

Interconnectedness Among Sovereign Yield Curve Factors - Working title

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Abstract

We are investigating the interconnectedness of the yield curve factors of 12 developed economies worldwide. From the yield curve time series we extract the Level, Slope and Curvature factors by the Diebold-Li decomposition technique for every day. On the received 36 observation series a pairwise Toda-Yamamoto causality test is performed in order to identify connections. Our static results show that there is a significant amount cross connections among the different factors. On average Level is the most connected factor, followed by Slope and Curvature. We also identify the USA to be the main driver of the observation universe. Our dynamic results show that during turbulent economic periods the density of the connections gets higher. On the chosen time horizon, USD Level, USD Curvature and Norwegian Slope are the most interconnected factors.

1 Introduction

The subprime crisis renewed the interest in analyzing the co-movements of different financial instruments and systemic risk related studies came to the forefront. Shocks can be transmitted differently across various assets, therefore it is convenient to achieve awareness both for regulators and other market participants in order to react more efficiently. Understanding such network structures are valuable for reducing potential damage and making appropriate future decisions. Analysis of the interconnectedness of different assets plays crucial role in systematic risk assessment. Furthermore, during crises the strength of connections sharply increases and risk spills over across financial institutes and sovereign bonds, as it happened during the Financial Crisis of 2008-2009 and during the European Sovereign Crisis ([Diebold and Yilmaz \(2012\)](#), [Diebold and Yilmaz \(2014\)](#), [Demirer et al. \(2018\)](#)).

The literature distinguishes between two different channels of impacts which are mutually exclusive. Fundamentals of different economical entities may be interconnected by flows of goods, services, and capital. These effects are known in the literature as *spillovers* ([Masson \(1999\)](#)), *interdependence* and *interconnectedness* ([Forbes and Rigobon \(2002\)](#), [Forbes \(2012\)](#)), or *fundamentals-based contagion* ([Kaminsky and Reinhart \(2000\)](#)). On the other hand, financial shocks in one firm or country may conceivably trigger crises elsewhere their fundamentals. This transmission mechanism is known in the literature as *pure contagion* ([Masson \(1999\)](#)).

Since the financial system is a huge, complicated, interactive system, in recent years scholars began using complex network theories to investigate the interconnectedness of financial institutions. [Acemoglu et al. \(2015\)](#) points out that in smaller financial systems, shocks make the densely interconnected network steadier, however after a certain size the opposite applies. [Glasserman and Young \(2015\)](#) has some common features with the previously mentioned article, however they allow continuous distributions of the shocks. By doing so, they state that the probability of default of a firm is lower when a shock hits some of its neighbors compared with when the firm is directly hit. According to [Elliott et al. \(2014\)](#), diversification initially allows failure cascades to travel within the system, but as it increases further, organizations are better insured against others' failures. Depending more on other participants makes personal sensitivity lower on own investments. An other mechanism of shock transmission is the decrease of interbank loan availability as known as funding liquidity shock. [Gai and Kapadia \(2010\)](#) examine the liquidity hoarding that formed on the interbank funding markets. They find that such accumulation of liquidity can flow through a banking network, with serious consequences. As soon as one bank draws down or shortens the terms of its interbank loans, the related banks are eager to do the same. This results a liquidity shock that is not characterized by the damping of interbank default shocks.

In the empirical literature there are several methods to measure connectedness. In the last decade the widespread methods are Granger causality network ([Billio et al. \(2012\)](#)), CoVaR ([Adrian et al. \(2008\)](#)), MES ([Acharya et al. \(2012\)](#)) and numerous studies appeared based on the Vector AutoRegressive Diebold-Yilmaz (DY) framework ([Diebold and Yilmaz \(2009\)](#), [Diebold and Yilmaz \(2012\)](#), [Diebold and Yilmaz \(2014\)](#)). Compared to CoVaR and MES methods, the advantage of Granger causality based frameworks is the ability to examine the network both on micro (pairwise connectedness) and macro (total connectedness) level. As result, these methods have been often used to analyse the network on different asset classes like equities, bonds, exchange rates or commodity prices. Most analysis focuses on the whole system or some subpart. The dynamics of individual assets' role in the system have not been explored yet.

First: Granger causality finds a lot of spurious correlations and time series are cointegrated, better to use Ty method

Second: There is a significant amount of cross connection between different factors of the yield curves

Third: The USA is the main driver of the univers

Fourth: Sertain factors behave differently in recession and in normal times

2 Literature review

Central banks traditionally rely on the co-movements of different maturities of yield curves to make effective monetary policy decisions. According to the expectations hypothesis, long-term interest rates are influenced by current and expected future short-term interest rates ([Laopodis \(2004\)](#)). However, increasing globalization of financial systems and structural changes across economies have disrupted the integration of the maturity spectrum of different yield curves. Short-end movements are more exposed to monetary policy decisions, so their interconnectedness is more consistent with the alternation of business cycles. The long end of the yield curve is mainly affected by global investment, with current preferences and risk appetite being the primary drivers. The integration of distant maturity points is driven by global capital flows and the volume of investments ([Ilmanen \(1995\)](#)).

An overview of existing literature on bond market reveals that connection metrics can be calculated via numerous methods based on different underlyings. Bond returns have been in the scope of research for decades. [Ilmanen \(1995\)](#) examines the predictable variation in long-maturity government bond returns in six countries using a linear regression model with local and global instruments. [Driessen et al. \(2003\)](#) estimate and interpret the factors that jointly determine bond returns of different maturities in the US, Germany, and Japan. They find that the positive correlation between bond markets is driven by the term structure levels, not by term structure slopes. [Engsted and Tanggaard \(2007\)](#) analyzed the co-movement of US and German bond markets and found significant spillover effects from the US to Germany and only limited spillover vice versa. [Piljak \(2013\)](#) compared the co-movement of the total bond return index in ten emerging economies and four frontier markets with that of the US market and found that domestic and global factors explain the variation in the bond returns in emerging and frontier markets. [Ahmad et al. \(2018\)](#) used panel regression method to analyze the determinants of net spillover. They found that government debt, current account deficit, and interest rate are major determinants of financial connectedness.

Other articles make consequences based on bond yields or certain points of the yield curve. [Sutton \(2000\)](#) examined the co-movement of bond yields of the US, the UK, Japan, Germany and Canada, and highlighted that the long end of term structure of interest rates is positively correlated across markets. He used bond yields of 3 months and 10 years as proxies for short-term and long-term interest rates. [Laopodis \(2004\)](#) examines the monetary policy implications of the greater integration of the capital markets using long-term interest rates. He finds greater convergence among countries in the EU (European Union) as Germany still retains its hegemonic status. [Kumar and Okimoto \(2011\)](#) examined the bond market integration in six G7 economies using the smooth-transition copula-GARCH model. Their results highlighted that the long end of the yield curve is more integrated than the short end of the yield curve. [Fernández-Rodríguez et al. \(2015\)](#) examine volatility spillovers in EMU sovereign bond markets. They find that slightly more than half of the total variance of the forecast errors is explained by shocks across countries rather than by idiosyncratic shocks. They also report that during the pre-crisis period, most of the triggers in the volatility spillovers were central EMU countries – peripheral countries imported credibility from them – while during the crisis, peripheral countries became the dominant transmitters. [Fernández-Rodríguez et al. \(2016\)](#) examine the time-varying behavior of net pair-wise directional connectedness at different stages of the recent sovereign debt crisis.

There are papers where bond spreads are used. [Balli \(2009\)](#) examines the time-varying nature of European government bond market integration by employing multivariate GARCH models. He

states that global factors are sufficient for the volatility of yield differentials among euro government bonds. [Favero and Missale \(2012\)](#) provide new evidence on the determinants of sovereign yield spreads and market sentiment effects in the Eurozone to evaluate the rationale for a common Eurobond jointly guaranteed by Eurozone member states. [Antonakakis and Vergos \(2013\)](#) examined the spillovers in the sovereign yield spread among Euro zone countries and found 61% of the variances are explained by the spillovers from other countries. [Sibbertsen et al. \(2014\)](#) study tests for a break in the persistence of EMU government bond yield spreads examining data from France, Italy and Spain and using German interest rates as a kind of benchmark. Their results provide evidence for breaks between 2006 and 2008. The persistence of the yield spreads against German government bonds has increased significantly after this period. [Claeys and Vašíček \(2014\)](#) measure direction and extent of sovereign bond markets linkages among sixteen EU (European Union) using a factor-augmented version of the VAR model.

[Bae and Kim \(2011\)](#) identified the yield curve interactions for the East Asian regions and found that more than regional factors, global factors play an important role in explaining yield curve dynamics. [Abbritti et al. \(2013\)](#) measured the impact of global factors using the affine term structure model, and concluded that global factors influence the long end of the yield curve. [Sowmya et al. \(2016\)](#) investigate linkages between latent factors of the yield curves of four developed countries and seven Asian Economies. They find that the regional influence is higher in slope and curvature factors among the Asian countries. The number of linkages are high during periods of crisis.

3 Methodology

3.1 The Nelson-Siegel yield curve model and the Diebold-Li decomposition

The target of the yield curve models is to enable the fitting of the yield curve, then the parametric interpolation and extrapolation afterwards, which is in line with the non-parametric (statistics based) fitting methods, such as smoothing splines. Besides the statistical approaches, the model of [Diebold and Li \(2006\)](#) spread widely both in the academic literature and in industrial applications. This method is the dynamic extension of the yield curve modelling elaborated by [Nelson and Siegel \(1987\)](#). The observed yield curve can be described with the following equation:

$$y_\tau = \beta_1 + \beta_2 \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) + \beta_3 \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right) \quad (1)$$

where y_τ are the realized values for τ maturity, β_1, β_2 és β_3 are time varying parameters, and λ is the exponential decay factor. The Nelson-Siegel model is a simple way of yield curve fitting, while the approach is capable to capture the stylized facts observable on the market, such as the usual shape of yield curves (forward sloping, inverse, humped). The β_i parameters have an economic meaning, β_1 represents the long end of the yield curve, β_2 is the short term component, while β_3 mimics the middle interval. According to the interpretation of [Litterman and Scheinkman \(1991\)](#) these factors can be considered as the Level, Slope and Curvature of the yield curve, accordingly. These components can be utilized for interest-rate asset immunization as well. Besides simple estimation, the model of [Diebold and Li \(2006\)](#) has two further advantages compared to non-parametric approaches. First is, that the extrapolation is more accurate thanks to the model being exponential. The other is the upper mentioned Litterman interpretation with which understanding and comparing results becomes much easier.

With the extension of [Diebold and Li \(2006\)](#) the Nelson-Siegel model becomes dynamic (the curve fits on multiple observations). The parametrization of the yield curve can be done at every point in time to form a set of time-dependent parameters. This is achieved in a two steps procedure:

- First, the λ parameter gets fixed such that the second factor attains its maximum at $\tau = 30$ months and the β parameters get derived.
- Next, an AR(1)-process is fitted to these time dependent parameters to model the dynamics over time, which results the dynamic Nelson-Siegel model.

Additional stylized facts achieved by the Diebold-Li model is the high persistence of time dynamics (same yield curve tenors are highly dependent on past values) and the fact that the long end of the curve is less volatile than the short end.

3.1.1 The Toda-Yamamoto model

The Today-Yamamoto framework is a popular causality testing method. It is widely used in time series analysis. [Zhang and Cheng \(2009\)](#) check the relationship between economic growth and carbon emissions or energy consumption and find that neither of the proposed variables leads

to economic growth. [Hansen and Rand \(2006\)](#) look for dependencies between foreign direct investments and increase of the GDP in a sample of 31 developing countries. They find evidence that FDI causes growth. While checking healthcare related expenditures and GDP growth, [Amiri and Ventelou \(2012\)](#) conclude that bidirectional causality is predominant. [Basher et al. \(2012\)](#) say that there is an evidence that increases in emerging market stock prices increase oil prices. The common factor in the upper mentioned researches, that the authors has to deal with integrated or cointegrated time series sets.

The [Toda and Yamamoto \(1995\)](#) method uses the followig premise: the classic Granger causality test ([Granger \(1969\)](#)) obtained by a VAR model may cause a non-stationarity problem since it does not account the potential cointegration between the used time series. [Toda and Yamamoto \(1995\)](#) point out, that the usual Wald test leads to integrated or cointegrated VAR model, which eventually results spurious Granger causal connections. The Toda-Yamamoto approach eliminates this shortcoming by introducing a modified Wald test (MWald) which has restrictions on the parameters of the VAR(p) model. The test is based on a χ_p distribuiton, where $p' = p + d^{max}$. The order of VAR is increased artificially, p gets increased by d^{max} which is the maximal order of the integration. Then a VAR with order of $(p + d^{max})$ is estimated, where the last d^{max} lag coefficient is ignored. A VAR($p + d^{max}$) model is described by equations a (2) and (3):

$$Y_t = \alpha_0 + \sum_{i=1}^p \delta_{1i} Y_{t-i} + \sum_{j=p+1}^{d^{max}} \alpha_{1j} Y_{t-j} + \sum_{j=1}^p \theta_{1j} X_{t-j} + \sum_{j=p+1}^{d^{max}} \beta_{1j} X_{t-j} + \omega_{1t} \quad (2)$$

$$X_t = \alpha_1 + \sum_{i=1}^p \delta_{2i} Y_{t-i} + \sum_{j=p+1}^{d^{max}} \alpha_{2j} Y_{t-j} + \sum_{j=1}^p \theta_{2j} X_{t-j} + \sum_{j=p+1}^{d^{max}} \beta_{2j} X_{t-j} + \omega_{2t} \quad (3)$$

where α, δ, θ and β are model parameters, p is the optimal lag of the original VAR model, ω_{1t} és ω_{2t} are the errors of the VAR model, and d^{max} is the maximal order of integration in terms of the Toda-Yamamoto model. Hereby based on (2), there is a Granger causality between X and Y , $\delta_{1i} \neq 0$ for all i . In the same manner, based on (3), Granger causality is observable between Y and X , if $\delta_{2i} \neq 0$ for all i . From the VAR($p + d^{max}$) model, the Toda–Yamamoto approach is realized in three steps:

- Perform d^{max} ordered stationarity test on all time series with applying ADF (Augmented Dickey-Fuller test), KPSS (Kwiatkowski-Phillips-Schmidt-Shin test) and PPE (Phillips-Perron test) tests individually or in combination.
- Determine the optimal lag, (p) with the maximal consistency of the AIC (Akaike's Information criterion), the FPE (Akaike's Final Prediction Error), the BIC (Bayesian Information Criterion), the HQ (Hannan-Quinn criterion) and the LR (Lielhood Ratio test) criteria.
- With the application of the upper mentioned parameters, rejecting the Granger test between X and Y means a causality relation in Toda-Yamamoto terms. Bivariate rejection suggests a mutual causal relationship between the variables.

The Toda-Yamamoto procedure has three main advantages. First and foremost, as mentioned above, it can be utilized on integrated an cointegrated time series without any preliminary testing. Second, according to [Rambaldi and Doran \(1996\)](#) the computaion of MWald test is simple, since

it can be calculated with a set of Seemingly Unrelated Regressions. Third, [Zapata and Rambaldi \(1997\)](#) shows that in an intentionally overfitted environment, the MWALD test performs as well as more complicated procedures (if the sample size is at least 50).

4 Data

Twelve developed countries were selected to the examination universe based on the OECD classification. We chose those twelve countries which have the highest GDP and have a yieldcurve time series history back from 1/1/1999. The rates were collected from Bloomberg. The following sovereigns were chosen: Australia, Canada, Switzerland, Germany, Spain, France, Great Britan, Italy, Japan, South Korea, The Neatherlands and The United states of America. Ongoingly they are referred as the three letter abbreviation introduced by OECD. Respectively: AUS, CAN, CHN, DEU, ESP, FRA, GBR, ITA, JPN, KOR, NLD and USA. During the empirical analysis, each yield curve is examined by its whole node structure with fifteen different maturities: 3, 6, 12, 24, 36, 48, 60, 72, 84, 96, 120, 180, 240 and 360 months. These apply for all countries. The first observation day is 1/1/1999 while the last one is 12/31/2021. Altogether we work with 6001 daily observations. Missing data points are forward filled from the previous day.

The inputs of the country yield curves are always zero-coupon bonds, denominated in the local currency of the sovereign. Debt in local currency represents the different interest rate cycles of the economy and represents the domestic monetary policy better. Furthermore the debt denominated in local currency has better liquidity and credit rating than holding the same in USD ([Sowmya et al. \(2016\)](#)). Table 2 in the appendix provides descriptive statistics for the 1, 5, 10 and 30 year nodes of each country yield curves. The Level (L), Slope (S) and Curvature (C) factors are calculated by [Diebold and Li \(2006\)](#), [Diebold et al. \(2008\)](#), assuming a dynamic Nelson-Siegel model. Figure 1 shows the normalized time series of the factors. On the below figure period denoted with green shading represents the dotcom bubble, the red shading represents the subprime crisis, the blue stands for the European sovereign debt crisis and yellow shading indicates the Covid19 pandemic. These periods are determined based on [Bostanci and Yilmaz \(2020\)](#) and [Hué et al. \(2019\)](#).

Observing the below graphs one can notice several stylized facts. Level factors declined and converged across countries during the observation period. [Holston et al. \(2017\)](#) point out that the natural rate r^* declined over the past 25 years in advanced economies thanks to global, macro and demographic factors. [Evans and Marshall \(2007\)](#) find evidence from the US market, claiming that macro shocks shift the level factor of the yield curve. Slope time series show countercyclical behavior and comoves across countries. According to [Estrella and Hardouvelis \(1991\)](#) slope factor can predict recessions. On Figure 1/(b) drops can be seen during the period of the dotcom bubble and the subprime crisis. Also majority of Slope time series are in a downward trend during the Covid19 period. Curvature explains the variation in interest rates across maturities and represents term premium. It is mainly related to the current state of monetary policy and it has less exposure to the macroeconomic shocks ([Dewachter and Lyrio \(2006\)](#))

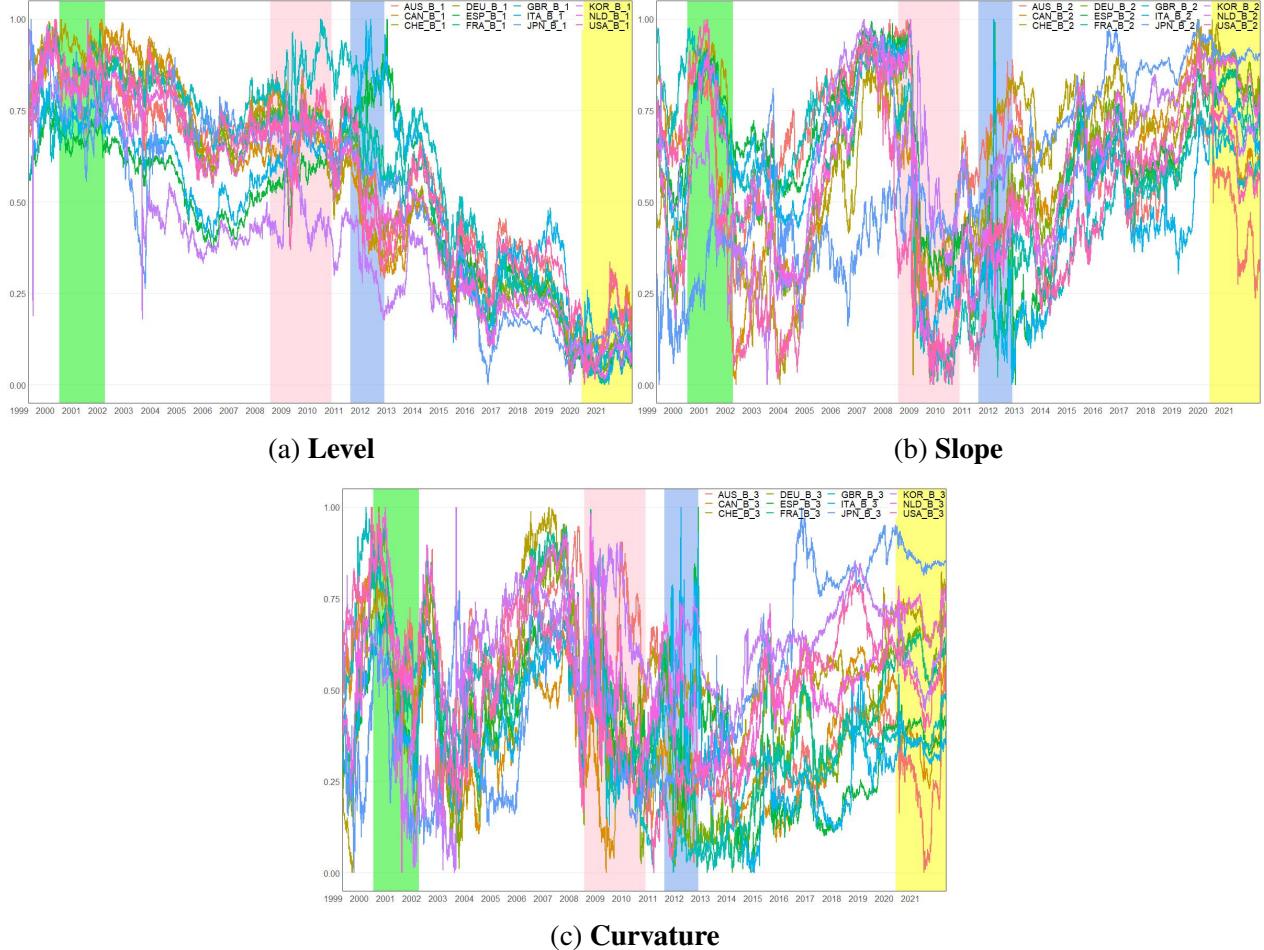


Figure 1: Normalized factor time series

Start of the dotcom bubble: NASDAQ Composite stock market index peaked at 5,048.62 (03/10/2000);

End of the dotcom bubble: Enron declared bankruptcy (12/02/2001);

Start of the subprime crisis: J.P. Morgan takes over Bear Stearns, the troubled investment bank (03/16/08);

End of subprime crisis: Dodd - Frank Act being enacted (06/21/2010);

Start of the European sovereign debt crisis: Portuguese government calls on EU for bailout (04/06/11);

End of the European sovereign debt crisis: Draghi makes the famous "Whatever It Takes" speech (07/26/12)

Start of Covid19 pandemic: WHO declared the novel coronavirus outbreak a global pandemic (01/20/2020).

The descriptive statistics of the factors are represented in Table 1. The average Level factor is positive in all cases, highest for South Korea and lowest for Japan. Average Slope refers to the typical increasing shape of the yield curves (negative values). Slope is negative for all countries meaning that longer maturities have higher values than shorter ones. In absolute terms Italy has the highest Slope, while Australia has the lowest. Potential positive values of Slope represent restrictive monetary policies. Curvature is always negative too, highest for Italy and lowest for Great Britain (in absolute terms).

Factor	Average	Std. dev.	Minimum	Maximum	Jarque-Bera t-stat.	P value
Australia						
Level	4.86	1.51	1.06	7.71	523	0
Slope	-1.11	0.99	-4.14	0.97	88	0
Curvature	-2.14	1.91	-6.8	2.93	207	0
Canada						
Level	3.92	1.56	0.7	6.62	394	0
Slope	-1.84	1.37	-5.35	0.58	346	0
Curvature	-2.19	1.95	-6.27	4.83	401	0
Australia						
Level	2.17	1.55	-0.79	4.63	516	0
Slope	-1.59	0.94	-4.1	-0.06	559	0
Curvature	-2.68	1.46	-7.25	1.05	46	0
Germany						
Level	3.33	1.98	-0.55	6.56	529	0
Slope	-1.84	1.11	-4.69	0.22	233	0
Curvature	-3.5	1.74	-6.81	0.96	251	0
Spain						
Level	4.53	1.73	0.75	8.56	382	0
Slope	-2.79	1.53	-7.35	-0.07	269	0
Curvature	-4	2.1	-8.75	3.9	111	0
France						
Level	3.7	1.8	0.11	6.63	559	0
Slope	-2.16	1.17	-4.85	0.16	241	0
Curvature	-3.98	1.91	-8.08	0.57	49	0
Great Britan						
Level	3.68	1.38	0.47	5.77	741	0
Slope	-1.43	1.69	-5.4	1.81	295	0
Curvature	-1.83	3.6	-8.79	8.77	96	0
Italy						
Level	4.82	1.44	1.43	7.9	466	0
Slope	-3.03	1.39	-6.36	-0.24	185	0
Curvature	-4.18	1.96	-8.74	4.06	136	0
Japan						
Level	1.79	0.91	-0.03	3.57	600	0
Slope	-1.42	0.75	-3.3	-0.09	322	0
Curvature	-3.73	1.44	-6.54	-0.95	507	0
South Korea						
Level	6.04	2.34	1.88	12.21	516	0
Slope	-3	1.59	-7.85	0.1	173	0
Curvature	-4.16	3.01	-14.38	2.67	1967	0
The Netherlands						
Level	3.43	1.97	-0.36	7.01	525	0
Slope	-1.96	1.15	-4.89	0.2	236	0
Curvature	-3.29	1.57	-8.4	0.74	176	0
USA						
Level	4.37	1.45	0.96	6.98	375	0
Slope	-2.46	1.72	-5.71	0.91	300	0
Curvature	-3.63	2.69	-10.35	3.27	199	0

Table 1: Descriptive statistics of yield curve factors

Factor time series are tested with ([Bera and Jarque \(1981\)](#)) test for normality. Neither of them passes the acceptance criteria therefore the null-hypothesis for normality is rejected. Furthermore ADF and KPSS unit-root tests for stationarity are applied. According to the ADF test, Level for Australia, Level for USA and Slope for Japan is stationary on 99% confidence level while according to the KPSS test, neither of the time series is stationary. The tests can be applied for first difference of the remaining time series too. The first difference is stationary for all of the time series which is confirmed by both of the used tests. The unit-root test results are represented in Table 5 in the

Appendix.

Before differentiating, a pairwise (Engle and Granger (1987) test is applied for determining cointegrations. Table 2 represents the ratio of the cointegrated time series aggregated by factors. Besides the diagonal, the Level - Curvature and the Slope - Curvature pairs both show a value more than 85%. Since the time series are not stationary on the same order and the ratio of cointegrated time series is high, we consider the Toda-Yamamoto approach to be justified for analyzing connections.

	Level	Slope	Curvature
Level	81.9%	22.2%	85.4%
Slope	15.3%	53.5%	90.3%
Curvature	23.6%	54.2%	91.0%

Table 2: Pairwise Engle-Granger test

Instead of the 36 x 36 matrix which we obtain from the pairwise Engle-Granger test, we highlight only the factor-wise aggregated values in this table.

5 Results

5.1 Static interconnectedness

We perform static and dynamic analysis of the factor interconnectedness resulted by the Toda-Yamamoto model. All of the available data points are used in the static method. Time series are differenciated once at maximum, and the optimal lag number is determined based on AIC. Figure 2 shows the causality relationships on 1 % significance level. Level factors are red, while Slope is blue and the Curvature is showed in green. The arrow between two factors shows the direction of the causality and its color represent the factor which it is started from.

From the three subsystems, the Slope network is the most dense. 31.06% of the potential relationships is significant. It is followed by Level (21.97%), then Curvature (17.42%). Considering cross connections, 31.25% of the possible edges going out from Level factors is significant. This ratio is 26.39% for Slope, and Curvature is the least interconnected factor in these terms, only 24.49% of the outgoing edges is significant.

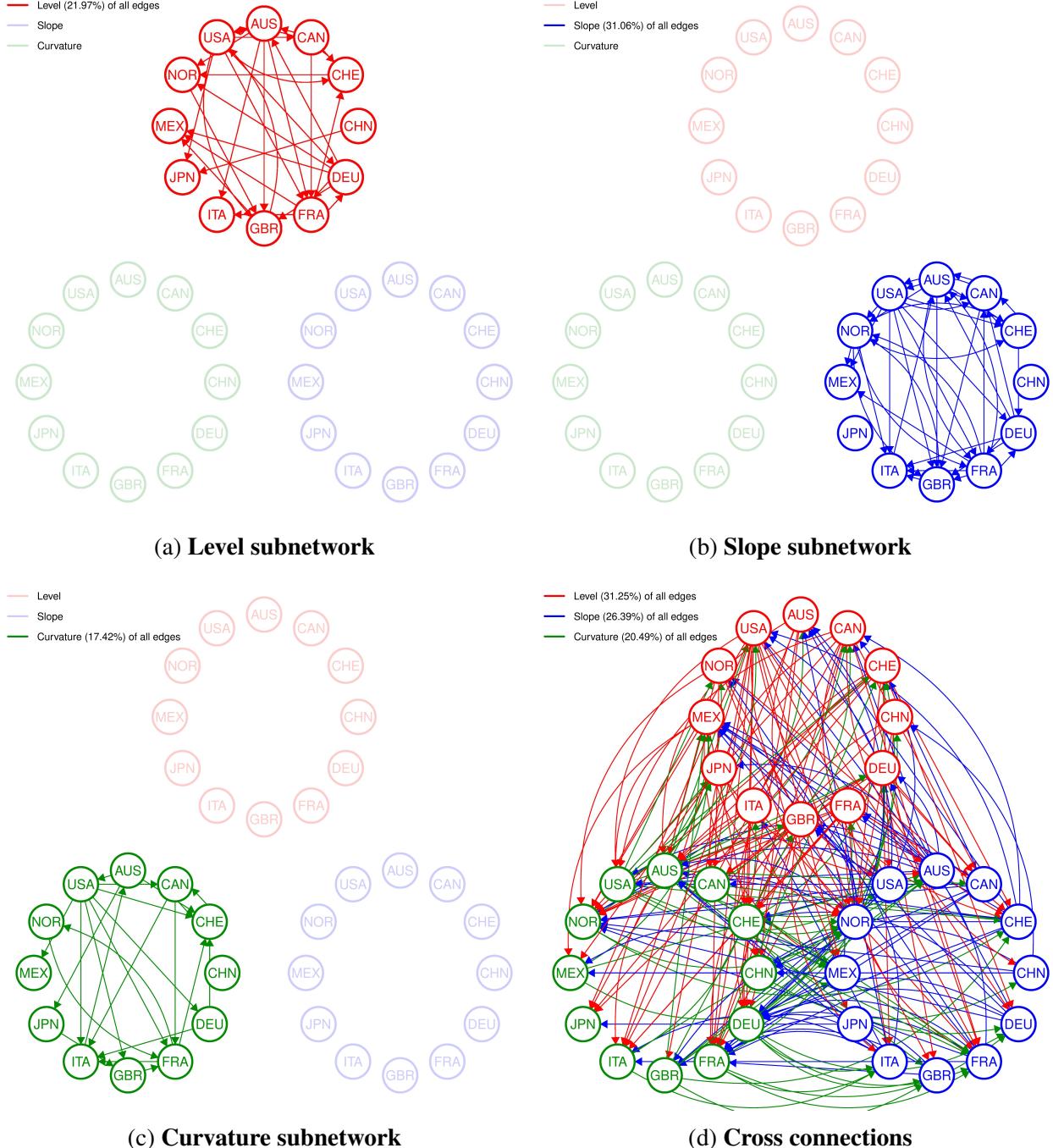


Figure 2: Interconnectedness in subnetworks

The (a) part of Table 3 contains the number of edges defined in the system. Rows of the table represent the origin of the relationship, while columns stand for the endpoints of the arrows. On 1% significance level, the graph has 318 edges which is 25.24% of the total potential edges. (b) part of Table 3 shows the ratio of the edges defined within subnetworks compared to the total potential edges definable in that given relationship system. Based on this, density of causality is the highest for Level - Curvature pair, 36.1% followed by Slope - Curvature which is 31.94%. The third place

goes for the Level subnetork with 31.06%. The relationship matrix is symmetrical for the diagonal, in total from the Curvature factor there is less arrows going out both internally and towards other subnetworks.

	Level	Slope	Curvature	Sum
Level	29	38	52	119
Slope	30	41	46	117
Curvature	25	34	23	82
Sum	84	113	121	318

(a) Number of edges, grouped by factors

	Level	Slope	Curvature	Sum.
Level	22.0%	26.4%	36.1%	84.5%
Slope	20.8%	31.1%	31.9%	83.8%
Curvature	17.4%	23.6%	17.4%	58.4%
Sum.	60.2%	81.1%	85.5%	25.2%

(b) Distribution of edges, grouped by factors

Table 3: The number and distibution of the sygnificant edges defined in the system

5.1.1 Top nodes

Table 4 contains the factors with the most edges. The first quarter of the list stands for the summarized relationships, then the following columns represent the nodes having the most incoming and outgoing edges separately. In total, Level factor of the United States has the most edges, which is 30. Fom this 30, there are 23 outgoing and 7 incoming arrows. This relationship system is shown on Figure 5. Generally speaking, all three factors of the USA leads the list regarding both outgoing and net (outgoing-incoming) edges. This can be interpreted as the USA has a high affecting power on the values of the factors of the remaining participants in the system and in the meanwhile it is not affected by the others. In the list of outgoing edges, Curvature of Asutralia is ahead of the Level of Germany which node is on the fourth place of the net chart, before the Level of Canada. The most causality effect is arriving towards the French Curvature followed by the Italian Slope, then the Curvature of the same country.

Top 5 Sum			Top 5 Incoming		Top 5 Outgoing		Top 5 Net		
Node	Total	In	Node	In	Node	Out	Node	Net	
USA_L	30	7	23	FRA_C	19	USA_L	23	USA_L	16
AUS_S	28	11	17	ITA_S	16	USA_S	18	USA_S	12
FRA_S	28	14	14	ITA_C	16	USA_C	17	USA_C	10
NOR_S	27	16	11	MEX_L	14	AUS_S	17	DEU_L	9
FRA_C	27	19	8	FRA_S	14	DEU_L	16	CAN_L	7

Table 4: Factors having most edges

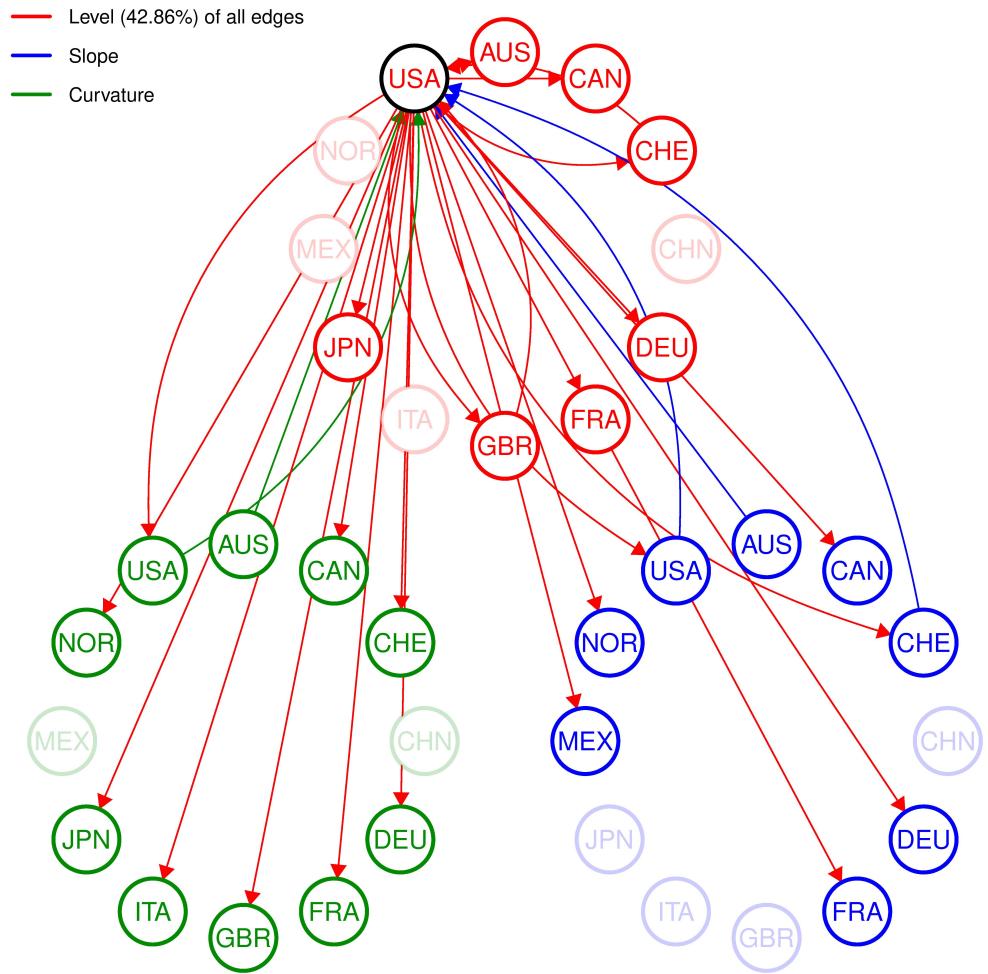


Figure 3: Node having most summarized edges

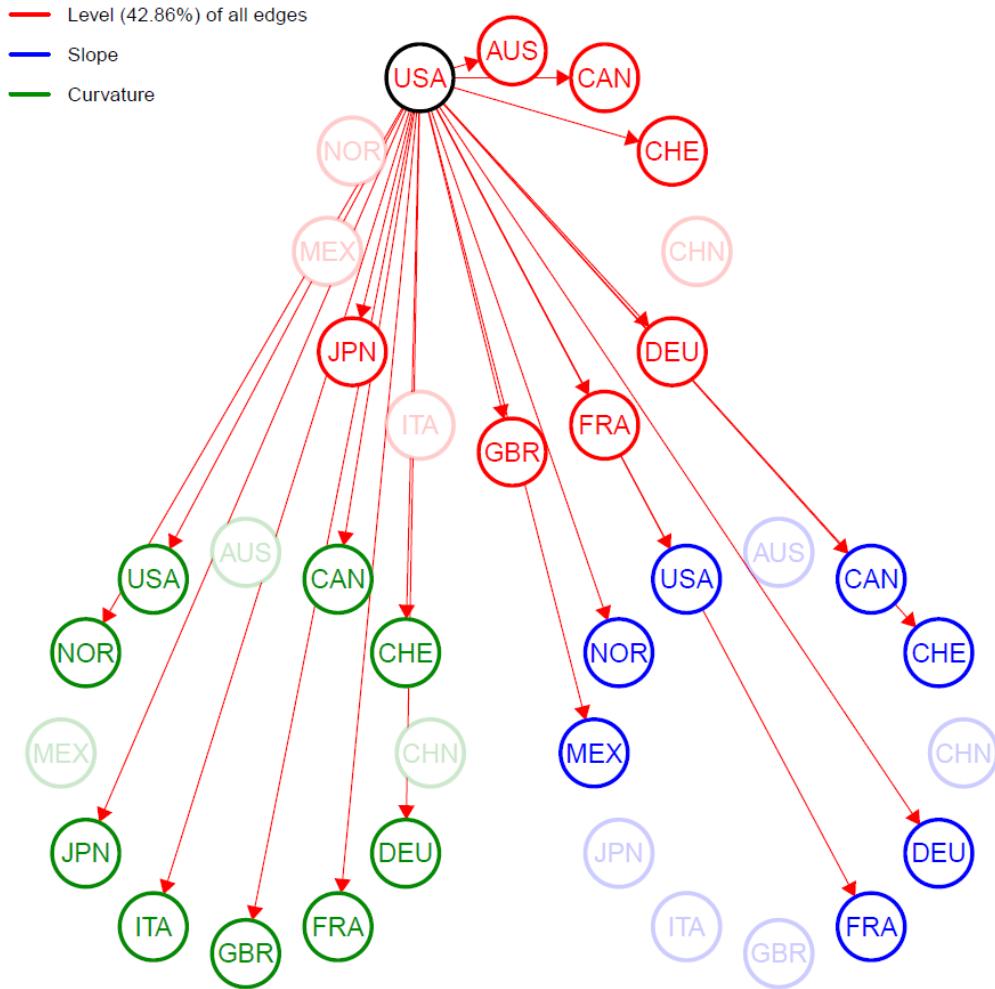


Figure 4: Node having most outgoing edges

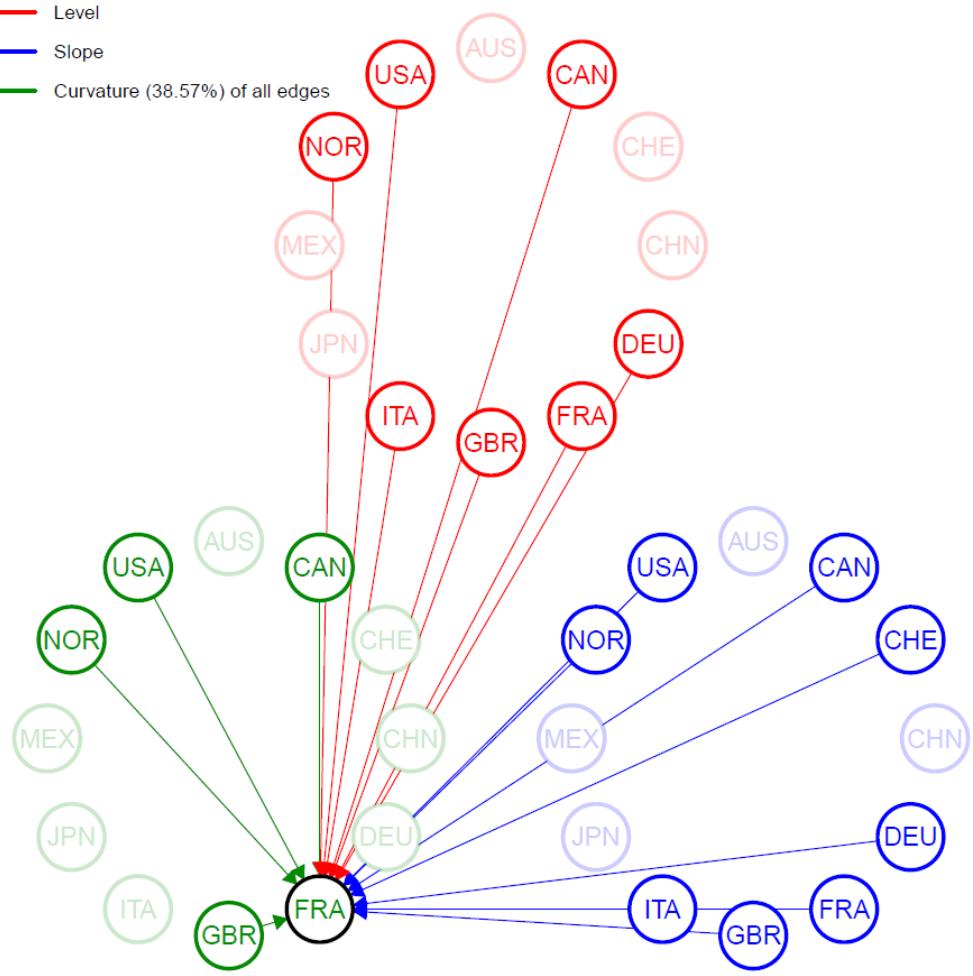


Figure 5: Node having most incoming edges

5.2 Time series analysis

After the static examination we performed a dynamic analysis of the factor interconnectedness. We chose a rolling window method with size of 750 observations. Considering 250 business days long years, this can be interpreted as a three years long period. With each shifting we move 5 observations ahead which can be seen as one business week. By doing so, we define 659 separated models. The time series coming from these models are shown on Figure 6. Purple line stands for the ratio of the significant edges in the whole network, cyan is the sum of the edges in different subnetworks and yellow represents edges coming from cross connections. As stated before, the subprime crisis is displayed by the red shaded area and the blue field covers the European sovereign debt.

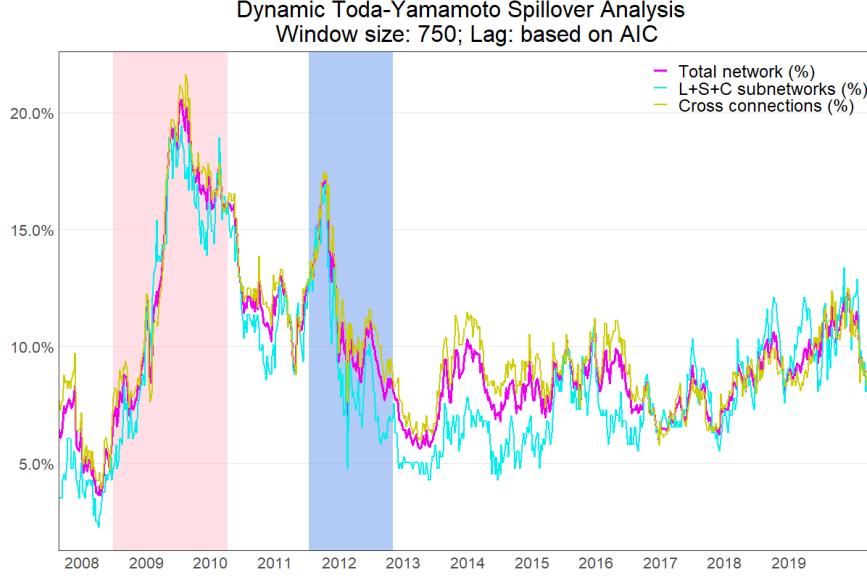


Figure 6: Dynamic Toda-Yamamoto analysis - 750 observations long window size

Figure 7 shows the factors having the most edges during the whole observation period. In ascending order, these are Norwegian Slope, American Curvature and American Level. Subprime crisis had an effect on both three of them, time series have a peak during this period. The Slope factor of Norway increased drastically during the European Sovereign crisis. This can be explained by the fact that in the end of 2011, the sovereign investment fund of Norway sold whole of its Irish and Portugal sovereign debt, and decreased the ownership ratio in Spanish and Italian bonds.

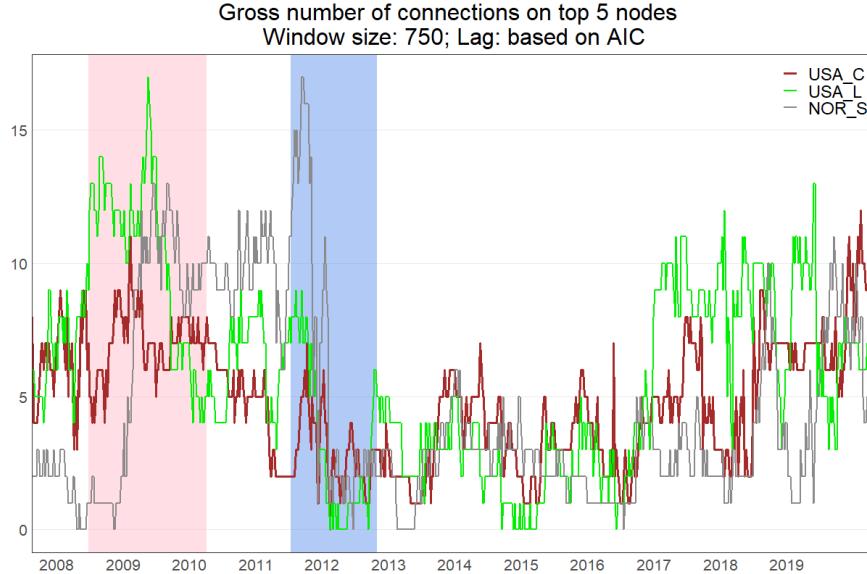


Figure 7: Edges having the most edges during the observation period - 750 observations long window size

By defining two turbulent periods, which are colored on the plots, and three calm ones we devide our observation horzone to five subsets. Table 5 shows the average edge count for such

periods aggregated by factors. One can see that during the subprime crisis, all of the edge numbers increases to more than double. This is followed by a slow decrease, the second turbulent period is not even represented by the numbers. The reason is that the crisis of 2008 was global, while the European sovereign crisis had affect mainly on the European countries and especially on the Euro-zone.

	Whole period	1. calm	1. crisis	2. calm	2. crisis	3. calm
Level	29	7	16.2	13.4	12.1	12
Slope	41	6	25.5	22.5	16.2	8.6
Curvature	23	7.3	20.7	9.7	9.2	9.9
Cross connections	225	61.8	142.2	109.1	101.2	76.1

Table 5: Average edge count by edges during the five sub-periods - 750 observations long window size

6 Robustness checks

Yet to come...

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Appendices

Node	Average	St. dev	Minimum	Maximum	$\rho(1)$	$\rho(10)$
Australia						
1 year	3.64	1.95	-0.05	7.39	0.999	0.994
5 years	4.01	1.91	0.24	7.3	0.999	0.994
10 years	4.36	1.75	0.61	7.43	0.999	0.993
30 years	4.77	1.46	1.17	7.67	0.999	0.99
Canada						
1 year	2.18	1.65	0.12	6.43	0.999	0.993
5 years	2.85	1.67	0.28	6.7	0.999	0.994
10 years	3.36	1.62	0.45	6.78	0.999	0.994
30 years	3.62	1.41	0.71	6.25	0.999	0.994
Australia						
1 year	0.53	1.28	-1.09	3.83	1	0.994
5 years	1.03	1.42	-1.11	3.97	1	0.996
10 years	1.54	1.44	-0.97	4.2	1	0.996
30 years	2.05	1.56	-0.7	4.95	0.999	0.994
Germany						
1 year	1.35	1.87	-0.99	5.24	1	0.997
5 years	1.92	1.97	-1.01	5.39	1	0.996
10 years	2.51	1.93	-0.87	5.75	1	0.996
30 years	3.14	1.88	-0.47	6.48	0.999	0.994
Spain						
1 year	1.78	1.77	-0.8	6.44	0.999	0.99
5 years	2.74	1.85	-0.45	7.65	0.999	0.992
10 years	3.53	1.81	-0.01	7.67	0.999	0.993
30 years	4.35	1.58	0.85	7.85	0.999	0.991
France						
1 year	1.4	1.84	-0.87	5.3	1	0.996
5 years	2.09	1.88	-0.78	5.4	1	0.996
10 years	2.81	1.84	-0.44	5.92	1	0.995
30 years	3.55	1.66	0.24	6.51	0.999	0.994
Great Britan						
1 year	2.28	2.24	-0.17	6.62	1	0.996
5 years	2.82	1.97	-0.11	6.52	1	0.996
10 years	3.23	1.67	0.11	5.92	0.999	0.994
30 years	3.46	1.26	0.53	5.06	0.999	0.992
Italy						
1 year	1.86	1.7	-0.59	8.17	0.999	0.989
5 years	2.92	1.66	-0.1	7.76	0.999	0.99
10 years	3.75	1.52	0.49	7.35	0.999	0.99
30 years	4.58	1.32	1.5	7.37	0.999	0.989
Japan						
1 year	0.08	0.24	-0.35	0.84	0.998	0.988
5 years	0.43	0.48	-0.39	1.72	0.998	0.985
10 years	0.96	0.71	-0.28	2.58	0.999	0.99
30 years	1.84	0.81	0.04	3.31	0.999	0.99
South Korea						
1 year	3.09	2.12	0.35	10.11	0.997	0.986
5 years	4.21	2.07	0.79	10.55	0.996	0.985
10 years	4.96	1.95	1.44	11.1	0.995	0.982
30 years	5.97	2.87	1.71	14.57	0.997	0.984
The Netherlands						
1 year	1.39	1.87	-0.94	5.31	1	0.997
5 years	2.05	1.95	-0.85	5.52	1	0.996
10 years	2.69	1.92	-0.63	5.91	1	0.996
30 years	3.19	1.86	-0.39	7.56	0.999	0.994
USA						
1 year	1.92	1.93	0.04	7.07	1	0.995
5 years	2.78	1.63	0.2	6.95	0.999	0.992
10 years	3.45	1.44	0.5	6.92	0.999	0.99
30 years	4.09	1.23	1.08	6.67	0.999	0.988

Table 6: Descriptive statistics of country yield curve nodes

Country	AUS		CAN		CHE		DEU		ESP		FRA	
	value	P										
Level	-4.07	0.01	-3.82	0.02	-3.28	0.07	-3.65	0.03	-1.81	0.66	-3.4	0.05
Slope	-2.76	0.26	-2.28	0.46	-2.85	0.22	-2.41	0.41	-2.12	0.53	-2.27	0.46
Curvature	-3.8	0.02	-2.96	0.17	-3.39	0.06	-3	0.15	-3.77	0.02	-2.93	0.18

Country	GBR		ITA		JPN		KOR		NLD		USA	
	value	P										
Level	-2.53	0.35	-2.13	0.52	-2.87	0.21	-3.8	0.02	-3.58	0.03	-4.85	0.01
Slope	-1.81	0.66	-2.65	0.3	-4.04	0.01	-3.01	0.15	-2.25	0.47	-2.11	0.53
Curvature	-1.74	0.69	-3.88	0.02	-3.23	0.08	-3.17	0.09	-3.37	0.06	-2.09	0.54

(a) ADF test results

Country	AUS		CAN		CHE		DEU		ESP		FRA	
	value	P										
Level	42.12	0.01	46.78	0.01	47.05	0.01	46.65	0.01	26.73	0.01	43.84	0.01
Slope	2.6	0.01	5.96	0.01	17.84	0.01	7.04	0.01	5.28	0.01	4.35	0.01
Curvature	25.95	0.01	9.02	0.01	2.19	0.01	4.68	0.01	13.63	0.01	9.35	0.01

Country	GBR		ITA		JPN		KOR		NLD		USA	
	value	P										
Level	37.13	0.01	27.24	0.01	41.1	0.01	40.53	0.01	46.11	0.01	43.45	0.01
Slope	11.57	0.01	6.97	0.01	42.39	0.01	8.66	0.01	6.15	0.01	4.17	0.01
Curvature	24.63	0.01	10.87	0.01	23.87	0.01	6.57	0.01	4.27	0.01	6.01	0.01

(b) KPSS test results

Country	AUS		CAN		CHE		DEU		ESP		FRA	
	value	P										
Level	-4.07	0.01	-17.58	0.01	-17.92	0.01	-18.64	0.01	-18.18	0.01	-17.19	0.01
Slope	-16.63	0.01	-15.41	0.01	-17.35	0.01	-17.26	0.01	-17.53	0.01	-15.97	0.01
Curvature	-18.11	0.01	-17.43	0.01	-17.52	0.01	-18.33	0.01	-18.47	0.01	-18.22	0.01

Country	GBR		ITA		JPN		KOR		NLD		USA	
	value	P										
Level	-17.96	0.01	-18.3	0.01	-18.15	0.01	-18.88	0.01	-18.39	0.01	-4.86	0.01
Slope	-15.86	0.01	-15.55	0.01	-4.05	0.01	-16.74	0.01	-16.62	0.01	-16.26	0.01
Curvature	-17.69	0.01	-19.95	0.01	-17.92	0.01	-19.12	0.01	-18.64	0.01	-18.58	0.01

(c) ADF(1) test results

Country	AUS		CAN		CHE		DEU		ESP		FRA	
	value	P										
Level	0.06	0.1	0.06	0.1	0.04	0.1	0.08	0.1	0.13	0.1	0.1	0.1
Slope	0.05	0.1	0.16	0.1	0.03	0.1	0.07	0.1	0.07	0.1	0.08	0.1
Curvature	0.03	0.1	0.06	0.1	0.05	0.1	0.04	0.1	0.03	0.1	0.03	0.1

Country	GBR		ITA		JPN		KOR		NLD		USA	
	value	P										
Level	0.11	0.1	0.14	0.1	0.03	0.1	0.05	0.1	0.09	0.1	0.05	0.1
Slope	0.24	0.1	0.07	0.1	0.02	0.1	0.06	0.1	0.09	0.1	0.14	0.1
Curvature	0.11	0.1	0.02	0.1	0.1	0.1	0.02	0.1	0.03	0.1	0.08	0.1

(d) KPSS(1) test results

Table 7: Results of unit-root tests