Interconnectedness - Working title

Milan Badics - Balazs Kotro

Uj szinkod: fekete: az eddigi torzsszoveg
zold: javitott reszek a megbeszeles alapjan,
kek: teljesen uj resz,
pink: az abrak, tablazatok szama, ami valtozhat meg,
pirossal a te megjegyzeseid, illetve a neked szant uzeneteim vannak jelolve.
Az elbeszeles ideje meg nem tisztazott, hogy mult vagy jelen ido lenne a jobb

Abstract

Ezt megirjuk kesobb

1 Introduction and literature review

The subprime crisis renewed the interest in analyzing the co-movement 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 participanst 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 2007-2009 and during the European Sovereign Crisis (Diebold and Yilmaz (2012)). IDE KELL MAJD HIVATKOZÁST KERESNI

Because the financial system is a huge complex interactive system, in recent years scholars began using complex network theory to investigate the interconnectedness of financial institutions. Acemoglu et al. (2015) pointed out that in smaller financial systems, shocks make the densely interconnected network steadier, however after a certain size the opposite applies. 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 one another's failures. Depending more on other participants makes personal sensitivity lower on own investments. SZERINTEM ITT VAN MÉG 1-2 FONTOS CIKK RÁNÉZEK MAJD

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)). Compared to CoVaR and MES methods the advantage of Granger causality based frameworks is the ability to examine the network both micro (pairwise connectedness) and macro (total connectedness) level. As a 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 focus on the whole system or some subpart.The dynamics of individual assets' role in the system have not been explored yet. IDE KELL hivatkozások összeszednem

KELLENE EGY KOINTEGRÁCIÓT Nem szokta vizsgálni bekezdés

Central banks traditionally rely on the co-movement 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. 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. IDE MINDENKÉPP KELLENEK HIVATKOZÁSOK

Usually, a tenor structure consists of multiple maturities which means one-one individual time series. It is challenging to deal with such a magnitude of data, therefore in raw format the yield curve itself is not used. Fernández-Rodríguez et al. (2016) examined only the 10Y yield curve point on EMU countries while Claeys and Vašíček (2014) chose the spread between EU government bond yieldsand German sovereign bondyield, also considering 10 years of maturity. Ahmad et al. (2018) picked bond indices to analyze and Sowmya et al. (2016) decomposed the yield curve to Level, Slope and Curvature factors with the Diebold-Li dimension reduction technique. Multi-layer networks, in which the links in each layer represent different types of connections between the same nodes, can combine different measures of interconnectedness to effectively describe complex financial systems. Such networks are already widely used in dependency networks of financial markets. However, few literatures consider multilayer networks to study the interconnectedness of the financial system from the perspective of information propagation. EZT KI KELL BŐVÍTENEM

We are eager to find the less and most interconnected participants of our system via understanding the connections not only between particular factors, but involving all three of them. We are also curious for the behavior of such linkages during time, thus besides static analysis we performed rolling window-based tests as well. Our contribution to the existing literature is fourfold. We analyze the interconnectedness of different yield curve factors with the consideration of cointegration among the time series. This is the first study which examines the crosswise causality connections among Level, Slope and Curvature. We chose developed economies from all over the World in order to achieve a wide geographical coverage. ITT LEHET KELLENE MÉG MAGYARÁZAT

We find, that there is cointegration between the yield curve factors, therefore our modelling approach (Toda-Yamamoto method) is justified. There is a not negligible amount of significant cross connections among these factors. The Level drives the highest number of linkages while the Curvature is the main receiver. Slope is ranked as second in both comparisons. USD factors have the most net connections (outgoing –incoming) thus it can be considered as the driver of the system. Our dynamic approach shows that during a recession period the sum of the connections in the network increases which statement is supported with different window sized robustness checks.

Itt volna meg nehany hivatkozas otletem, itt hagyom magyarul a szoveget ahogy megirtam:

Yang et al. (2016) az európai kötvények függetlenségét vizsgálják meg és azt találják, hogy a hozamgörbe hosszú vége sokkal integráltabb a rövid lejáratoknál. A hosszú lejárat a befektetői preferenciák szerint, míg a rövid a gazdasági ciklusoktól függ. Összevetve a lejárati szerkezetet, az összekapcsoltság diverz mintát mutat. Engsted and Tanggaard (2007) a német és amerikai kötvénypiac együttmozgását tanulmányozzák és jelentős okságot tapasztalnak az amerikai kötvények felől a németek irányába és csak gyenge kapcsolatot fordítva. Davies (2007) az angol, német, japán és svájci államkötvényindexek integrációját vizsgálja és mind a négy ország piacain azonos trendeket figyel meg. Vo (2009) ázsiai kötvényeket vet össze fejlett országok (USA és Ausztrália) állampaírjaival. Arra az eredményre jut, hogy az ázsiai oszágok és az Egyesült Államok közötti, ilyen értelemben vett integrációja alacsony szintű. Bizonyos tanulmányok a kötvények közötti volatilitás átterjedést vizsgálják. Ahmad et al. (2018) kutatásának középpontjába a BRICS államok, valamint három globális kötvénypiaci index (USA, Európai Monetáris Unió, Japán) került és hozam, illetve volatilitásterjedési vizsgálatot végeznek rajtuk. Azt tapasztalják, hogy a redszerbe elsődlegesen Oroszroszág, majd Dél-Afrika által jutnak be a sokkok. Kína és India kevésbé kitett, így ezek az országok fedezési célokat szolgálhatnak. Fernández-Rodríguez et al. (2016) az EMU tagállamait tanulmányozva arra jutnak, hogy nyugodt időszakban a volatilitás a mag államokból a periféria felé terjed, de az európai szuverén válság idején ez az irány megfordul. Más cikkek a kötvények hozamfeláraiból indultak ki. Antonakakis and Vergos (2013) az eurozóna tagállamainainak kötvényfelárait vizsgálják és azt tapasztalják, hogy a variancia 61%-át a más országokból való átgyűrűzés magyarázza. Claeys and Vašíček (2014) is Európai Uniós országok kötvényfelárait vizsgálják (16, nem csak eurozóna országok) és konklúziójuk szerint az összekötöttség nagy mértékben nőtt a 2008-as pénzügyi válság óta. Néhány szerző az adott ország hozamgörbéjére ható globális faktorokat elemzi. Driessen et al. (2003) főkomponenselemzéssel találják meg a kötvényhozamokat mozgató faktorokat és szignifikáns pozitív kapcsolatot állapítanak meg a hozamgörbe szintjei között a vizsgált országok esetén. Abbritti et al. (2013) könyvükben affin lejárati szerkezetű hozamgörbékre ható globális faktorokat elemeznek és arra a következtetésre jutnak, hogy ezek a görbe hosszú végét befolyásolják. Diebold et al. (2008) létrehozzák dinamikus hozamgörbe modelljüket és kimutatják a Szint, Meredekség és Görbület faktorok szignifikanciáját. Ezt Bae and Kim (2011) kiegészítik regionáls attribútumokkal is ázsiai országok alapján, de a globális együtthatókat erősebbnek találják a lokálisoknál. Sowmya et al. (2016) négy fejlett nyugati, és hét ázsiai ország hozamgörbéinek teljes lejárati stuktúráját modellezik. A Diebold-Li faktorok közötti varaiancia terjedését vizsgálva azt kapják, hogy a Szint faktorok között a legnagyobb az átterjedés, ezt követi a Meredekség, majd a Görbület.

2 Methodology

2.1 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 dinamic extension of the yield curve modelling elaborated by Nelson and Siegel (1987). The observed yield curve can be described with the following equation:

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

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 in 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 Curveture 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 accuratge thanks to the model being exponential. The other is the upper mentioned Litterman interpretation with which understanding and comapring results being much easier.

With the extension of Diebold and Li (2006) the Nelson-Siegel model becomes dynamic (the curve fits on multiple observations), which is achieved the below three steps:

- The Nelson-Siegel model is fitted based on the Ordinary Least Squares principle, estimating the β_1 , β_2 , β_3 parameters. (The λ parameter is being fixed, therefore the approach is linear.)
- The dyniamics of the system are described by a Vector AutoRegressive (VAR) model, based on the β_1, β_2 és β_3 parameters estimated in the first phase.
- The β parameters can be predicted with the VAR modellel and replacing them to equation (1) the future yield curve is predictable.

Additional stylized facts achieved by the Diebold-Li model is the high persistance 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.

2.1.1 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 growh 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 desribed by equations a (2) and (3):

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

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

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 (Lielihood 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 calulated 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).

Multilayer causality based network - ez most nem merult fel, kicsit meg is feledkeztem arrol, hogy ezt is akarjuk

3 Data

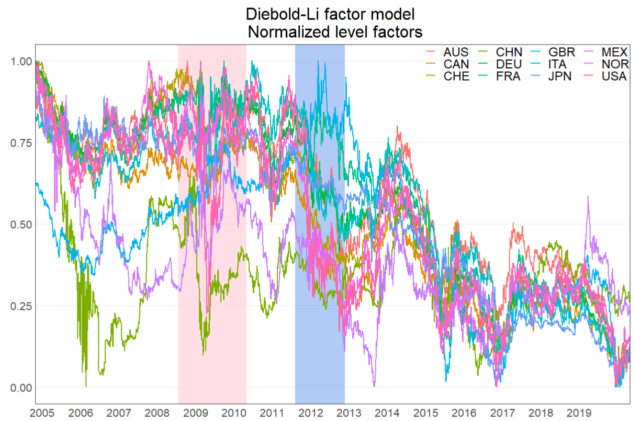
The yield curve time series of the countries were downloaded from Bloomberg. Twelve developed countries were involved into the examination universe, which cover more geographic regions, since they were selected from different continents. Evenually four regions were defined with three-three suvereigns in each. These are the *Pacific* (Australia, China, Japan), *American* (Canada, Mexico, United States), *Euro-zone* (France, Germany, Italy) and the *Non Euro-zone* (United Kingdom, Norway, Switzerland). Ongoingly they are referred as the three letter abbreviation introduced by Worldbank. Respectively: AUS, CHN, JPN, CAN, MEX, USA, FRA, DEU, ITA, GBR, NOR, CHE. During the empirical analysis, the yield curve is examined by its whole tenor structure with fifteen different maturities: 3, 6, 12, 24, 36, 48, 60, 72, 84, 96, 120, 180, 240 and 360. These apply for all countries. The firs observation day is 7/1/2004 while the last one is 12/31/2019. The uniusual period is determined by the Chinese yieldcurve since in this case data is available form July 2014 only. Furthermore the effects of recent COVID19 pandemic is exluded from this study, therefore we chose the last day of 2019 for ending the time horyzone. Altogether 4045 we work with 4045 daily observations. Missing data points are forward filled ffrom the previous day.

Note1: Kik hasznaltak ezeket az orszagokat? nem nagyon talaltam erre forrast

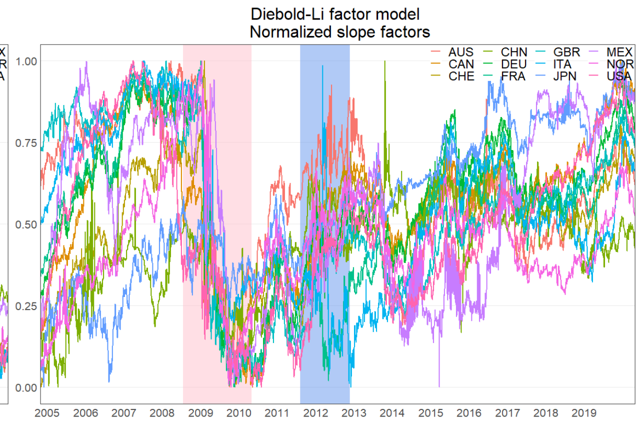
Note 2: DY ezeket a tenorokat hasznalta: 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 48, 60, 72, 84, 96, 108 and 120

The inputs of the country yield curves are always zero-coupn bonds, denominated in the local currency of the sovereing. Debt in local currency represents the different interest rate cicle of the economy and represents the domestic monetary policy better. Furthermore the debt denominated in local currency has better liquidity and credit rating then holding the same in USD (Sowmya et al. (2016)). Table 2 in the appendix provides descriptive statistics for the 1, 5, 10 and 30 years tenors 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 Nelso-Siegel model. Figure 1 shows the normalized time series of the factors. On the below figure period denoted with red shading represents the subprime crysis, while blue shading stands for the European sovereign debt crysis. These periods were determined based on Bostanci and Yilmaz (2020).

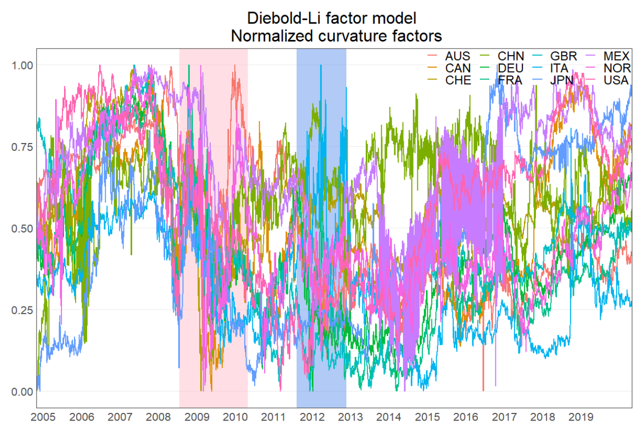
Figure 1: Normlized factor time series



(a) **Levle**



(b) **Slope**



(c) **Curvature**

Start of the subprime crysis: J.P. Morgan takes over Bear Stearns, the troubled investment bank (03/16/08);
End of subprime crysis: 12/31/2009 ez teljesen onkenyes;
Start of the European sovereign debt crysis: Portuguese government calls on EU for bailout (04/06/11);
End of the European sovereign debt crysis: Draghi makes the famous Whatever It Takes speech (07/26/12).

The descriptive statistics of the factors are represented in Table 1. The average Level factor is positive in all cases, highest for Mexico and lowest for Japan. Average Slope refers to the tipical 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 the USA has the highest Slope, while Australia has the lowest. Potential positive values of Slope represent restricittive monetary politics. Curvature is always negative too, highest for France and lowest for China (in absoluter terms).

Table 1: Descriptive statistics of yield curve factors

Factor	Average	Std. dev.	Minimum	Maximum	Jarque-Bera t-stat.	P value
Germany						
Level	2.92	1.54	-0.34	5.41	347	0.00
Slope	-1.86	1.06	-4.54	0.14	210	0.00
Curvature	-3.72	1.72	-7.15	0.73	234	0.00
Italy						
Level	4.78	1.29	1.98	8.00	106	0.00
Slope	-3.43	1.57	-7.01	-0.44	183	0.00
Curvature	-4.25	2.24	-8.60	4.75	194	0.00
France						
Level	3.39	1.37	0.26	5.48	417	0.00
Slope	-2.24	1.19	-4.73	0.02	162	0.00
Curvature	-4.29	1.96	-7.82	1.07	210	0.00
USA						
Level	3.96	0.99	1.88	5.87	323	0.00
Slope	-2.41	1.55	-5.52	0.71	139	0.00
Curvature	-3.63	2.50	-9.58	0.72	228	0.00
Canada						
Level	3.43	1.10	1.23	5.90	274	0.00
Slope	-1.73	1.23	-4.84	0.58	251	0.00
Curvature	-2.49	1.63	-6.26	1.31	206	0.00
Mexico						
Level	8.58	1.28	5.56	13.41	834	0.00
Slope	-2.36	1.83	-6.14	0.67	340	0.00
Curvature	-4.16	2.85	-14.84	0.49	321	0.00
Japan						
Level	1.70	0.83	-0.02	3.26	406	0.00
Slope	-1.28	0.63	-2.83	-0.02	155	0.00
Curvature	-3.69	1.28	-6.03	-0.87	278	0.00
China						
Level	4.02	0.62	2.70	6.52	2047	0.00
Slope	-1.53	0.81	-3.87	1.65	275	0.00
Curvature	-1.24	0.92	-5.20	1.25	1128	0.00
Australia						
Level	4.63	1.23	1.40	6.77	262	0.00
Slope	-0.89	0.98	-3.87	1.00	105	0.00
Curvature	-2.08	1.84	-6.59	2.25	296	0.00
Norway						
Level	3.22	1.12	1.02	5.23	333	0.00
Slope	-1.22	1.07	-4.04	2.26	167	0.00
Curvature	-1.59	1.22	-4.68	1.73	337	0.00
United Kingdom						
Level	3.66	1.23	0.87	5.80	329	0.00
Slope	-1.76	1.75	-5.42	1.35	211	0.00
Curvature	-3.33	3.02	-8.77	3.65	159	0.00
Switzerland						
Level	1.77	1.18	-0.76	3.86	289	0.00
Slope	-1.18	0.70	-3.32	0.91	219	0.00
Curvature	-2.94	1.21	-7.77	0.62	543	0.00

Factor time sereies are tested with (Bera and Jarque (1981)) test for normality. Neither of them passes the acceptance criteria therefor null-hypothesis for normaility is rejected. Furthermore ADF and KPSS unit-root tests for stationarity is applied. Curvature for China and Slope for Japan is stationary on the usual 95% confidence level. The tests can be applied for first difference of the remaining time series. 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 cointegration. Table 2. represents the ratio of the cointegrated time series aggregated by factors.

Besides the diagonal, the Slope - Curvature and the Curvature - Slope pairs both show a value more than 70%. Since the time series are not stationary on the same order and the ratio of cointegrated time series are high, we consider the Toda-Yamamoto approach to be justified for analyzing connections.

Table 2: Pairwise Engle-Granger test

	Level	Slope	Curvature
Level	75.694%	44.444%	64.583%
Slope	29.167%	74.306%	71.528%
Curvature	29.167%	78.472%	75.000%

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.

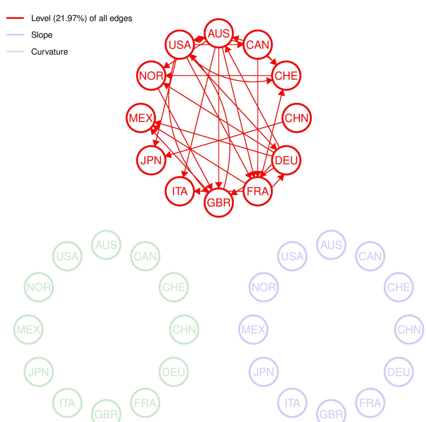
3.1 Results

3.1.1 Static interconnectedness

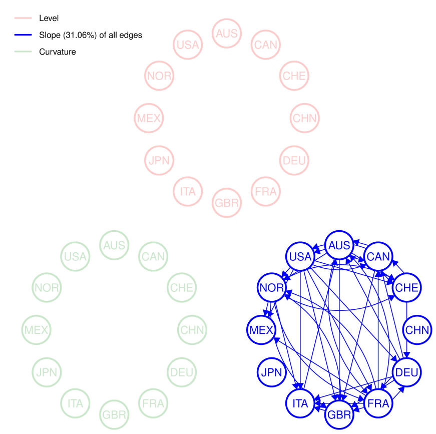
We performed statical and dynamical analysis of the factor interconnectedness resulted by the Toda-Yamamoto model. All of the available data points were used in the static method. Time series are differenciated once at maximum, and the optimal lag number is determined based on AIC. Figure textcolormagenta2 shows the causailiy relationships on 1 % sigificance level. Level factors are red, while Slope is blue and the Curvature is shwed in green. The arrow between two factors shows the direction of tha 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 are 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 are 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 are significant.

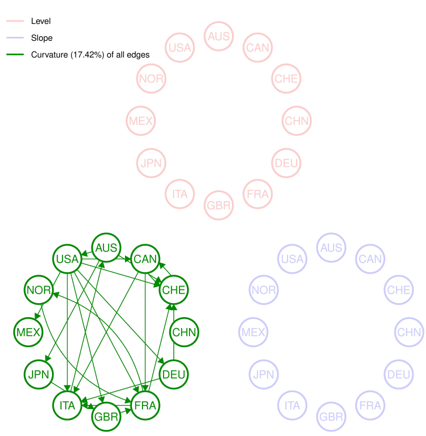
Figure 2: interconnectedness in subnetworks



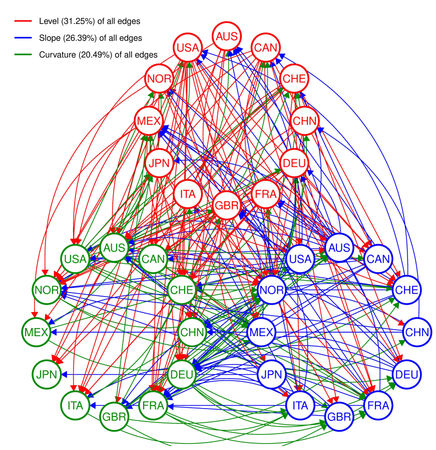
(a) **Level subnetwork**



(b) **Slope subnetwork**



(c) **Curvature subnetwork**



(d) **Cross connections**

The (a) part of Table 4 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 4 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 highes for Level - Curvature par, 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 simmetrical for the diagonal, in total, from the Curvature factor there is less arrows going out both internally and towards other subnetworks.

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

	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	21.97%	26.39%	36.10%	84.47%
Slope	20.83%	31.06%	31.94%	83.84%
Curvature	17.36%	23.61%	17.42%	58.40%
Sum.	60.16%	81.06%	85.48%	25.24%

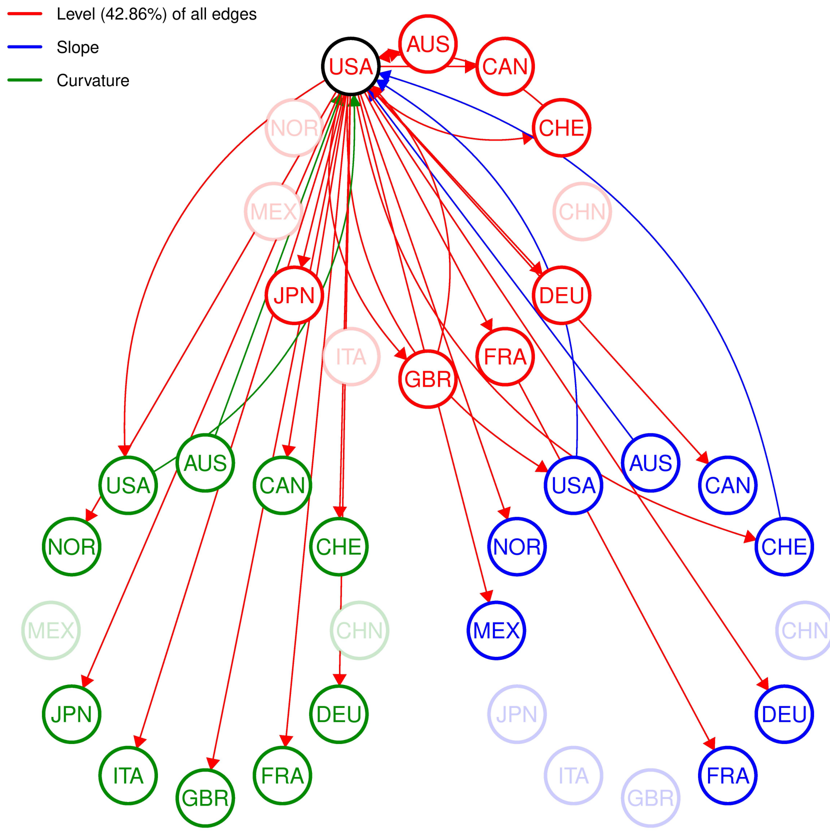
(b) **Distribution of edges, grouped by factors**

A legtöbb éllel rendelkező faktorokat az 5. táblázat szemlélteti. A lista első negyede az összesített kapcsolatokra utal, majd a következő oszlopokban külön fel vannak tüntetve a legtöbb bejövő és kimenő nyíllal rendelkező faktorok. Összességében az Egyesült Államok Szintje rendelkezik a legtöbb éllel, 30-cal. Ugyanakkor ezek közül 23 kimenő él és csak 7 bejövő. Ezt a kapcsolati rendszert mutatja a 4 ábra. Általánosságban elmondható, hogy az USA mindhárom faktora listavezető mind a kimenő, mind a nettó (kimenő - bejövő) élek számának tekintetében is. Ez úgy értelmezhető, hogy az Egyesült Államok mindhárom faktora okozója a többi ország faktorainak, míg ők maguk kevés hatást tapasztalnak a többi résztvevőtől. A kifelé mutató nyilak listájában Ausztrália Görbülete előzi Németország Szint faktorát, míg utóbbi faktor foglalja el a nettó élek listáján a negyedik helyet, Kanada Szintje előtt. A legtöbb oksági hatást kapó faktor a francia Görbület, amit az olasz Meredekség, majd ugyanezen ország Görbülete követ.

Table 4: A legtöbb éllel rendelkező faktorok

Top 5 Össz.				Top 5 Bejövő		Top 5 Kimenő		Top 5 Nettó	
Csomópont	Össz.	Be	Ki	Csomópont	Be	Csomópont	Ki	Csomópont	Nettó
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

Figure 3: A legtöbb éllel rendelkező csomópont



Bibliography

Abbritti, Mirko, Mr Salvatore Dell'Erba, Mr Antonio Moreno, and Mr Sergio Sola (2013), *Global factors in the term structure of interest rates*. 13-223, International Monetary Fund.

Acemoglu, Daron, Asuman Ozdaglar, and Alireza Tahbaz-Salehi (2015), "Systemic risk and stability in financial networks." *American Economic Review*, 105, 564–608.

Acharya, Viral, Robert Engle, and Matthew Richardson (2012), "Capital shortfall: A new approach to ranking and regulating systemic risks." *American Economic Review*, 102, 59–64.

Adrian, Tobias, Emanuel Moench, and Hyun Song Shin (2008), "Federal reserve bank of new york." In *Liquidity, Monetary Policy, and Financial Cycles, Federal Reserve Bank of NY Current Issues in Econ. and Fin*, Citeseer.

Ahmad, Wasim, Anil V Mishra, and Kevin J Daly (2018), "Financial connectedness of brics and global sovereign bond markets." *Emerging Markets Review*, 37, 1–16.

Amiri, Arshia and Bruno Ventelou (2012), "Granger causality between total expenditure on health and gdp in oecd: Evidence from the toda–yamamoto approach." *Economics Letters*, 116, 541–544.

Antonakakis, Nikolaos and Konstantinos Vergos (2013), "Sovereign bond yield spillovers in the euro zone during the financial and debt crisis." *Journal of International Financial Markets, Institutions and Money*, 26, 258–272.

Bae, Byung Yoon and Dong Heon Kim (2011), "Global and regional yield curve dynamics and interactions: The case of some asian countries." *International Economic Journal*, 25, 717–738.

Basher, Syed Abul, Alfred A Haug, and Perry Sadorsky (2012), "Oil prices, exchange rates and emerging stock markets." *Energy Economics*, 34, 227–240.

Bera, Anil K and Carlos M Jarque (1981), "Efficient tests for normality, homoscedasticity and serial independence of regression residuals: Monte carlo evidence." *Economics letters*, 7, 313–318.

Billio, Monica, Mila Getmansky, Andrew W Lo, and Loriana Pelizzon (2012), "Econometric measures of connectedness and systemic risk in the finance and insurance sectors." *Journal of financial economics*, 104, 535–559.

Bostanci, Gorkem and Kamil Yilmaz (2020), "How connected is the global sovereign credit risk network?" *Journal of Banking & Finance*, 113, 105761.

Claeys, Peter and Bořek Vašíček (2014), "Measuring bilateral spillover and testing contagion on sovereign bond markets in europe." *Journal of Banking & Finance*, 46, 151–165.

Davies, Andrew (2007), "International bond market cointegration using regime switching techniques." *The Journal of Fixed Income*, 16, 69–80.

Diebold, Francis X and Canlin Li (2006), "Forecasting the term structure of government bond yields." *Journal of econometrics*, 130, 337–364.

Diebold, Francis X, Canlin Li, and Vivian Z Yue (2008), "Global yield curve dynamics and interactions: a dynamic nelson–siegel approach." *Journal of Econometrics*, 146, 351–363.

Diebold, Francis X and Kamil Yilmaz (2009), "Measuring financial asset return and volatility spillovers, with application to global equity markets." *The Economic Journal*, 119, 158–171.

Diebold, Francis X and Kamil Yilmaz (2012), "Better to give than to receive: Predictive directional measurement of volatility spillovers." *International Journal of Forecasting*, 28, 57–66.

Driessen, Joost, Bertrand Melenberg, and Theo Nijman (2003), "Common factors in international bond returns." *Journal of International Money and Finance*, 22, 629–656.

Elliott, Matthew, Benjamin Golub, and Matthew O Jackson (2014), "Financial networks and contagion." *American Economic Review*, 104, 3115–53.

Engle, Robert F and Clive WJ Granger (1987), "Co-integration and error correction: representation, estimation, and testing." *Econometrica: journal of the Econometric Society*, 251–276.

Engsted, Tom and Carsten Tanggaard (2007), "The comovement of us and german bond markets." *International Review of Financial Analysis*, 16, 172–182.

Fernández-Rodríguez, Fernando, Marta Gómez-Puig, and Simón Sosvilla-Rivero (2016), "Using connectedness analysis to assess financial stress transmission in emu sovereign bond market volatility." *Journal of international Financial Markets, institutions and Money*, 43, 126–145.

Granger, Clive WJ (1969), "Investigating causal relations by econometric models and cross-spectral methods." *Econometrica: journal of the Econometric Society*, 424–438.

Hansen, Henrik and John Rand (2006), "On the causal links between fdi and growth in developing countries." *World Economy*, 29, 21–41.

Litterman, Robert and Jose Scheinkman (1991), "Common factors affecting bond returns." *Journal of fixed income*, 1, 54–61.

Nelson, Charles R and Andrew F Siegel (1987), "Parsimonious modeling of yield curves." *Journal of business*, 473–489.

Rambaldi, Alicia N and Howard Edwin Doran (1996), *Testing for granger non-casuality in cointegrated systems made easy*. Department of Econometrics, University of New England.

Sowmya, Subramaniam, Krishna Prasanna, and Saumitra Bhaduri (2016), "Linkages in the term structure of interest rates across sovereign bond markets." *Emerging Markets Review*, 27, 118–139.

Toda, Hiro Y and Taku Yamamoto (1995), "Statistical inference in vector autoregressions with possibly integrated processes." *Journal of econometrics*, 66, 225–250.

Vo, Xuan Vinh (2009), "International financial integration in asian bond markets." *Research in International Business and Finance*, 23, 90–106.

Yang, Lu, Xiao Jing Cai, Huimin Zhang, and Shigeyuki Hamori (2016), “Interdependence of foreign exchange markets: A wavelet coherence analysis.” *Economic Modelling*, 55, 6–14.

Zapata, Hector O and Alicia N Rambaldi (1997), “Monte carlo evidence on cointegration and causation.” *Oxford Bulletin of Economics and statistics*, 59, 285–298.

Zhang, Xing-Ping and Xiao-Mei Cheng (2009), “Energy consumption, carbon emissions, and economic growth in china.” *Ecological economics*, 68, 2706–2712.

Appendices

Table 5: Descriptive statistics of country yield curve nodes

Node	Average	St. dev	Minimum	Maximum	ρ(1)	ρ(10)
Germany						
1 year	0.026	1.628	-0.969	4.690	1.000	0.996
5 years	0.026	1.632	-0.941	4.767	0.999	0.993
10 years	0.024	1.545	-0.722	4.686	0.993	0.964
30 years	0.023	1.448	-0.244	5.195	0.999	0.988
Italy						
1 year	0.024	1.533	-0.484	8.394	0.998	0.986
5 years	0.024	1.520	0.237	7.895	0.998	0.985
10 years	0.022	1.388	0.875	7.492	0.998	0.986
30 year	0.019	1.197	2.043	7.584	0.998	0.985
France						
1 year	0.025	1.589	-0.801	4.657	1.000	0.996
5 years	0.025	1.573	-0.773	4.910	0.999	0.993
10 years	0.023	1.467	-0.415	4.851	0.999	0.991
30 years	0.019	1.235	0.419	5.116	0.999	0.986
USA						
1 year	0.025	1.613	0.054	5.323	1.000	0.998
5 years	0.019	1.232	0.559	5.301	0.999	0.980
10 years	0.016	1.039	1.389	5.388	0.998	0.983
30 years	0.015	0.962	1.992	5.839	0.997	0.976
Canada						
1 year	0.019	1.230	0.300	4.809	1.000	0.995
5 years	0.018	1.146	0.484	4.801	0.999	0.989
10 years	0.017	1.098	0.983	5.076	0.999	0.987
30 years	0.016	1.012	1.306	5.612	0.998	0.985
Mexico						
1 year	0.032	2.025	1.512	10.570	0.979	0.988
5 years	0.024	1.511	3.786	10.897	0.986	0.981
10 years	0.021	1.352	4.619	12.413	0.992	0.970
30 years	0.020	1.238	5.873	12.726	0.993	0.947
Japan						
1 year	0.004	0.272	-0.371	0.850	0.999	0.992
5 years	0.008	0.485	-0.396	1.631	0.999	0.990
10 years	0.010	0.656	-0.285	2.050	0.999	0.990
30 years	0.012	0.761	0.053	3.295	0.998	0.985
China						
1 year	0.012	0.730	0.957	4.382	0.992	0.966
5 years	0.009	0.594	1.782	4.874	0.997	0.973
10 years	0.009	0.570	2.481	5.503	0.993	0.964
30 years	0.010	0.615	2.470	6.009		
Australia						
1 year	0.028	1.775	0.675	7.376	0.999	0.992
5 years	0.026	1.677	0.639	6.960	0.999	0.990
10 years	0.024	1.497	0.885	6.873	0.999	0.988
30 years	0.019	1.207	1.558	6.888	0.998	0.983
Norway						
1 year	0.022	1.410	0.199	6.243	0.999	0.994
5 years	0.020	1.273	0.545	5.335	0.999	0.991
10 years	0.019	1.194	0.888	5.276	0.999	0.989
30 years	0.018	1.113	0.882	5.273	0.999	0.987
United Kingdom						
1 year	0.031	1.956	0.024	5.883	0.999	0.995
5 years	0.026	1.644	0.161	5.821	0.999	0.991
10 years	0.022	1.418	0.400	5.543	0.999	0.989
30 years	0.018	1.110	0.939	5.070	0.999	0.987
Switzerland						
1 year	0.020	1.241	-1.165	3.375	1.000	0.996
5 years	0.019	1.192	-1.196	3.200	0.999	0.993
10 years	0.019	1.198	-1.138	3.455	0.999	0.991
30 years	0.017	1.101	-0.644	3.733	0.998	0.986

Table 6: Results of unit-root tests

Country	DEU		ITA		FRA		USA		CAN		MEX	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	-2.30	0.45	-1.47	0.81	-2.16	0.51	-3.66	0.03	-3.06	0.13	-3.97	0.01
Slope	-2.09	0.54	-2.26	0.47	-1.64	0.73	-1.50	0.79	-1.57	0.76	-1.88	0.63
Curvature	-2.22	0.49	-3.59	0.03	-2.36	0.43	-1.62	0.74	-2.35	0.43	-2.71	0.28
Country	JPN		CHN		AUS		NOR		GBR		CHE	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	-2.97	0.17	-3.69	0.02	-2.90	0.20	-2.63	0.31	-2.16	0.51	-2.50	0.37
Slope	-4.85	0.01	-3.69	0.03	-2.30	0.45	-2.72	0.27	-0.95	0.95	-3.14	0.10
Curvature	-2.03	0.57	-5.52	0.01	-2.61	0.32	-3.67	0.02	-1.62	0.74	-3.14	0.10

(a) **ADF test results**

Country	DEU		ITA		FRA		USA		CAN		MEX	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	32.89	0.01	14.58	0.01	29.87	0.00	26.85	0.01	32.18	0.01	15.24	0.01
Slope	4.26	0.01	7.61	0.01	4.50	0.01	5.30	0.01	5.40	0.01	4.78	0.01
Curvature	8.96	0.01	10.21	0.01	15.21	0.01	7.34	0.01	4.59	0.01	4.92	0.01
Country	JPN		CHN		AUS		NOR		GBR		CHE	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	33.94	0.01	3.55	0.01	29.17	0.01	30.06	0.01	28.70	0.01	31.96	0.01
Slope	33.21	0.01	14.99	0.01	7.32	0.01	1.25	0.01	7.53	0.01	5.49	0.01
Curvature	15.95	0.01	2.91	0.01	24.67	0.01	11.56	0.01	13.33	0.01	5.67	0.01

(b) **KPSS test results**

Country	DEU		ITA		FRA		USA		CAN		MEX	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	-17.05	0.01	-16.01	0.01	-15.99	0.01	-15.79	0.01	-16.35	0.01	-16.56	0.01
Slope	-15.90	0.01	-14.62	0.01	-14.59	0.01	-16.55	0.01	-16.32	0.01	-15.19	0.01
Curvature	-18.52	0.01	-18.67	0.01	-17.65	0.01	-17.45	0.01	-16.02	0.01	-18.88	0.01
Country	JPN		CHN		AUS		NOR		GBR		CHE	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	-16.55	0.01	-16.99	0.01	-15.61	0.01	-16.43	0.01	-16.48	0.01	-15.57	0.01
Slope			-18.90	0.01	-17.87	0.01	-17.61	0.01	-16.12	0.01	-14.59	0.01
Curvature	-17.51	0.01			-18.06	0.01	-17.04	0.01	-16.45	0.01	-14.27	0.01

(c) **ADF(1) test results**

Slope	DEU		ITA		FRA		USA		CAN		MEX	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	0.04	0.10	0.13	0.10	0.06	0.10	0.03	0.10	0.06	0.10	0.08	0.10
Slope	0.08	0.10	0.07	0.10	0.12	0.10	0.16	0.10	0.17	0.10	0.09	0.10
Curvature	0.05	0.10	0.02	0.10	0.05	0.10	0.08	0.10	0.08	0.10	0.01	0.10
Slope	JPN		CHN		AUS		NOR		GBR		CHE	
	value	P	value	P	value	P	value	P	value	P	value	P
Level	0.03	0.10	0.16	0.10	0.05	0.10	0.04	0.10	0.07	0.10	0.04	0.10
Slope	0.03	0.10	0.03	0.10	0.04	0.10	0.08	0.10	0.24	0.10	0.14	0.10
Curvature	0.06	0.10	0.05	0.10	0.04	0.10	0.03	0.10	0.16	0.10	0.05	0.10

(d) **KPSS(1) test results**