

# Interconnectedness - Working title

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Par gondolat a formazasrol: 12-es betumeret, times new roman, 1-es sorkoz, tehat eleg suru, ennél elkepzelheto, hogy hosszabb lesz, ha ezeket a megkoteseket elengedjuk. Minden egyes fejezetet most kulon oldalon kezdek ily jobban latjuk, hogy mennyit fog kitenni.

**pirossal** a te megjegyzeseid vannak jelolve.

Az elbeszeles ideje meg nem tisztazott, hogy mult vagy jelen ido lenne a jobb

## Abstract

Ezt megirjuk kesobb

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# 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 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 institutions 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 alteration 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 govern-

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ment bond yields and German sovereign bond yield, 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. Multilayer 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 néhány hivatkozás ötletem, itt hagyom magyarul a szöveget ahogy megírtam:

[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 lejárat 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) állampapíraival. Arra az eredményre jut, hogy az ázsiai országok és az Egyesült Államok közötti, ilyen értelemben vett integrációja alacsony szintű. Bizonyos tanulmányok a kötvények közötti volatilitás áttérjedést 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 rendszerbe elsődlegesen Oroszország, 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 tagállamainak kötvényfelárait vizsgálják és azt tapasztalják, hogy a variancia 61%-át a más országokból való átgúnyítás magyarázza. [Claeys and Vašíček \(2014\)](#) is Európai Unió

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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 lejáratú 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 regionális 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 lejáratú struktúráját modellezzik. A Diebold-Li faktorok közötti variancia terjedését vizsgálva azt kapják, hogy a Szint faktorok között a legnagyobb az áttekintés, ezt követi a Meredekség, majd a Görbület.

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## 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 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  $y_\tau$  are the realized values for  $\tau$  maturity,  $\beta_1, \beta_2$  és  $\beta_3$  are time varying parameters, and  $\lambda$  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  $\beta_i$  parameters have an economic meaning,  $\beta_1$  represents the long end of the yield curve,  $\beta_2$  is the short term component, while  $\beta_3$  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 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  $\beta_1, \beta_2, \beta_3$  parameters. (The  $\lambda$  parameter is being fixed, therefore the approach is linear.)
- The dynamics of the system are described by a Vector Autoregressive (VAR) model, based on the  $\beta_1, \beta_2$  és  $\beta_3$  parameters estimated in the first phase.
- The  $\beta$  parameters can be predicted with the VAR model and replacing them to equation (1) the future yield curve is predictable.

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.

#### 2.1.1 The Toda-Yamamoto model

The [Toda and Yamamoto \(1995\)](#) method uses the following 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  $\chi_p$  distribution, 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 (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  $\alpha, \delta, \theta$  and  $\beta$  are model parameters,  $p$  is the optimal lag of the original VAR model,  $\omega_{1t}$  és  $\omega_{2t}$  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 (Likelihood 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.

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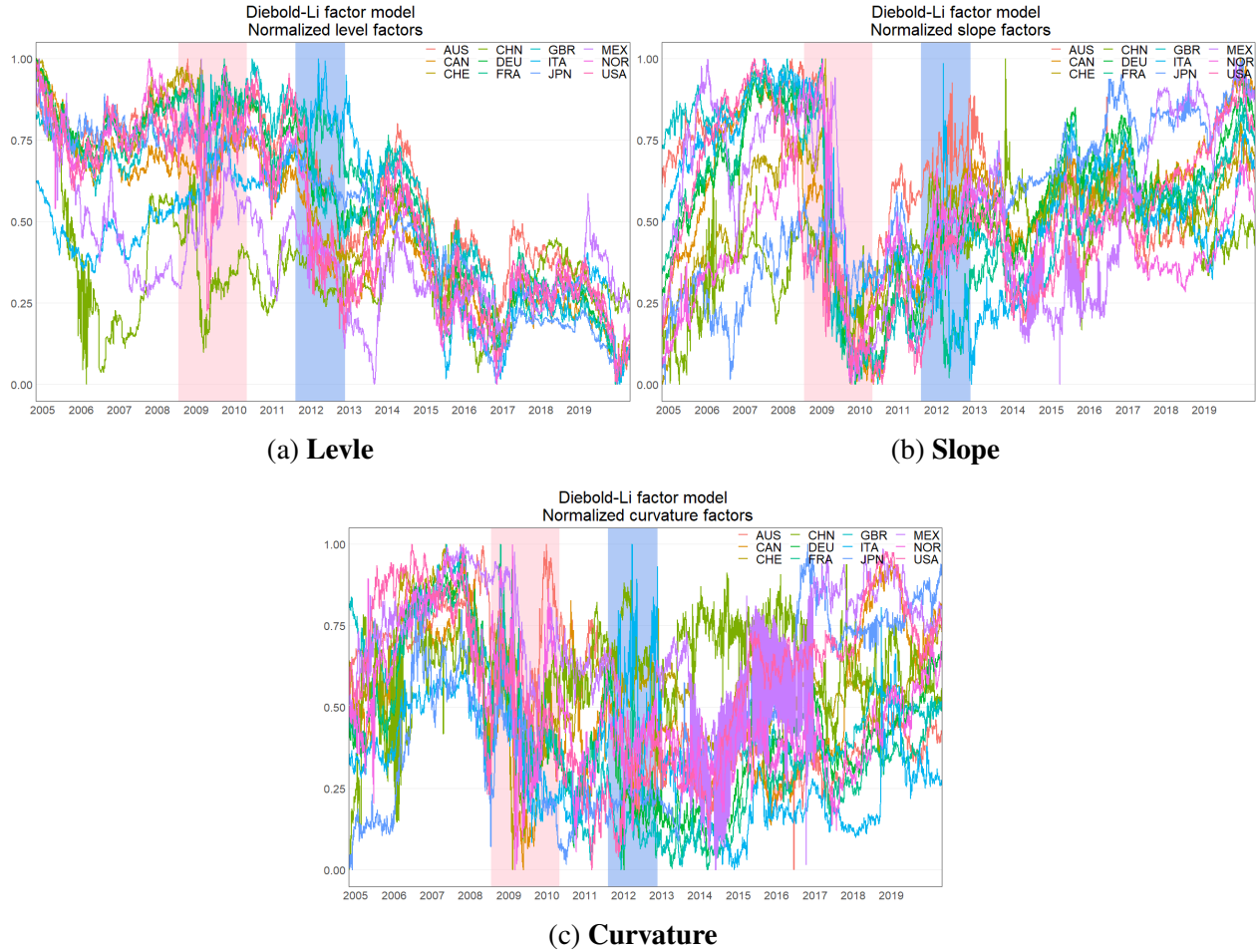
### 3 Data

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. Eventually four regions were defined with three-three sovereigns 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 first observation day is 7/1/2004 while the last one is 12/31/2019. The unusual period is determined by the Chinese yieldcurve since in this case data is available from July 2014 only. Furthermore the effects of recent COVID19 pandemic is excluded from this study, therefore we chose the last day of 2019 for ending the time horizon. Altogether 4045 we work with 4045 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 cycle 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 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 Nelson-Siegel model. Figure 1 shows the normalized time series of the factors.



Figure 1: Normlized factor time series



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 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 the USA has the highest Slope, while Australia has the lowest. Potential positive values of Slope represent restrictive monetary politics. Curvature is always negative too, highest for France and lowest for China (in absolute terms).



Table 1: Descriptive statistics of yield curve factors

Factor	Average	Std. dev.	Minimum	Maximum	Jarque-Bera t-stat.	P value
<i>Germany</i>						
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
<i>Italy</i>						
Level	4.78	1.29	1.98	8.00	106	0.00
Slope	-3.43	1.57	-7.01	-0.44	183	0.00
Görbület	-4.25	2.24	-8.60	4.75	194	0.00
<i>France</i>						
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
<i>USA</i>						
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
<i>Canada</i>						
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
<i>Mexico</i>						
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
<i>Japan</i>						
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
<i>China</i>						
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
<i>Australia</i>						
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
<i>Norway</i>						
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
<i>United Kingdom</i>						
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
<i>Switzerland</i>						
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 series are tested with (Bera and Jarque (1981)) test for normality. Neither of them passes the acceptance criteria therefore null-hypothesis for normality is rejected. Furthermore ADF

Table 2: 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

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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.

Before differentiating, a pairwise ([Engle and Granger \(1987\)](#)) test is applied for determining cointegration. Table 3. 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 3: Blocked 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%

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# Appendices

Table 4: Descriptive statistics of country yield curve nodes

Node	Average	St. dev	Minimum	Maximum	$\rho(1)$	$\rho(10)$
<i>Germany</i>						
1 year	0.0256	1.6275	-0.9690	4.6900	1.0000	0.9960
5 years	0.0257	1.6324	-0.9410	4.7670	0.9990	0.9930
10 years	0.0243	1.5451	-0.7220	4.6860	0.9930	0.9640
30 years	0.0228	1.4482	-0.2440	5.1950	0.9990	0.9880
<i>Italy</i>						
1 year	0.0241	1.5327	-0.4840	8.3940	0.9980	0.9860
5 years	0.0239	1.5199	0.2370	7.8950	0.9980	0.9850
10 years	0.0218	1.3876	0.8750	7.4920	0.9980	0.9860
30 year	0.0188	1.1971	2.0430	7.5840	0.9980	0.9850
<i>France</i>						
1 year	0.0250	1.5891	-0.8010	4.6570	1.0000	0.9960
5 years	0.0247	1.5730	-0.7730	4.9100	0.9990	0.9930
10 years	0.0231	1.4670	-0.4150	4.8510	0.9990	0.9910
30 years	0.0194	1.2351	0.4190	5.1160	0.9990	0.9860
<i>USA</i>						
1 year	0.0254	1.6128	0.0540	5.3230	1.0000	0.9980
5 years	0.0194	1.2315	0.5590	5.3010	0.9990	0.9890
10 years	0.0163	1.0394	1.3890	5.3880	0.9980	0.9830
30 years	0.0151	0.9618	1.9920	5.8390	0.9970	0.9760
<i>Canada</i>						
1 year	0.0193	1.2301	0.3000	4.8090	1.0000	0.9950
5 years	0.0180	1.1463	0.4840	4.8010	0.9990	0.9890
10 years	0.0173	1.0976	0.9830	5.0760	0.9990	0.9870
30 years	0.0159	1.0118	1.3060	5.6120	0.9980	0.9850
<i>Mexico</i>						
1 year	0.0318	2.0250	1.5120	10.5700	0.9790	0.9880
5 years	0.0238	1.5108	3.7860	10.8970	0.9860	0.9810
10 years	0.0213	1.3524	4.6190	12.4130	0.9920	0.9700
30 years	0.0195	1.2384	5.8730	12.7260	0.9930	0.9470
<i>Japan</i>						
1 year	0.0043	0.2715	-0.3710	0.8500	0.9990	0.9920
5 years	0.0076	0.4852	-0.3960	1.6310	0.9990	0.9900
10 years	0.0103	0.6563	-0.2850	2.0500	0.9990	0.9900
30 years	0.0120	0.7606	0.0530	3.2950	0.9980	0.9850
<i>China</i>						
1 year	0.0115	0.7296	0.9570	4.3820	0.9920	0.9660
5 years	0.0093	0.5939	1.7820	4.8740	0.9970	0.9730
10 years	0.0090	0.5702	2.4810	5.5030	0.9930	0.9640
30 years	0.0097	0.6149	2.4700	6.0090		
<i>Australia</i>						
1 year	0.0279	1.7749	0.6750	7.3760	0.9990	0.9920
5 years	0.0264	1.6769	0.6390	6.9600	0.9990	0.9900
10 years	0.0235	1.4971	0.8850	6.8730	0.9990	0.9880
30 years	0.0190	1.2069	1.5580	6.8880	0.9980	0.9830
<i>Norway</i>						
1 year	0.0222	1.4100	0.1990	6.2430	0.9990	0.9940
5 years	0.0200	1.2734	0.5450	5.3350	0.9990	0.9910
10 years	0.0188	1.1935	0.8880	5.2760	0.9990	0.9890
30 years	0.0175	1.1127	0.8820	5.2730	0.9990	0.9870
<i>United Kingdom</i>						
1 year	0.0308	1.9558	0.0240	5.8830	0.9990	0.9950
5 years	0.0259	1.6444	0.1610	5.8210	0.9990	0.9910
10 years	0.0223	1.4181	0.4000	5.5430	0.9990	0.9890
30 years	0.0175	1.1099	0.9390	5.0700	0.9990	0.9870
<i>Switzerland</i>						
1 year	0.0195	1.2405	-1.1650	3.3750	1.0000	0.9960
5 years	0.0187	1.1921	-1.1960	3.2000	0.9990	0.9930
10 years	0.0188	1.1976	-1.1380	3.4550	0.9990	0.9910
30 years	0.0173	1.1006	-0.6440	3.7330	0.9980	0.9860