bank (ECB) increase uncertainty and decrease the level of integration of European government bond markets with the euro area. Thus, if monetary policy announcements surprise the markets and generate uncertainty, this could weaken integration. To test this hypothesis, we include the "surprise" or the unexpected component of the news announcements[10] released by the ECB.

Finally, with the aim of distinguishing regional factors from global factors, the fourth group of variables is associated with the US. These variables are the return of the US stock market (S&P500 Composite index), the three-month Treasury bill rate, the US stock return volatility[11] and the "surprise" or the unexpected component of the news announcements released by the Federal Reserve (Fed). The hypotheses to be tested are (i) whether there is a

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[7] The relevant indexes are the ATX index for Austria, the BEL 20 index for Belgium, the CAC 40 index for France, the PX index for the Czech Republic, the OMXC20 index for Denmark, the DAX 30 index for Germany, the ATHEX Composite index for Greece, the BUX index for Hungary, the ISEQ index for Ireland, the FTSE MIB index for Italy, the AEX index for the Netherlands, the WSE index for Poland, the PSI-20 for Portugal, the IBEX 35 for Spain, the OMXS30 index for Sweden, and the FTSE 100 for the UK.

[8] The Euribor is included in first differences because a unit root cannot be rejected.

[9] To avoid the problem of so-called complete separation when estimating the binomial logit regression, we do not include the volatility of European government bond markets as an explanatory variable.

[10] An important common finding in the extant literature is that only the surprise component of monetary policy has a significant effect on asset returns, whereas the effect of expected policy actions is statistically insignificant (see Bomfim, 2003, and Bernanke and Kuttner, 2005, among others).

[11] The correlation between the US and the European stock return volatilities during our sample period is 0.9. With the aim of avoiding the multicollinearity problem, we proceed as follows. First, we calculate the US stock return volatility as the square root of the conditional variance estimated using an AR(1)-GARCH(1,1) model. Then, we remove the influence of the European stock return volatility by running a regression of the US stock return volatility on European stock return volatility. Finally we take the residuals of this regression as our proxy for the US stock return volatility.

substitution effect between European and US assets similar to that between European asset classes, (ii) whether higher volatility in international financial markets increases the level of integration and, (iii) whether increasing uncertainty in the US (measured though monetary policy surprises) leads to a decrease in the level of integration, as suggested by Abad and Chuliá (2013).

To obtain a measure of the surprise in the Fed announcements we use the methodology proposed by Kuttner (2001). For an event taking place on day *d*, the unexpected, or "surprise" target rate change can be calculated as the change in the rate implied by the current-month futures contract, scaled up by a factor related to the number of days in the month affected by the change. In sum, we compute the unexpected target rate change or the "surprise", as

$$S = [D/(D-d)] \cdot (f_d - f_{d-1}) \tag{1}$$

where f_d is the current-month futures rate at the end of the announcement day *d* and *D* is the number of days in the month. Kuttner (2001) uses a scaled version of the one-day change in the current-month federal funds future rate because in the US the futures contract's payoff depends on the monthly average federal funds rate, and the scaled factor is included to reflect the number of days remaining in the month that are affected by the change. This scaled factor is not required to obtain a measure of the surprise in the ECB announcement and, following Bredin *et al.* (2007), we proxy surprises in ECB policy rates using the one-day change in the three-month Euribor futures rate.[12] The data for the monetary policy related variables are provided by Bloomberg.

3. Dynamics of European government bond market integration: Cluster Analysis

Given the diversity of economic and financial structures across the EU economies, the fact that not all the countries belong to the EMU and that some countries only became members of the EU relatively recently, it is standard in the literature to divide European countries into four groups: (1) EMU EU-15 central countries, (2) EMU EU-15 peripheral countries, (3) Non-EMU new EU countries, and (4) non-EMU EU-15 countries. However, the recent years of turmoil might have produced heterogeneity within groups or even

[12] Bernoth and Von Hagen (2004) find that the three-month Euribor futures rate is an unbiased predictor of euro area policy rate changes.

homogeneity between countries in different groups in terms of their respective levels of integration. To analyse this possibility, we carry out a hierarchical cluster analysis that enables us to group countries that present similar characteristics across a set of variables. Here, this set of variables refers exclusively to the coexceedances of each government bond market with the euro area over time, i.e. its level of integration. The end result is a map (dendrogram) that allows us to visualize the groups. In so doing, we are able to test whether the cluster analysis (in terms of the level of integration) leads to the same classification of countries as described above. As mentioned, from the introduction of the common currency until the end of 2007, the bonds of the EMU countries were almost perfect substitutes but this situation changed, first, with the financial crisis and, subsequently, with the European sovereign debt crisis. For this reason, to determine whether the cluster groups have been stable over the sample period, we perform the cluster analysis for three sub-samples: the "tranquil period", the financial crisis and the European sovereign crisis.

Figure 1 shows that during the "tranquil period", the central countries (Austria, Belgium, France, Germany and the Netherlands) form a cluster, to which Italy is added. The dendrogram also shows the similarity between the peripheral bond markets (Greece, Ireland, Portugal and Spain), with the exception of Italy, and to which Denmark, Hungary and Poland are added. Finally, the UK, Sweden and the Czech Republic form a separate alignment.

The picture changes somewhat when we consider the financial crisis (Figure 2). As in the "tranquil period", the central countries form a cluster, to which Spain and Denmark are now added.[13] The Czech Republic and Poland, the new EU members, cluster together. The similarities between Greece, Ireland and Portugal, the first peripheral economies to collapse, can be clearly identified and they form a group together with Italy. The UK and Sweden continue to be independent of the other countries, as now is Hungary.

Finally, Figure 3 shows that during the European sovereign debt crisis, as expected, the central countries once more form a group (together with Denmark).[14] Italy and Spain cluster together, as do the new members of the EU together with Greece, Ireland and Portugal. This result indicates that the peripheral bond markets are divided into two

[13] It is not until the second quarter of 2008 that Spain went into recession (Ortega and Peñalosa, 2012).

[14] As Ehrmann *et al.* (2011) and Söderström (2010) point out, Denmark's exchange rate and monetary policy are pegged so tightly to the euro and the ECB that the country's bonds display a very high degree of integration with those of the euro area.

groups: those most affected by the European sovereign debt crisis (Greece, Ireland and Portugal), whose levels of integration fall to levels similar to those of the new member states; and Italy and Spain, which remain at higher levels of integration. Sweden and the UK also form a separate alignment.

Overall, the results of the clustering analysis suggest that the level of integration of European government bond markets with the euro area, measured in terms of coexceedances, has changed over the three sub-samples under analysis. Although the central bond markets cluster together and the UK and Sweden are independent throughout the three sub-periods, the remaining government bond markets present a certain degree of instability indicating that the effects of the crises have not been homogeneous across these countries. As a consequence, opportunities for diversification have changed over the sample period.

4. Determinants of European government bond market integration: Logistic regression model

Our aim is to identify the underlying determinants of the dynamics of integration observed and to determine whether their importance varies across countries and/or groups of countries. A coexceedance is a variable equal to one when we record an extreme return in a European government bond market and in the euro area simultaneously on a given day and zero otherwise. As such, we can use the binomial logit model, a frequently adopted approach for estimating the probabilities associated with events captured in a dichotomous variable. Defining y_t as being equal to one when there is a coexceedance on a given day and zero otherwise, the probability of a coexceedance in the binomial logit model can be given by

$$\Pr(y_t = 1) = \exp(\tilde{x}_t^{'}\beta) / [1 + \exp(\tilde{x}_t^{'}\beta)] \tag{2}$$

where the vector $\tilde{x}_t^{'}$ includes the explanatory variables mentioned above plus a constant and β is a vector of coefficients. When β_i is significant, then the variable x_i affects the probability of the occurrence of a coexceedance. The model is estimated using maximum likelihood and goodness-of-fit is measured using McFadden's (1974) pseudo-R^2 approach. We estimate the model separately for positive and negative coexceedances to allow the factors to have different effects on each tail. As we are also interested in determining whether the effects of the factors differ during the financial and the European sovereign debt crises, we include an intercept dummy as well as interaction dummies for all model variables, where the dummy variable equals one during the sovereign debt crisis (from 1 January 2010 until the end of the sample period) and zero before.[15]

Table 3 (Table 4) shows the parameter values when estimating the binomial logit model for the negative (positive) coexceedance variable for each European government bond market with the euro area. To test the substitution effect we include both money market and stock market variables. Our results reveal a substitution effect primarily between bonds and money market instruments. Specifically, the likelihood of observing coexceedances is negatively related to the Euribor, which indicates that increasing interest rates are likely to induce flight-to-quality episodes, and thus, diminish integration. This might be because money market instruments present a lower degree of risk than bonds and this is especially important in periods of turmoil when investors are interested in safe assets. Interestingly, in the case of top-tail coexceedances, the substitution effect was recorded during the sovereign debt crisis, while in the case of bottom-tail coexceedances, the substitution effect took place during the financial crisis. As for the stock market, evidence in favour of a substitution effect between stock and bond markets is scarce and heterogeneous.

In general, our results confirm the hypothesis that integration increases in highly volatile periods in the regional market. The likelihood of positive coexceedances increases during both crises while, in the case of negative coexceedances, the likelihood increases only during the sovereign debt crisis. As for differences across countries, the central bond markets are those that show most evidence in favour of high-frequency propagation of shocks in a volatile European environment. In contrast, the results from the new members' bond markets fail to support this hypothesis.

An examination of the impact of unexpected news announcements released by the ECB shows that they only appear to be useful in explaining negative coexceedances in the case of central and non EMU EU-15 bond markets during the sovereign debt crisis, and in the case of Greece, Italy and the UK during the financial crisis. In line with Abad and Chuliá (2013), this result suggests that unexpected news releases from the ECB increase uncertainty and decrease the level of integration of these bond markets with the euro area.

[15] As the number of coexceedances during the tranquil period is almost zero, the binomial logit regression analysis is carried out only during the crisis periods.

In addition, we examine whether some fraction of the coexceedances of each bond market with the euro area can be explained by the explanatory variables associated with the US, i.e. whether global factors have an effect on the integration of European government bond markets.[16] Our results do not show a substitution effect between the US and European assets considered; however, as the US stock market becomes more volatile, the more likely we are to observe a rise in the level of integration of European government bond markets. As in the case of regional volatility, there is no evidence of this effect among the new members. Interestingly, in the case of top-tail coexceedances, the volatility effect is recorded during the financial crisis while in the case of bottom-tail coexceedances, it is recorded during the sovereign debt crisis but in fewer bond markets. Finally, the regression coefficients for the monetary policy surprises announced by the Fed are insignificant during both the financial and the sovereign debt crises and for both bottom- and top-tail coexceedances.

Finally, our analysis of the factors associated with the integration of European government bond markets only reveals differences between new members and the EU-15 members in terms of the impact of unexpected news announcements from the ECB and of both European and US volatility.

5. Conclusions

Using the coexceedance measure proposed by Bae *et al.* (2003), we have analysed the degree of integration of European government bond markets with the euro area. This approach has allowed us to adopt an intuitive measure of integration: the higher the number of coexceedances of each bond market with the euro area, the higher the degree of integration. In a first step, we carried out a hierarchical cluster analysis that allowed us to analyse the way in which the bond markets group over the sample period (comprising a tranquil period, the financial crisis and the sovereign debt crisis) in terms of the degree of integration. In a second step, we have used a binomial logistic regression model to determine the factors associated with an increase (decrease) in the probability of observing a coexceedance. Specifically, we were interested in testing whether (i) there is a substitution effect between equities, money market instruments and bonds, (ii) the propagation of shocks is more likely in a highly volatile environment, (iii) monetary policy surprises

[16] Owing to timing conventions (European markets close before their US counterpart), US explanatory variables enter the model lagged one period. We interpret these results as evidence of the predictability of coexceedances.

announced by the ECB decrease the level of integration of European government bond markets, and (iv) European integration is also driven by international factors.

We report evidence that the degree of integration of European government bond markets has changed over the sample period: first, during the financial crisis and, subsequently, during the European sovereign debt crisis. Moreover, the effects of these crises have not been the same across all the bond markets, to the extent that the traditional groupings of markets on the basis of the level of integration vary across the three sub-samples. In the case of the factors associated with the likelihood of the occurrence of coexceedances, we obtain a number of interesting results. For example, our findings point to a substitution effect between bonds and European money market instruments, but not between bond and stock markets (in either the US or Europe). As expected, in turbulent times the substitution effect involves the least risky asset. In addition, we find evidence indicating that the greater the volatility in European and US financial markets, the more likely we are to observe the propagation of shocks in both tails. Finally, our results show that unexpected news announcements from the ECB increase uncertainty and weaken the degree of integration of European government bond markets.

Our results should enable market participants to make effective investment decisions, given that they need to have an understanding of the way in which extreme shocks propagate across European government bond markets. Additionally, our findings should be of use to policymakers as they strive to understand the effects of their monetary policy decisions on bond markets in times of extreme shocks.

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6. Tables

Table 1. Coexceedances: Relative Frequency

	Coexceedances				Negative coexceedances				Positive coexceedances			
	Entire sample	Sample A	Sample B	Sample C	Entire sample	Sample A	Sample B	Sample C	Entire sample	Sample A	Sample B	Sample C
Panel a) EMU EU-15 Central												
Austria	0.068	0.025	0.116	0.066	0.035	0.013	0.059	0.034	0.033	0.012	0.057	0.031
Belgium	0.074	0.028	0.140	0.064	0.037	0.015	0.065	0.035	0.037	0.013	0.075	0.029
France	0.068	0.027	0.115	0.067	0.035	0.015	0.056	0.036	0.033	0.012	0.059	0.030
Germany	0.060	0.024	0.108	0.054	0.030	0.015	0.048	0.028	0.029	0.009	0.061	0.022
Netherlands	0.066	0.030	0.118	0.057	0.034	0.015	0.057	0.032	0.031	0.015	0.061	0.023
Panel b) EMU EU-15 Peripheral												
Greece	0.027	0.004	0.062	0.020	0.009	0.000	0.024	0.006	0.014	0.004	0.038	0.006
Ireland	0.029	0.006	0.064	0.023	0.013	0.004	0.026	0.011	0.014	0.001	0.037	0.008
Italy	0.050	0.027	0.081	0.046	0.023	0.015	0.040	0.018	0.026	0.012	0.041	0.025
Portugal	0.025	0.001	0.045	0.029	0.012	0.001	0.024	0.012	0.011	0.000	0.021	0.013
Spain	0.044	0.006	0.086	0.043	0.020	0.006	0.040	0.018	0.023	0.000	0.046	0.024
Panel c) non-EMU new EU												
Czech Republic	0.020	0.007	0.035	0.019	0.005	0.003	0.006	0.005	0.007	0.004	0.006	0.010
Hungary	0.024	0.001	0.051	0.023	0.006	0.001	0.008	0.007	0.005	0.000	0.003	0.009
Poland	0.021	0.004	0.035	0.022	0.006	0.004	0.005	0.007	0.005	0.000	0.005	0.008
Panel d) non-EMU EU-15												
Denmark	0.044	0.001	0.070	0.055	0.023	0.001	0.035	0.029	0.020	0.000	0.035	0.023
Sweden	0.028	0.007	0.040	0.035	0.013	0.004	0.019	0.016	0.010	0.003	0.011	0.014
UK	0.033	0.007	0.067	0.029	0.016	0.001	0.037	0.013	0.014	0.006	0.026	0.012

Note: Sample A refers to the "tranquil period" extending form 1 January 2005 to 6 August 2007. Sample B refers to the financial crisis period extending from 7 August 2007 to 31 December 2009. Sample C refers to the European sovereign debt crisis extending from 1 January 2010 to 15 December 2013.

Table 2. ANOVA test of mean equality

	Coexceedances		Negative coexceedances		Positive coexceedances	
	B–C samples	A–B–C samples	B–C samples	A–B–C samples	B–C samples	A–B–C samples
Panel a) EMU EU-15 Central						
Austria	12.728*	22.790*	5.854*	10.296*	6.859*	11.700*
	(0.000)	(0.000)	(0.016)	(0.000)	(0.009)	(0.000)
Belgium	27.187*	33.185*	8.137*	11.982*	18.595*	20.307*
	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)
France	11.454*	21.164*	3.689*	8.223*	8.270*	12.608*
	(0.001)	(0.000)	(0.055)	(0.000)	(0.004)	(0.000)
Germany	17.267*	22.585*	4.380*	6.275*	16.185*	18.057*
	(0.000)	(0.000)	(0.037)	(0.002)	(0.000)	(0.000)
Netherlands	19.594*	23.019*	6.270*	9.252*	15.124*	14.069*
	(0.000)	(0.000)	(0.012)	(0.000)	(0.000)	(0.000)
Panel b) EMU EU-15 Peripheral						
Greece	19.670*	23.569*	10.226*	11.974*	23.335*	18.783*
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Ireland	17.311*	20.549*	5.344*	5.585*	17.876*	18.151*
	(0.000)	(0.000)	(0.021)	(0.004)	(0.000)	(0.000)
Italy	8.917*	11.111*	6.912*	5.366*	3.356*	6.282*
	(0.003)	(0.000)	(0.009)	(0.005)	(0.067)	(0.002)
Portugal	2.763*	13.775*	3.649*	7.332*	1.649	6.917*
	(0.097)	(0.000)	(0.056)	(0.001)	(0.199)	(0.001)
Spain	13.222*	25.812*	7.729*	9.561*	5.956*	16.419*
	(0.000)	(0.000)	(0.006)	(0.000)	(0.015)	(0.000)
Panel c) non-EMU new EU						
Czech Republic	3.857*	6.866*	0.166	0.480	0.519	0.953
	(0.05)	(0.001)	(0.684)	(0.619)	(0.471)	(0.386)
Hungary	9.182*	17.873*	0.074	1.628	1.825	3.713*
	(0.003)	(0.000)	(0.786)	(0.197)	(0.177)	(0.025)
Poland	2.384	8.338*	0.265	0.306	0.529	2.781*
	(0.123)	(0.000)	(0.607)	(0.736)	(0.467)	(0.062)
Panel d) non-EMU EU-15						
Denmark	1.478	21.863*	0.447	9.613*	1.990	11.700*
	(0.224)	(0.000)	(0.504)	(0.000)	(0.159)	(0.000)
Sweden	0.259	7.631*	0.300	2.618*	0.186	2.687*
	(0.611)	(0.001)	(0.584)	(0.073)	(0.666)	(0.068)
UK	13.478*	18.776*	10.637*	12.995*	4.499*	5.254*
	(0.000)	(0.000)	(0.001)	(0.000)	(0.034)	(0.005)

Note: F-test denotes the ANOVA test with the null hypothesis that the number of coexceedances is equal in the A, B and C (B and C) sub-samples (see note to Table 1). * indicates that the null hypothesis is rejected.

Table 3. Parameter estimates from the binomial logit model for the positive coexceedance variable

	Constant	SR_t^{ECB}	SR_t^{FED}	R_t^{EA}	R_{t-1}^{US}	S_t^{EA}	S_{t-1}^{US}	S_t^{C}	$\sigma_t^{S,EA}$	$\sigma_{t-1}^{S,US}$	
Austria	-3.484	-0.076	-0.003	7.522	2.120	-46.265*	-5.235	21.06*	810.78*	1765.034*	
Belgium	-3.11	0.062	0.103*	3.869	0.125	-12.192	-12.732*	-13.159	554.851	1874.804*	
France	-3.433	-0.085	-0.013	4.000	0.243	-17.347	-7.597	-5.995	847.892*	1542.855*	
Germany	-3.545	-0.088	-0.039	7.579	-0.37	-22.149	-9.085	3.493	1014.349*	2298.313*	
Netherlands	-3.507	-0.088	-0.043	3.107	-0.208	-1.889	-7.754	-18.832	947.572*	1808.897*	
Greece	-3.778	-0.02	0.031	-7.911	2.871*	-23.204*	-5.855	13.049	520.169	1356.211	
Ireland	-3.675	-0.097	0.043	-4.403	2.407	-34.192*	-8.491	-4.936	-15.342	342.036	
Italy	-3.83	0.129	0.017	6.07	-0.791	-27.688	-4.484	17.249	873.121*	2030.891*	
Portugal	-3.976	-0.119	0.004	12.618	-0.622	-29.866	-8.480	13.114	1119.652*	2777.628*	
Spain	-5.137	-0.199	0.041	13.056	1.298	5.023	7.313	-43.617*	1158.995*	2368.994*	
Czech	-6.502	0.036	-0.300	-22.375	-10.872*	7.741	43.898*	0.342	71.679	360.901	
Hungary	-6.652	-0.045	-0.294	-8.328	0.249	13.016	-26.528	-18.746	-336.184	4300.496	
Poland	-7.268	0.077	-0.527	-1.153	-0.659	-7.056	32.969	30.414	1793.26*	880.664	
Denmark	-4.029	-0.139	0.025	1.668	1.725	3.145	-2.727	-36.906*	364.11	2270.556*	
Sweden	-5.588	-0.032	-0.320	1.855	2.619	-32.354	-17.263	34.43	900.071	2993.231*	
UK	-4.368	0.116	0.075	7.212	1.170	-47.943	-17.913*	22.291	393.296	2216.545*	
	D_t	$D_t \cdot SR_t^{ECB}$	$D_t \cdot SR_t^{FED}$	$D_t \cdot R_t^{EA}$	$D_t \cdot R_{t-1}^{US}$	$D_t \cdot S_t^{EA}$	$D_t \cdot S_{t-1}^{US}$	$D_t \cdot S_t^{C}$	$D_t \cdot \sigma_t^{S,EA}$	$D_t \cdot \sigma_{t-1}^{S,US}$	MF R^2
Austria	-1.022*	0.157	0.567	-38.793*	4.363	-4.575	3.745	2.523	3248.724*	2520.22	0.143
Belgium	-1.373*	-0.128	0.511	-44.952*	19.99	-30.219	8.704	45.721	3119.28*	2152.571	0.134
France	-1.005*	0.155	-0.108	-39.111*	13.346	56.261	11.414	-63.701	2535.65*	1327.275	0.123
Germany	-1.365*	0.077	-0.124	-33.049*	13.503	23.8	-0.247	-61.99	2065.85	218.11	0.182
Netherlands	-1.416*	0.081	-0.012	-33.237*	14.904	-40.634	-5.41	6.098	2410.61*	1445.982	0.178
Greece	-2.663*	0.025	0.322	-44.871	66.485*	51.865*	0.893	14.446	215.806	-4003.923	0.172
Ireland	-2.451*	0.333	0.034	-45.991	41.528	105.287*	15.467	-24.338	2250.288	294.287	0.174
Italy	-1.174*	-0.224	0.742	-41.147*	18.486	-	3.419	150.926*	1874.827	631.129	0.158
Portugal	-0.525	-0.016	0.732	-45.137*	13.621	-7.773	25.836	47.78	1185.944	-1433.581	0.199
Spain	-0.48	0.176	1.048	-41.294	14.674	-42.704	8.6	106.417*	2943.911*	883.659	0.140
Czech	0.196	0.203	0.254	-46.808	80.486*	16.216	-52.293	93.514*	1252.511	1848.029	0.289
Hungary	0.815	0.091	-0.377	-79.073*	33.857	84.768*	55.554	71.306	-5450.643	-9956.382	0.339
Poland	1.395	-0.053	0.175	-61.121	9.72	96.456*	1.038	7.412	-4509.754	-4288.565	0.311
Denmark	-0.939*	0.144	-0.227	-38.389*	10.679	-29.731	-3.034	-15.412	2646.257*	400.96	0.195
Sweden	-0.196	0.012	-0.26	-55.88*	17.197	47.745	11.483	-93.561*	3756.226*	2389.205	0.203
UK	-2.056*	-0.182	-0.656	5.802	29.114	57.882	12.22	-	4957.798*	3541.887	0.235

Note: * indicates significance at the 10% level. SR_t^{ECB} and SR_{t-1}^{FED} refer to monetary policy surprises announced by the ECB and the Fed, respectively; R_t^{EA} and R_{t-1}^{US} refer to the 3-month interbank interest rate (Euribor) and the 3-month Treasury bill rate, respectively; S_t^{EA}, S_{t-1}^{US} and S_t^{C} refer to the Eurostoxx50 index returns, the S&P500 index returns and the stock index returns of each country, respectively; and $\sigma_t^{S,EA}$ and $\sigma_{t-1}^{S,US}$ refer to the volatility of the Eurostoxx50 index returns and the S&P500 index returns, respectively. Volatility series have been multiplied by 100. D_t refers to a dummy variable that equals one during the sovereign debt crisis (from 1 January 2010 until the end of the sample period) and zero before. MF R^2 refers to McFadden's pseudo-R^2.

Table 4. Parameter estimates from the binomial logit model for the negative coexceedance variable

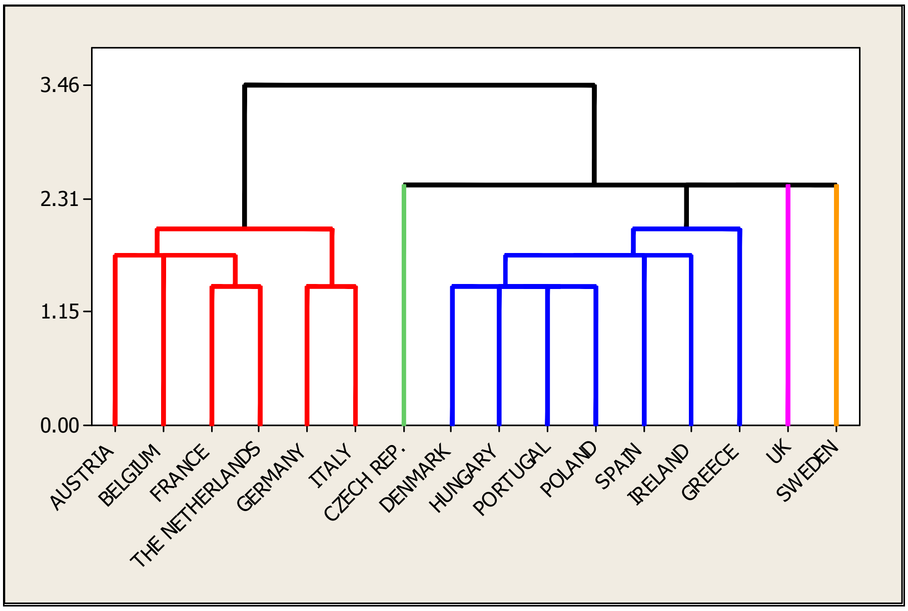
	Constant	SR_t^{ECB}	SR_t^{FED}	R_t^{EA}	R_{t-1}^{US}	S_t^{EA}	S_{t-1}^{US}	S_t^{C}	$\sigma_t^{S,EA}$	$\sigma_{t-1}^{S,US}$
Austria	-3.084	-0.124	-0.394	-6.596	-1.985	34.327*	1.182	-0.168	148.338	-157.705
Belgium	-3.085	-0.111	-0.423	-11.658	-1.897	-2.126	3.429	47.059*	45.759	720.765
France	-3.182	-0.053	-0.393	-8.643	-2.715	35.065	1.652	2.574	99.702	-184.228
Germany	-3.393	-0.062	-0.422	-14.215	-2.185	30.034	4.589	0.412	123.937	475.328
Netherlands	-3.121	-0.052	-0.371	-11.025	-2.576	19.237	-1.911	16.425	2.538	-135.368
Greece	-4.521	-0.209*	-0.425	-31.563*	-3.672	16.319	17.532	-9.038	331.598	-194.819
Ireland	-4.672	-0.11	-0.481	-25.906*	2.491	9.673	3.969	42.625*	269.642	-465.153
Italy	-3.79	-0.159*	-0.365	-15.835	-3.304*	-9.351	5.595	30.333	463.947	520.441
Portugal	-3.628	-0.087	-0.423	-16.191	-1.95	8.553	3.744	18.325	225.412	283.695
Spain	-4.083	-0.113	-0.556	-31.479*	2.09	8.161	4.173	28.197	-389.348	-390.693
Czech	-5.914	0.011	-0.329	-35.757*	-6.202*	6.496	3.320	-7.652	-335.709	1410.031
Hungary	-6.136	-0.155	-0.253	-22.414	-5.03*	-24.365	16.805	-19.182	239.952	-42.665
Poland	-8.858	-0.061	-0.334	-82.38*	-0.06	-3.592	15.711	-	-1560.019	-3268.738
Denmark	-3.66	-0.094	-0.453	-22.89*	0.855	37.108*	-1.864	-20.872	-167.627	586.471
Sweden	-5.09	-0.14	-0.512	-12.025	1.532	31.498	-13.326	-14.132	761.85	2602.408*
UK	-3.844	-0.259*	-0.394	-23.485*	-3.904*	20.985	4.693	-5.863	203.992	73.573

	D_t	$D_t \cdot SR_t^{ECB}$	$D_t \cdot SR_t^{FED}$	$D_t \cdot R_t^{EA}$	$D_t \cdot R_{t-1}^{US}$	$D_t \cdot S_t^{EA}$	$D_t \cdot S_{t-1}^{US}$	$D_t \cdot S_t^{C}$	$D_t \cdot \sigma_t^{S,EA}$	$D_t \cdot \sigma_{t-1}^{S,US}$	MF R^2
Austria	-0.894*	-0.208	0.447	17.2	10.15	-22.483	-15.011	13.479	2541.701*	4336.641*	0.096
Belgium	-0.939*	-0.186	0.438	5.927	15.645	30.96	-1.146	-71.938*	2891.23*	2183.815	0.103
France	-0.904*	-0.254*	0.448	1.7	13.907	-120.887	-0.317	104.015	2868.618*	2705.561	0.100
Germany	-0.938*	-0.309*	0.418	22.756	23.149	-53.961	-6.468	72.571	2376.541*	5020.625*	0.123
Netherlands	-0.917*	-0.283*	0.314	17.231	15.966	-32.644	5.333	38.815	2348.179*	4440.557*	0.106
Greece	-1.862*	0.216	0.504	58.405	-40.569	-30.744	-23.771	17.472	4534.3*	3213.252	0.183
Ireland	-0.018	0.028	0.261	70.504*	-17.668	-31.127	29.411	-38.898	351.286	2515.842	0.163
Italy	-0.802	-0.116	0.32	12.557	-0.376	8.334	4.032	-67.069	977.221	-71.779	0.128
Portugal	-0.774	-0.230	0.395	18.596	4.380	-34.024	-6.053	-32.288	444.564	416.436	0.107
Spain	-0.968	0.024	0.270	83.201*	-18.564	14.655	-15.778	-81.324*	2975.186*	4476.486	0.105
Czech	-0.096	-0.14	-0.292	94.692*	-20.25	-88.247*	30.086	-2.505	-811.582	-3528.975	0.176
Hungary	0.21	-0.252	0.276	20.755	-16.063	-9.85	-43.29	-13.388	1230.489	1150.414	0.230
Poland	3.244	-0.557	0.041	126.500	-52.125	-18.072	22.210	-19.104	-4218.89	-2667.215	0.432
Denmark	-0.61	-0.28*	0.456	27.28	10.524	-25.574	12.619	56.543*	2758.365*	3213.08	0.104
Sweden	0.784	-0.298*	0.491	28.308	-5.909	-40.936	30.492	53.05	-803.114	-467.842	0.150
UK	-1.451*	0.189	0.254	62.404*	45.785*	-21.286	-16.234	79.834	2029.392	5809.845*	0.158

Note: See note to Table 3.

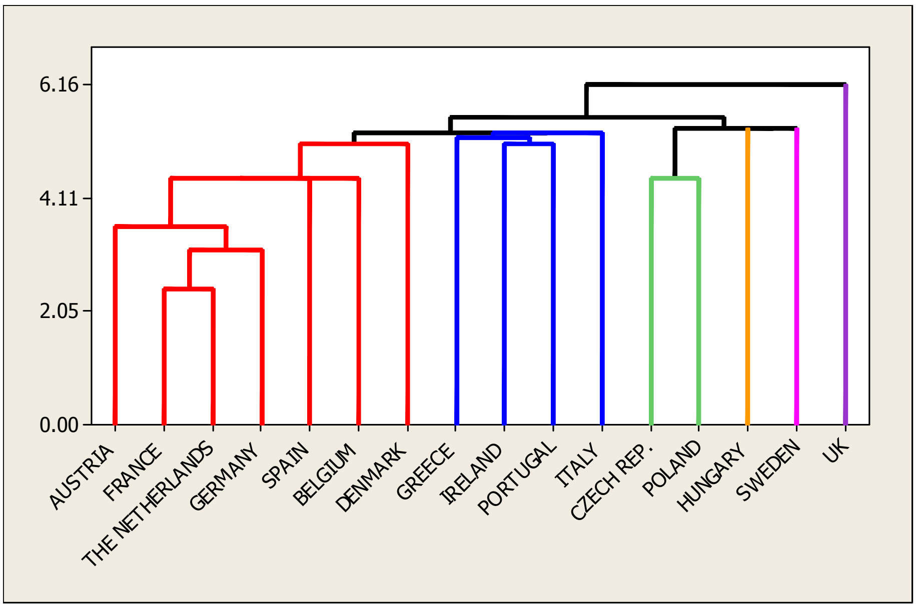
7. Figures

Figure 1: Hierarchical Cluster Analysis ("Tranquil" period: 1 January 2005 to 6 August 2007)



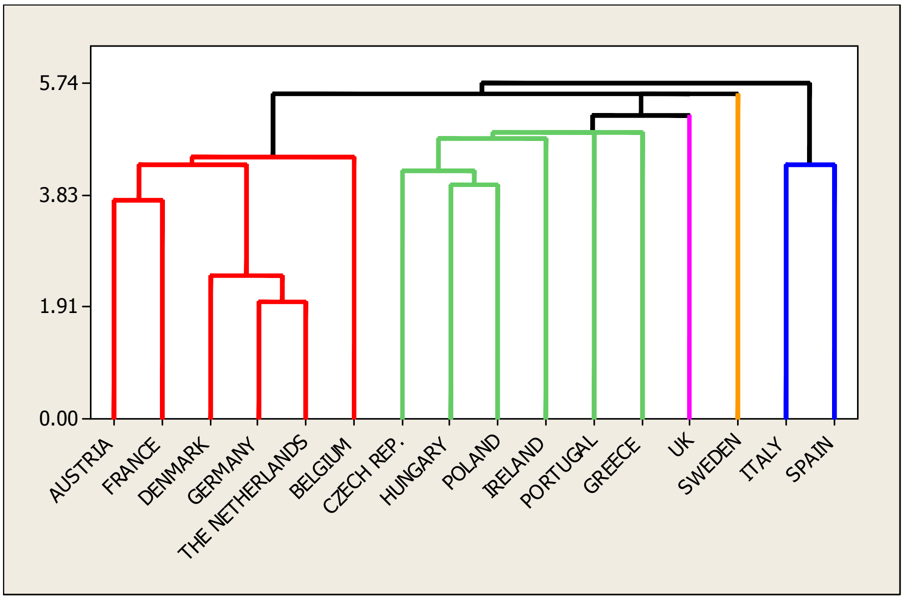
Note: The dendrogram is based on the single amalgamation method with a Euclidean distance measure.

Figure 2: Hierarchical Cluster Analysis (Financial crisis: 7 August 2007 to 31 December 2009)



Note: The dendrogram is based on the single amalgamation method with a Euclidean distance measure.

Figure 3: Hierarchical Cluster Analysis (European Sovereign debt crisis: 1 January 2010 to 15 December 2013)



Note: The dendrogram is based on the single amalgamation method with a Euclidean distance measure.

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