Stock Market Integration of the New EU Member States: a Cointegration-network Approach

By

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Abstract

In this thesis I analyze whether the stock markets of those countries that joined the European Union in 2004 and afterwards became more integrated with the stock markets of countries that were members of the Union before. In order to answer this question, I apply a network based approach with rolling-windows on a dataset that contains 34 stock market indices in the period from November 2000 to April 2014. I build networks based on the results of the Engle-Granger cointegration test on country stock index pairs. The structure of the links, the time evolution of the degree of each index and the components of the detected communities are analyzed. The results confirm the time varying nature of stock market integration that was previously observed by other studies. Based on my results, new members experienced a period of higher stock market integration right before their accession in 2004. Stock markets overall showed an extremely increased degree of integration beginning with the outburst of the interbank lending crisis and during the global financial and economic crisis. This makes inference about the effect of European Union membership on the stock market integration of countries that joined later (Romania, Bulgaria and Croatia) difficult.

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1. Introduction

In my thesis my goal is to examine whether stock markets of the new European Union member states (those which joined after 2004) show integration with the markets of the old member states. In the light of increasing globalization and recent developments in international financial markets, the co-movement of stock markets is a frequently researched topic. Developments in IT, the elimination of capital and exchange controls and increasing deregulation in recent years made it possible for investors to have access to foreign markets. Investment theory suggests international portfolio diversification as well: both the Capital Asset Pricing Model (Sharp, 1964) and the Modern Portfolio Theory (Markowitz, 1952) suggest that investors should hold a well-diversified portfolio in order to reduce the risk they are exposed to. As a result, many investors have diversified their portfolios internationally. For this reason it is important to know whether this international diversification does indeed have benefits or these benefits are vanished due to increased international market-correlations, exposure to common shocks and strong international financial market integration.

Several studies concentrated on this topic and found evidence for increased stock-market integration. An early study by Kasa (1992) shows evidence for the presence of a common stochastic trend driving the stock markets of the most developed countries (US, Japan, England, Germany and Canada) between 1974 and 1990. Song et al. (2011, pg. 1) examine market indices of 57 countries from all over the world in the period 1996-2009 and find that "correlation among market indices presents both a fast and slow dynamics. The slow dynamics reflects the development and consolidation of globalization." As the presence of "fast and slow dynamics" in the data shows, return correlations are not constant over time: there are periods of increased correlation – for example during periods of economic turmoil – and periods of decreased correlation – for example during bullish periods. Further evidence in the literature for this can be found in Longin and Solnik (1995 and 2001). This of course has an effect on the benefits of portfolio diversification. In the long term, probably there are no considerable benefits, while in the short term international diversification might reduce risk.

Member states of the European Union (hereafter EU) are special from the point of view of stock market integration. Ever since the Maastricht Treaty was signed in 1992, there has been a strong political interest in the integration and efficient functioning of the financial system of member states and future member states of the European Union. To underline its importance, the promoting of European financial integration is one of the three objectives included in the mission statement of the Eurosystem (European Central Bank). In addition, financial integration is a key aspect of the objective of completing the EU Single Market. The European Central Bank (2005) defined a set of indicators of financial integration and publishes a yearly report that assesses the state of Euro area financial integration. However, this report is restricted only to those countries that have the Euro as a common currency. According to the latest "Financial Integration in Europe" report (European Central Bank, 2014 pg. 8), integration is important because it "fosters a smooth and balanced transmission of monetary policy throughout the euro area. In addition, it is relevant for financial stability and is among the reasons behind the Eurosystems's task of promoting well-functioning payment systems." According to the classification of the European Central Bank, we can distinguish between the integration of: money markets, bond markets, equity markets and banking markets. In my thesis I focus solely on the integration of equity markets.

It is clear that financial integration is an important European goal. But what exactly is financial integration? In the literature there are several different definitions. Baele et al. (2004) state that the market of a certain financial instrument (or financial service) can be considered completely integrated once all similar agents participating in that market face a single set of rules, have equal access and are treated equally. A different definition is the adoption of the law of one price (see Adam et al. 2002). The law of one price basically means that assets that have identical risk and return characteristics should be traded on the same price, irrespective of the location of the trade.

The above two definitions are of course theoretical ones; their statements are rarely observable in real life. In case of equity markets there are many obstacles to measuring financial integration. It is nearly impossible to find assets with identical risk and return characteristics, as different securities might be characterized by different cash flows and heterogeneous sources of risk. This makes the direct comparison of their price nearly impossible. As a result, researches focus on examining the impact of common shocks on price movements when trying to assess the level of financial integration.

There are several different econometrical approaches for measuring the extent of financial market integration: GARCH models and its variations (Kenourgios and Samitas, 2011; Gjika and Hortvath, 2013); Partial Component Analysis (Gilmore et al., 2008, European Central Bank, 2014); Beta and Sigma convergence (Erdogan, 2009 and Babetskii et al., 2007); Granger Causality tests (Cerny and Koblas, 2008) and cointegration tests (Gilmore et al., 2008; Fonesca, 2008). These studies report considerably different results depending on the sample period, the countries included in the analysis and the methodology chosen. A common observation is that the level of stock market integration is not constant in time, it has a time varying nature.

In this study I will apply the Engle-Granger cointegration method in order to find out whether the stock markets from new EU member states became more integrated during the time period before and after the EU accession. Based on the existence of cointegrating relationships, I build stock market networks for different periods and analyze the structure of these networks to answer my research question. This method of building networks is similar to that of Mantegna (1999) and Onnela (2003) where correlations were used as a similarity measure to establish the presence or absence of a link between distinct financial assets. Cointegrating relationships as links in a network were previously used in two very recent studies by Yang et al. (2014) and Tu (2014). The former study analyses the effect of the 2007-2009 financial crisis on worldwide stock market integration while the latter study analyses the Chinese stock market based on cointegration networks. Cointegration networks were not yet used in order to analyze the effect of EU membership on stock market integration. This is where my thesis contributes to the literature of checking for the existence and measuring stock market integration. Furthermore, the two aforementioned papers use a weighted network approach where the chosen weights are somewhat arbitrary. In order to avoid this issue, I build unweighted networks.

I examine the period between January 2000 and April 2014. This interval includes the accession of the "EU 10 countries" in 2004 and those of Romania and Bulgaria in 2007 and Croatia in 2013. Thirty four stock market indices were collected and analyzed.

By analyzing the structure of the networks, the time evolution of the degree of each country and the results of the Infomap community detection algorithm I find evidence for the time-varying nature of stock market integration. Based on the resulted networks, the new member states went through a period of increased stock market integration right before their accession to the European Union. Stock markets showed a very high degree of integration beginning with the outburst of the interbank lending market crisis and throughout the first years of the world economic and financial crisis. Therefore the effect of EU membership on the integration of countries that joined the EU in this period can not be unambiguously inferred from this kind of analysis. In the autumn of 2009 a re-shuffling of the network takes place, in this period there are very few links observable among the analyzed countries. After this period an increasing amount of integration can be observed again.

The next Section lists the most relevant literature with an emphasis on studies that use cointegration as a measure of stock market integration in Europe. In Section three the dataset analyzed is described in detail. In Section four the methodology of building and analyzing cointegration networks based on the Engle-Granger cointegration test is presented. The structure of the resulting cointegration networks is analyzed in detail and the inference on the market integration of new member states is discussed in Section five. Limitations and possible extensions of the study are presented in Section six, before concluding in Section seven.

2. Literature Review

As I mentioned before, cointegration is one of the most used methods to check whether stock markets are integrated or not, because cointegration tests can reveal long-rung equilibrium relationships between variables, even if they drift apart in the short term. There are three generally used cointegration tests: the basic method of Engle and Granger (1987), the approach of Gregory and Hansen (1996) and the method of Johansen (1988). The first two are residual based tests and rely on an OLS estimation, while the third is a maximum likelihood based method, which checks for the number of cointegrating vectors in a system. The advantage of the Engle-Granger test lies in its simplicity, but it can be applied only in case of two variables. The Gregory and Hansen method is used frequently because it accounts for possible structural breaks in the data, furthermore it makes possible to estimate the exact date of the structural change in the cointegrating relationship. The strength of the Johansen method lies in the fact that it can be used for multiple variables.

Already in the late 1990's it became clear that several states will join the EU in 2004. From that moment scholars started to examine the stock market integration of these new countries. In the following I present several recent studies that include countries which became members of the EU in or after 2004. Before discussing these papers, however, I present a few studies that check for the level of integration of old EU members. These studies are important both because the respective countries are also part of my analysis and because they discuss important aspects of the applied methodology as well. The results of the papers discussed are summarized in **Table 1** (page 11) and show that different sample periods and different estimation strategies might yield different results. After presenting these papers, I mention two studies that build networks based on cointegration tests.

Pascual (2003) compares the results of a recursive and a rolling-window approach for three developed Western European countries. While he finds an increasing trend in the number of cointegrating vectors (and thus a deeper integration of the three markets) through recursive estimations, this is not the case using the rolling-window approach. His paper is very important because he is the first who argues for the use of a rolling-window approach and against the use of a recursive approach. He shows that an increasing number of cointegrating vectors obtained through the recursive method might be only the result of an increasing sample size that is reflected in the higher power of the Johansen test. An alternative to the application of a rolling-window or of a recursive approach is the study of Bley (2009), who applies the Johansen test for eleven Euro area countries by splitting his data into three equal subperiods. His analysis covers the time interval between 1998 and 2006 and he finds that the number of cointegrating vectors changes in the following way: there are two cointegrating vectors in the first period, three in the second and only one single cointegrating vector in the third period. This result suggests that after a period of stronger integration between 1998 and 2003, Euro area countries started to drift apart, which means that a divergence of markets previously cointegrated can be observed.

The paper of Fonseca (2008) is of particular interest for this thesis as he uses the two-step Engle-Granger methodology to examine the integration of the stock markets of sixteen European countries in the period 2001-2005, using weekly data. The author does a pairwise cointegration test of each market with a European index and then with a World index. He finds that based solely on the Engle-Granger methodology, only the French and the German stock markets are integrated with the European index. However, when he uses the Gregory and Hansen approach to check whether a regime shift causes the rejection of the cointegration hypothesis, he finds that in many cases the lack of stationarity of the long-term relationship can be explained by a level/trend break. Furthermore, the author does not find any significant difference in the integration of Eurozone and non-Eurozone members.

Voronkova (2004) analyzes three Central European stock markets (Poland, the Czech Republic and Hungary) and four developed markets between 1993 and 2002, using daily market index data. She finds that by using the Gregory-Hansen methodology and allowing for a more general specification, one can observe several long-run relations that are not present using regular cointegration tests (the one of Engle and Granger or Johansen). More precisely, she finds one extra cointegrating relationship among the Central European markets and five additional relationships between Central European and the developed markets, by allowing for structural breaks. This shows that a specification that allows for structural breaks in the data, or tries to reduce their effect on the cointegration test might reveal additional information. Gilmore et al. (2008) analyze the same set of Central European countries in relation with Germany and the United Kingdom through static and dynamic tests. Based on a static test done on the whole period, they can not find any cointegrating relationship between the countries. In order to account for structural breaks – as an alternative to the Gregory and Hansen approach used by Voronkova (2004) and in a similar manner to Pascual (2003) – they apply a recursive Johansen test and a rolling-window variation of it. In the case of the recursive method they start with a 2 year period beginning with 1995 and increase the period-length by one week in each estimation, leaving the beginning of the period fixed. In the rolling-window approach, they keep the period length constant and move forward both the beginning and the end by one week in each estimation. Results based on these techniques show that there are alternating periods of increased cointegration and dominance of domestic factors.

Kenourgios and Samitas (2011) check for cointegration of Balkan and more developed markets in a period ranging from 2000 to 2009. Based on the Johansen methodology, they find one single cointegrating vector for the system analyzed and based on the Gregory-Hansen approach, they identify two structural breaks: one of them in 2002 (around the dot-com bubble) and another one in the period 2007-2008 (due to the recent financial crisis).

In their recently published paper, Guidi and Ugur (2014) examine the integration of South-Eastern European stock markets. Four new EU member states (Romania, Bulgaria, Croatia and Slovenia are included in the analysis. They check whether these markets show integration with Germany, UK and the US based on both static and dynamic cointegration analysis in the time period 2000-2013. What is different in their study compared to the above presented ones is that they apply the Johansem methodology in the following way: in one estimation they include the five South-East European countries and only one single developed country and they do this estimation with the three different developed countries. Through this approach they try to eliminate the existing cointegration between the developed countries from their analysis. They find evidence for the cointegration of the analyzed new members states with Germany and the United Kingdom based on the static analysis. The dynamic analysis shows a time-varying level of integration that is more pronounced in the period of the recent financial crisis.

The idea of modeling complex systems as financial markets with the help of networks is not new. Building networks based on the existing correlations between financial assets has already a vast literature (see for example Mantegna, 1999 or Onnela et al., 2003). On the contrary, using cointegrating relationships in order to build networks is a pretty new idea. There are two very recent papers that use this approach.

Yang et al. (2014) build networks consisting of 26 nodes (each node represents a stock market from a certain country), where two nodes are considered to be connected if there is a cointegrating relationship between the two indices. They check for cointegration by using the Engle-Granger methodology and infer the “strength” or “degree” of the relationship from the cointegrating regression and use certain parameters of it as link weights in their network.

They build up four different networks based on consecutive periods (01/2002-12/2005, 01/2006-09/2008, 09/2008-12/2009 and 01/2010-04/2012) in order to check how worldwide market integration changed due to the financial and economic crisis. According to their methodology, changes in the structure and characteristics of the network (for example: link density, average weight, degree distribution, etc.) reflect changes in integration. They find evidence for a deepening integration (higher number of cointegrating relationships) in the period after the 2008 Lehman bankruptcy, however, the strength of the cointegrations decreases gradually over the four periods. Based on the PageRank algorithm they observe that the relative importance of the US stock market decreased after the collapse of Lehman Brothers.

The other author to use cointegration to build a network is Tu (2014), who examines the Chinese stock market through 197 stocks. Just as Yang et al. (2014), he uses the Engle-Granger methodology to check for the cointegration of pairs of stocks. He builds his network based on a weighted adjacency matrix whose weights are the p-values of the ADF test on the cointegrating residuals. According to him, the lower the p-value of the test, the stronger the cointegrating relationship. Once he has a complete graph, he prunes this graph with different methods (Minimum Spanning Tree, Partially Filtered Graph, pruning based on a statistical threshold) and analyses the statistical characteristics of the resulting networks.

Table 1 Findings of the literature focusing on stock market integration by applying the method of cointegration

Author	Period	Data freq.	Old Members	New Members	Method	Results
Studies concerning new member states						
Voronkova (2004)	1993-2002	Daily	UK, France, Germany (US)	Hungary, Poland, Czech Republic	1. Static Gregory and Hansen 2. Static Johansen	Evidence for integration More cointegrating relationships when accounted for structural breaks compared to other methods
Gilmore et al. (2008)	1995-2005	Daily	UK, Germany	Hungary, Poland, Czech Republic	1. Static Johansen and Gregory and Hansen 2. Recursive Johansen 3. Rolling-window Johansen	Alternating periods of increased and decreased cointegration
Kenourgios and Samitas (2011)	2000-2009	Daily	UK, Germany, Greece (US)	Romania, Bulgaria, Croatia	1. Static Johansen 2. Gregory and Hansen	1. Only 1 cointegrating vector 2. Structural break in 2002 and in 2007-2008
Guidi and Ugur (2014)	2000-2013	Weekly	Germany, UK, (US)	Romania, Bulgaria, Croatia, Slovenia (Turkey)	1. Static Johansen 2. Rolling-window Johansen	All new members cointegrated with Germany and UK Time varying cointegration, especially during the crisis
Studies concerning old member states						
Pascual (2003)	1960-1991	Quarterly	UK, France, Germany	-	1. Recursive Johansen 2. Rolling-window Johansen	1. Increasing integration 2. Stable level of integration
Fonseca (2008)	2001-2005	Weekly	12 European Monetary Union (EMU) members + Norway, Sweden, Switzerland, UK,	-	Pairwise cointegration with World and European index 1. Two step Engle-Granger 2. Gregory and Hansen	When accounted for structural breaks, more cointegrating relationships revealed
Bley (2009)	1998-2006	Daily	11 EMU members + UK (US)	-	Johansen 3 subperiods	First period: 2 coint. vectors Second period: 3 coint. vectors Third period: 1 cointegrating vector

3. Data

The analysis is based on stock market index time series obtained from the Bloomberg Database. The time series collected covers member states that joined the EU before 2004, member states that joined after 2004 and non-member states, as summarized in **Table 2** (page 16). Cyprus and Slovenia are missing from the group of new members due to lack of data for the whole time interval of the analysis. A few non-member states were included for various reasons: the United States has a global reference role in case of financial markets and it is very often included in market integration studies (Voronkova, 2004; Bley, 2009; Guidi and Ugur, 2014); a European Stock market index is included because if one of the new members shows cointegration with this index, it can be seen as evidence for stock market integration (see Fonseca, 2008); Switzerland is an important financial center in Europe and its stock market is very closely related to other important financial centers of the continent; Iceland and Norway might be important for the Baltic countries; while Russia, Ukraine and Turkey are all important economies outside the EU which have stock markets with a similar level of development as the new member states and it is interesting to analyze whether new member states show signs of integration or not.

The analysis covers the time period between 1. November 2000 and 16. April 2014. Important dates of this time period were the following:

- May 2004, the accession of the so called "EU 10" countries (Hungary, Estonia, Latvia, Lithuania, Malta, Cyprus, Poland, the Czech Republic, Slovakia, Slovenia);
- January 2007, the accession of Romania and Bulgaria;
- the summer of 2007, the outbreak of the interbank-lending crisis;
- September 2008, the failure of the investment bank Lehman Brothers and the beginning of the world-wide financial and economic crisis;

- May 2010, the first agreement between the EU and Greece, setting the beginning of the sovereign debt crisis in Europe
- January 2013, the accession of Croatia to the European Union.

In cases of those public holidays that did not coincide in all the countries, the missing values were completed by the index values of the previous days. When most of the public holidays were on the same day in the analyzed countries and there were many missing data points, the day was deleted.

The investigated time interval is split into 18 sub-periods due to the rolling-window methodology applied in order to account for the existence of structural breaks. With the exception of the last period, each period has a length of 500 observations (considering an approximate value of 250 trading days in a year this means two calendar years). The last period contains only 451 observations. The shift between the first time points in two consecutive time windows is 180 trading days which is equivalent to three quarters. Using a two years period is common in the literature (see for example Guidi and Ugur, 2014 and Gilmore et al., 2008). It is a reasonable time period to expect cointegration without having a too large probability of a structural break. Furthermore, it is important for the Augmented Dickey Fuller test (that is used as part of the Engle-Granger cointegration test) that the number of observations is large enough, as the test is sensitive to the sample size. The use of 180 days in the rolling-window procedure allows to obtain networks approximately each 9 months that are characterized by a not too large overlap. Exploratory analyses were made using 375, 625 and 750 trading day length windows with 90 and 180 days shift as well, but due to the reasons mentioned before, the 500/180 version was chosen as the most informative set of parameters.

All the indices are expressed in local currencies. This follows the strategy of Voronkova (2004) and Onay (2006). According to these studies the use of local currencies eliminates the effect of exchange rate fluctuations that might distort the outcome of cointegration tests. By focusing on local currencies, the test takes into account only the movements in asset prices. Exchange rate fluctuations were significant in case of the new members in the analyzed time interval as only a few of them adopted the common currency after accession. A comparative analysis was done on a shorter time period with indices denominated in US Dollars; the findings of this analysis are presented in Section six.

Table 2 on page 16shows summary statistics for the daily returns of the stock market indices covered in the analyzed period. The highest volatility can be seen in case of Turkey, Russia, Iceland and Ukraine, all of them non-member states. In the majority of the old members the average daily return was negative, the only exceptions are Germany, UK, Portugal, Luxemburg, Sweden and Austria. All the new members show positive average returns. With a very few exceptions, the return distributions are characterized by negative skew. This means that the distributions show long tails to the left. Extremely negative returns were more frequent than in case of a normally distributed random variable. All the index returns are leptokurtic, which means that their excess kurtosis (kurtosis compared to the standard normal distribution) is positive. Leptokurtic distributions are characterized by fat tails and extreme events are more probable in these cases than for normally distributed variables. Observing a leptokurtic behavior is very common in case of stock return distributions.

Table 2 Summary statistics of the analyzed stock market index returns

COUNTRY	INDEX	MIN	MAX	MEAN	STD. DEV.	SKEWN.	EXC. KURT.
EUROPE	EURO STOXX 50	-8.21%	10.44%	-0.014%	1.54%	0.027	4.64
OLD MEMBER STATES							
GERMANY	DAX	-8.87%	10.80%	0.007%	1.56%	-0.012	4.70
UK	FTSE 100	-9.27%	9.38%	0.000%	1.24%	-0.149	6.64
FRANCE	SBF250	-9.26%	10.22%	-0.006%	1.41%	-0.005	5.34
SPAIN	IBEX	-9.59%	13.48%	-0.001%	1.52%	0.113	5.32
ITALY	FTSE MIB	-8.60%	10.87%	-0.023%	1.53%	-0.070	4.90
PORTUGAL	PSI	-10.65%	10.11%	0.004%	1.09%	-0.212	10.01
IRELAND	ISEQ	-13.96%	9.73%	-0.005%	1.43%	-0.591	7.92
NETHERLAND	AEX	-9.59%	10.03%	-0.016%	1.51%	-0.067	6.40
BELGIUM	BEL20	-8.32%	9.33%	-0.001%	1.30%	0.011	6.18
LUXEMBURG	LUXX	-11.16%	9.10%	0.001%	1.29%	-0.441	7.73
DENMARK	KAX	-10.58%	8.20%	0.020%	1.14%	-0.400	6.28
FINLAND	HEX	-17.42%	9.23%	-0.018%	1.75%	-0.258	5.87
SWEDEN	OMX STOCKHOLM	-8.07%	8.63%	0.009%	1.42%	-0.022	3.91
AUSTRIA	ATX	-10.25%	12.02%	0.023%	1.48%	-0.313	7.47
GREECE	ASE	-10.21%	13.43%	-0.033%	1.74%	-0.004	4.12
NEW MEMBER STATES							
HUNGARY	BUX	-12.65%	13.18%	0.021%	1.58%	-0.065	6.36
ROMANIA	BET	-13.12%	14.58%	0.071%	1.65%	-0.209	9.29
CROATIA	CROBEX	-10.76%	14.98%	0.020%	1.33%	0.338	19.16
ESTONIA	OMX TALLIN	-7.05%	12.09%	0.049%	1.14%	0.139	8.65
LATVIA	OMX RIGA	-14.71%	10.18%	0.028%	1.46%	-0.721	16.80
LITHUANIA	OMX VILNIUS	-11.94%	11.00%	0.046%	1.10%	-0.563	19.32
BULGARIA	SOFIX	-20.90%	21.07%	0.048%	1.63%	-0.526	31.02
MALTA	MALTEX	-4.74%	6.10%	0.000%	0.73%	0.224	8.62
POLAND	WIG20	-8.44%	8.15%	0.013%	1.53%	-0.136	2.55
CZECH	PX	-16.19%	12.36%	0.019%	1.46%	-0.497	13.08
SLOVAKIA	SKSM	-14.81%	11.88%	0.023%	1.16%	-0.951	18.80
NON MEMBERS							
RUSSIA	MICEX	-20.66%	25.23%	0.055%	2.17%	-0.254	15.58
UKRAINE	PFTS	-16.38%	20.01%	0.056%	1.92%	0.141	11.81
TURKEY	XU100	-19.98%	17.77%	0.048%	2.21%	-0.069	8.23
ICELAND	ICEXI	-106.2%	5.06%	-0.015%	2.13%	-36.9	1778
NORWAY	OSEAX	-9.71%	9.19%	0.031%	1.44%	-0.636	6.35
SWITZERLAND	SMI	-8.11%	10.79%	0.001%	1.22%	-0.032	6.63
USA	S&P 500	-9.47%	10.96%	0.007%	1.28%	-0.187	8.66

4. Methodology

My goal is to build cointegration-networks that represent different periods in order to track changes in the level of stock market integration. I apply a rolling-window approach in order to account for possible structural breaks in the data. By splitting the data, I get 18 different periods with a partial overlap among groups of three successive periods. For each period I build a network based on the following procedure: first I rescale the data to the beginning of each period, then I consider the natural logarithm of the data; afterwards I check whether each series in each period is integrated of the same order, based on the Augmented Dickey Fuller test and then I apply the Engle-Granger cointegration test in case of every index-pair. Based on the results of the test I build a network for each period, where the nodes are country stock market indices and there is a link between two nodes if the two index series were cointegrated in the respective period. Once I have the networks, I analyze their structure in order to check whether states that joined the EU after 2004 showed increased stock market integration or not. In the following the methodology is described in detail.

4.1. Rescaling the data

In each period I rescale the data. First I calculate percentage changes in case of each index series:

$$\Delta_{it} = \frac{I_{it}}{I_{it-1}}, for\ all\ t \geq 2$$

where I_{it} is Index *i* in time *t*. Then I create the "Rescaled" series *R*, where I set the first entry in each series to one ($R_{i1} = 1$). Then I apply the following operation for all subsequent entries in each series:

$$R_{it} = R_{it-1} * \Delta_{it}\ \ , for\ all\ t \geq 2.$$

Finally I transform the obtained series in each period to natural logarithms.

4.2. Unit root test

According to Engle and Granger (1987), in order to check whether two series are cointegrated, one first has to be sure that the two series are integrated of the same order. There are various methods to measure the order of integration of a series: the Dickey-Fuller (DF) and the Augmented Dickey-Fuller test (ADF) presented by Dickey and Fuller (1979, 1981); a generalization of the ADF presented by Phillips and Perron (1988), the Kwiatkoswski-Phillips-Schmidt-Shin (KPSS) test (1992).

In my thesis I will apply the ADF test, which I present based on Hamilton (1994). The test equation of the ADF test is the following:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{k} \rho_i \Delta Y_{t-i} + \varepsilon_t$$

where Y_t is the logarithm of the rescaled stock market index series for time period *t*, $\Delta Y_t = Y_t - Y_{t-1}$, α is a constant representing a possible drift term, β accounts for a possible time trend that is present in the series, $\sum_{i=1}^{k} \rho_i \Delta Y_{t-i}$ are lagged values of Y_t and ε_t is a residual that should be a white noise process. Adding lagged values is important in order to remove the serial correlation in the residuals (this is actually the difference compared to the simple DF test). The coefficient of interest is γ and the ADF test measures the t-statistic of γ. The hypotheses of the test are the following:

$$H_0: \gamma = 0 \; and \; H_{alternative}: \gamma < 0.$$

The test is one-sided and accepting the null hypothesis means that the series tested is non-stationary, i.e. contains a unit root. The critical values for the test have been identified by Dickey and Fuller through Monte Carlo simulations. An important question is how many lags to include in the test equation. The method I apply to decide about the number of lags is based on the Akaike Information Criterion (AIC). The AIC is calculated for equations with different lag lengths and the lag length with the smallest AIC values is chosen. It is important to note that different critical values apply if there is no constant and time trend, a constant, a time trend or both a constant and a time trend included in the test equation. Choosing between these four cases depends on the characteristics of the series to be analyzed. I used the package "urca" by Pfaff (2008) in the statistical software R to perform the necessary Augmented Dickey Fuller tests.

4.3. Cointegration test

The concept of cointegration was introduced by Granger and became very important in the analysis of nonstationary time series. The concept and its test are presented based on the book of Hamilton (1994) and a publication by the Royal Swedish Academy of Sciences (2003).

Let us consider two time series: x_t and y_t. We know that both of them are integrated of order one (i.e. they are I(1) series). If one is able to find a linear combination of x_t and y_t (for example $z_t = y_t - \beta * x_t$) and the resulting combination is stationary (I(0)), then the variables x_t and y_t are cointegrated. This means that even though x_t and y_t seem to wander all over (as they are I(1) series), they seem to wander in such a way that they do not shift away from each other too much. As a result, we can consider the existence of cointegration as an indicator of the presence of a long-run equilibrium relationship. If it happens that the two series drift too far away from the equilibrium, economic forces will act to restore the equilibrium relationship. This equilibrium relationship can be the integrated nature of two stock markets. This makes cointegration a good proxy for measuring (or better said deciding: over the existence of) stock market integration.

Engle and Granger (1987) developed the statistical theory for testing the cointegration between two I(1) variables. After an OLS estimation of the relationship between the two variables, residuals are saved and tested for stationarity with the previously described ADF test. Due to the two steps involved in the test, this method is called as the "Engle-Granger two step method". This first step is running the so called "cointegrating regression", which is the following:

$$y_t = \alpha + \beta * x_t + \varepsilon_t.$$

Through this regression one can obtain an estimate for β, let's call it $\hat{\beta}$. The next step is the estimation of the residual series – the so called cointegrating residual – $\widehat{\varepsilon_t}$ in the following way:

$$\widehat{\varepsilon_t} = y_t - \hat{\beta} * x_t.$$

In order to test whether x_t and y_t are cointegrated, one has to test whether $\widehat{\varepsilon_t}$ is stationary or not. The null hypothesis of the Engle-Granger test is that "there is no cointegration" which translates to the null hypothesis of an ADF test on the residual series ("the residual series contains a unit root"). Engle and Granger suggested to test for the unit root in the conventional way, using the ADF test presented before. The ADF test is more suitable than the conventional DF as one has to allow for dynamics in the residual. However, according to Phillips and Oularis (1990), slightly different critical values have to be used because the residual series is an estimation and this has to be taken into account. For this reason, Phillips and Oularis (1990) estimated and published modified critical values for the ADF test that have to be used in case of residual based cointegration tests. In this thesis I apply the critical values estimated by them in the second step of the Engle-Granger test.

The coefficients in the linear combination (usually noted as (1 –β)) are called the cointegrating vector. When we check whether two variables are cointegrated or not, we can be sure that if they are cointegrated, there exists only one single cointegrating vector. In case of a multivariate cointegration test (like the Johansen approach) this is not the case. I have to note that in case of the Engle-Granger test, the choice of the dependent variable makes a difference.

Choosing *x* or *y* as a dependent variable is actually an arbitrary normalization and the results in the two cases might differ. Therefore, in case of my analysis all the indices appear as both dependent and independent variables in separate tests. This makes the cointegration network a directed one.

4.4. Building and analyzing the network

The idea of a cointegration network between financial assets builds on the idea of correlation networks, first introduced by Mantegna (1999). In case of correlation networks (mostly used for the analysis of stocks) financial assets are connected by weighted links, where the weights represent the degree of correlation between them. This method results in a fully complete network that is pruned afterwards through different methods (Minimum Spanning Tree, Planar Maximally Filtered Graph, threshold, etc.). It turned out that the structure of these networks can be used in various ways. Mantegna (1999) finds that stocks from different industry sectors are clustered together in the network. Onnela et al (2003) find that stocks that have positive weight in the Minimum Variance Portfolio tend to be on the "outskirts of the network" and when these networks are analyzed dynamically (i.e. networks built for successive periods are analyzed), important market events – such as crashes – are reflected in the changes of network structure.

As we can see, the use of correlation to build a network was introduced long time before and has a rich literature, on the contrary there are not many studies that use cointegration to define the presence of a link in a network. There are two recent papers by Yang et al. (2014) and Tu (2014) where the authors build weighted networks based on cointegration, just as Mantegna does with correlations. In both of the studies the authors extract the weights of the links from the two-step Engle-Granger method. Yang et al. (2014) use as weight the β coefficient from the cointegrating regression by stating that this coefficient shows actually the strength of the cointegrating relationship. According to them, the larger the value of the coefficient, the stronger the cointegrating relationship between the analyzed variables. Tu (2014) uses the p-value of the ADF test on the cointegrating residuals as weights. He argues that the lower the p-value, the stronger is the relationship between x_t and y_t because the more we can reject the existence of a unit root in the residual series (i.e. the residuals are "very" stationary).

It would be beneficial to build the cointegration network using weighted links, because this makes it possible to analyze the network using a more wide variety of methods. However the choices of Tu (2014) and Yang et al. (2014) as measures of the strength of the cointegrating relationship seem arbitrary and not well founded in the literature of cointegration. I did not find any other study that would use these two measures as measures of cointegration and unfortunately I did not find any measure that alone captures the strength of cointegration. An intuitive solution would be to build such a measure based on a mixture of quantities, like the β coefficient of the cointegrating regression, the t-statistic of the β coefficient and the test-statistic of the ADF test on the residuals. None of these quantites is able in its own to capture the strength of the relationship but all of them contributes to have an "idea" or a "feeling" about it. However, defining such a measure is out of the scope of this thesis. Therefore I build and analyze unweighted cointegration networks, even though it might significantly limit the number of analyzes that I can perform.

In order to examine the level of integration of the new EU member states, the dynamics of the degree of each country is analyzed. The degree of a node shows the number of links that go out or go in from/to the respective node. In this case, through the degree of a node actually the number of its cointegrating relationships are counted. A high degree for a new member state, however, does not directly imply that the respective country is highly integrated with old member states. It might very well happen that in certain periods new member states are more integrated with each other and form a separate group inside the network. To account for this, the community structure of each network in each period is examined using the Infomap community detection algorithm. According to Radicchi et al. (2004), a community in a network is generally defined as a subset of nodes where connections inside the subset are more frequent than connections with nodes that do not make part of the subset.

The Infomap community detection algorithm was first introduced by Rosvall and Bergstrom (2007). This is one of the most powerful algorithms to identify communities in directed networks according to Lancinchinetti and Fortunato (2009), who compare several different algorithms on benchmark networks and random graphs. The Infomap algorithm is based on the following idea: if there is a random walker in a network, she will be inclined to get "captured" in a community and thus will spend a lot more time stepping from one member of a community to the other member, than stepping between members of different communities. Based on this, it is possible to define communities in the network. The algorithm is implemented in the package "igraph" by Csardi and Nepusz (2006) for the statistical software R.

5. Empirical results

5.1. The results of the cointegration tests

Before testing for cointegration, the level of integration for each series was tested in each period using the Augmented Dickey Fuller test. First the rescaled and logged series were tested for a unit root in each period. According to the ADF test statistics (**see Appendix A Table 1**), the null hypothesis of the existence of a unit root can not be rejected in case of any of the series in all periods at 5 percent significance level. This result is not surprising at all considering that we are examining stock market data which is rarely stationary. In order to be sure that all the series are integrated of order one, the Augmented Dickey Fuller test is repeated on the first difference of all series in all periods. According to the ADF test statistics, the null hypothesis of an existing unit root can be rejected at 5 percent significance level (it can be rejected even at 1 percent significance level either). These statistics are reported in **Appendix A Table 2**. Based on these results, all the variables have the same level of integration, which is a necessary condition for the next step, the test of cointegration.

The results of the two-step Engle-Granger test are actually the Augmented Dickey Fuller test statistics on the residuals that are estimated based on the cointegrating equation. For each index pair in each period there was a residual series estimated using the *beta* coefficients of the pairwise cointegrating equations.[1] When testing for a unit root in these series through the ADF test, modified critical values were used, based on Philips and Oularis (1990). The test statistics and the respective critical values for certain countries from the first period are shown in **Appendix B** for an illustrative purpose.[2]

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[1] These *betas* and the estimated residual series are not reported due to space limitations but are available from the author on request

[2] Results for the full set of countries for the first period and results for subsequent periods are not reported due to space limitations but are available from the author on request

By using the results of the Engle-Granger test for each period, adjacency matrices were built in each period. If the ADF test statistic on the residual series of an index pair is lower than the modified critical value, the index pair is cointegrated and the corresponding value in the adjacency matrix has value one. When no cointegration is found, the corresponding value in the adjacency matrix has a zero value. With this approach I obtained 18 adjacency matrices describing the cointegration relationships among the investigated stock exchanges. Based on the resulting adjacency matrices there were built the cointegration networks for each subsequent period.

5.2. Analysis of the cointegration networks

If there were cointegrating relationships observed between all index pairs (which is of course nearly impossible), one would get a complete network. Therefore, in order to assess how dense my cointegration networks are, I compared the number of links in each network to the number of links in a hypothetical complete network. Based on the results presented in **Table 3**, the obtained cointegration networks are considerably more sparse than those obtained by Yang et al. (2014) in their analysis of world stock markets. This is most probably due to the different critical values used in the ADF test while testing for cointegration.

Table 3 shows the absolute value of the number of links in each network in each period as well. This is actually the number of cointegrating relationships in each period. If we assume that the number of cointegrating relationships is a good proxy of the degree or deepness of financial market integration, then the time-varying nature of integration is clearly visible in the results. This finding is similar to those of Gilmore et al. (2008) and Guidi and Ugur (2014). There are two periods of increased overall integration of the analyzed stock markets, the first one is the period short before and immediately after the accession of the EU 10 countries (periods 4 and 5) and the second one is observed during the world financial crisis and the European sovereign debt crisis (periods 11-13). Beginning with period 14 with a midpoint in

October 2010, there is a "re-shuffling" of the network, the number of cointegrating relationships reaches its lowest value and then starts increasing slowly.

Table 3 Number of links and cointegrating country pairs in each period

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Midpoint	10/2001	06/2002	03/2003	11/2003	07/2004	03/2005	12/2005	08/2006	04/2007
Number of links	39	92	99	156	102	71	76	61	65
Double linkpairs	16	22	22	64	37	31	23	24	28
% Double links	82%	48%	44%	82%	73%	87%	61%	79%	86%
N. of coint. country pairs	23	70	77	92	65	40	53	37	37
Density	0.035	0.082	0.088	0.139	0.091	0.063	0.068	0.054	0.058

Period	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Midpoint	01/2008	09/2008	05/2009	01/2010	10/2010	06/2011	02/2012	10/2012	06/2013
Number of links	87	122	73	154	14	28	53	63	57
Double linkpairs	38	54	28	44	4	5	17	13	15
% Double links	87%	89%	77%	57%	57%	36%	64%	41%	53%
N. of coint. country pairs	49	68	45	110	10	23	36	50	42
Density	0.078	0.109	0.065	0.137	0.012	0.025	0.047	0.056	0.051

In order to check the number of cointegrating country pairs, the number of double links has to be subtracted from the number of total links. As the network is directed, in case of some country pairs it might happen that two countries are connected with two links, if the Engle-Granger test showed cointegration in both directions. The ADF test statistic in case of those country pairs where both links are present are generally lower compared to the cases where there is only one link. The average test statistic in the first case is -3.91, while the average in the second case is -3.69. Based on the Welsh t-test, the two means are significantly different from each other. Therefore, the presence of two links in case of a country pair suggests a stronger cointegrating relationship compared to the case where there is only one link, because the null hypothesis of no cointegration can be rejected based on a lower p-value. Based on the results presented in **Table 3**, it is to be observed that not only the number of links is time-varying, but the share of double links as well. This means that the strength of the relationships changes in time too. In periods four and eleven an increased number of links is associated with a higher percentage of double links. In these periods, not only there is an increased level of integration, but it is stronger as well, compared to the majority of other periods.

5.2.1. The structure of the links

It is clear from the previous subsection that both the number of links and the number of double links has a time varying nature. There are periods with higher and lower overall integration of the analyzed markets. The main focus of this thesis are those countries that became members of the European Union after 2004, therefore it is important to see what behavior show links associated with these countries.

Figure 1 The share of link categories in total links

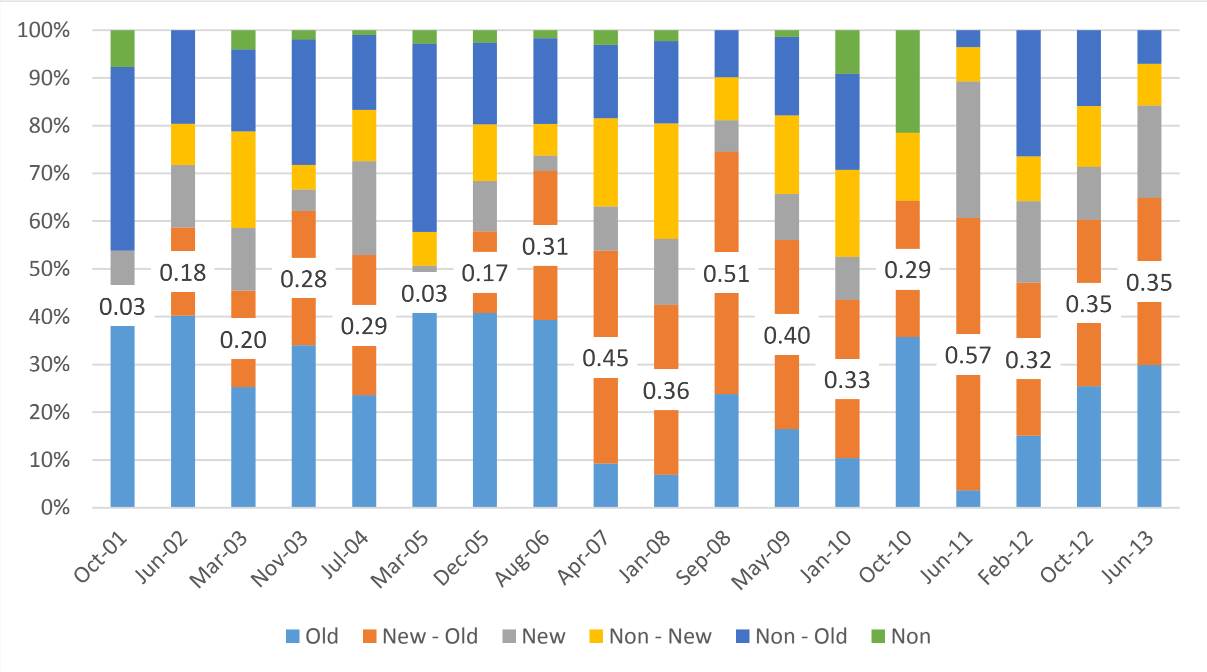


Figure 1 presents the share of the following link categories in each period: links that connect only old members, links that connect a new member with an old member, links that connect only new members, links that connect a new member with a non-member, links that connect an old member with a non-member and links that connect only non-members. It can be observed that the fraction of links that connect old members with new members is increasing. Between November 2003 and May 2009 this increase is mostly due to double links (the share

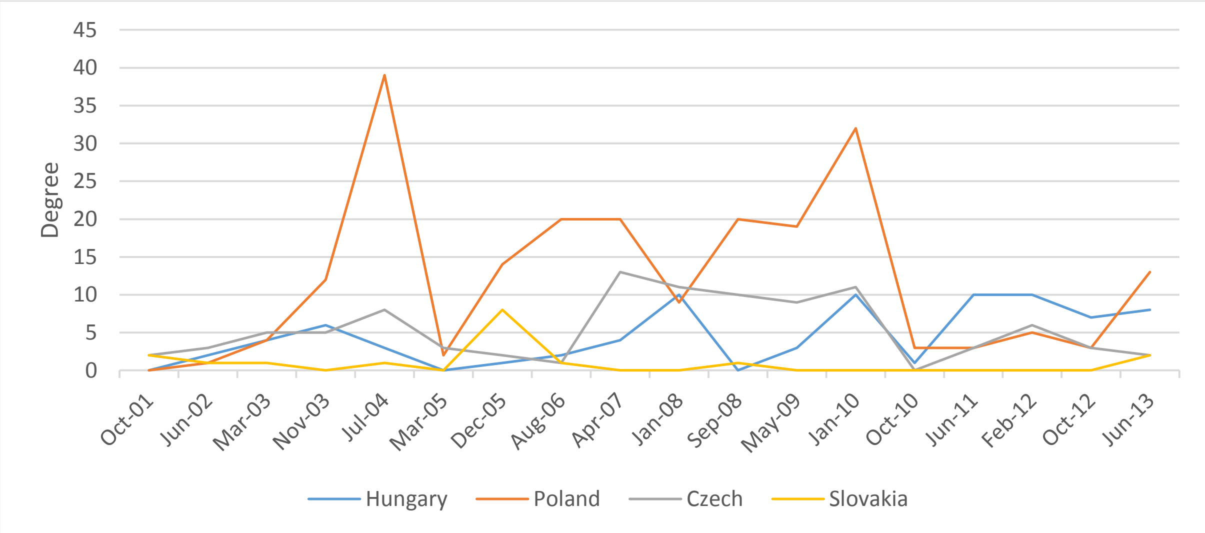
of double links among new-old links in this period is above two third), while later this is governed by single links. This suggests an increasing integration of new members with old members, with stronger relationships between 2003 and 2009.

5.2.2. The time evolution of the degrees

The degree of each country in each period shows the number of cointegrating relationships of the country in the certain period. As a next step I will analyze the evolution of the degree of the new member states that were included in the analysis in order to see how the individual integration of their stock markets evolved with time.

The four most developed stock markets among the EU 10 countries were those of Poland, Hungary, Slovakia and the Czech Republic. The time evolution of their degree is presented in **Figure 2**. Among these four countries, **Poland** has the biggest and most important stock market. This is the only country that shows an increased level of integration both before the accession in 2004 and in the period between the accession and the financial crisis. Based on the number of cointegrating links, Poland seems to be the most well integrated stock market until late 2010. On average, 70% of these connections are links between Poland and an old member. Beginning with the period centered in June 2011, however, the number of Polish links decreases dramatically. In case of **Hungary** there is an increasing trend in the degree. With an initial peak in the period centered in late 2003, the series reaches its highest value (10) in the beginning of 2008. After this, periods with high and low degrees follow each other, while in the last four periods there is again an increased level of integration. The first peak in the degree is driven by links with old member states while the second peak is characterized by a higher level of integration with the new member states. In the last four periods of the analysis, periods with high and low degree are observed to follow each other. The **Czech Republic** reaches a peak of eight connections in the period centered in the year of its accession to the EU which is driven by links to other new member states. After a few periods of low degree, the Czech Republic shows signs of stronger integration starting already before the beginning of the 2008 financial crisis. This period of deeper integration is driven by links to old member states. In the last periods, the Czech market shows a limited degree of integration and is mostly linked to other new member states. What is interesting in the case of **Slovakia** is that it did not experience a high degree of integration during the financial crisis. There is only one single period, in which Slovakia has a higher number of links: in the period after accession, centered in December 2005, the country had eight cointegrating relationships. In this period new and old members have an equal weight among links.

Figure 2 The time evolution of the degree in case of Hungary, Poland, the Czech Republic and Slovakia



These four countries were previously analyzed by Voronkova (2004) until 2002 and Gilmore et al. (2008) until 2005 and both showed evidence for stock market integration for these countries, however the degree of integration varies with time.

The integration of the three small Baltic countries Estonia, Latvia and Lithuania with the EUROSTOXX50 stock index was previously analyzed by Nikkinen et al. (2012). By applying a variance decomposition analysis, they found that in the period 2004-2007 these markets were segmented while during the financial crisis, during 2008-2009 they became highly integrated.

Figure 3 The time evolution of the degree in case of the Baltic countries and Malta

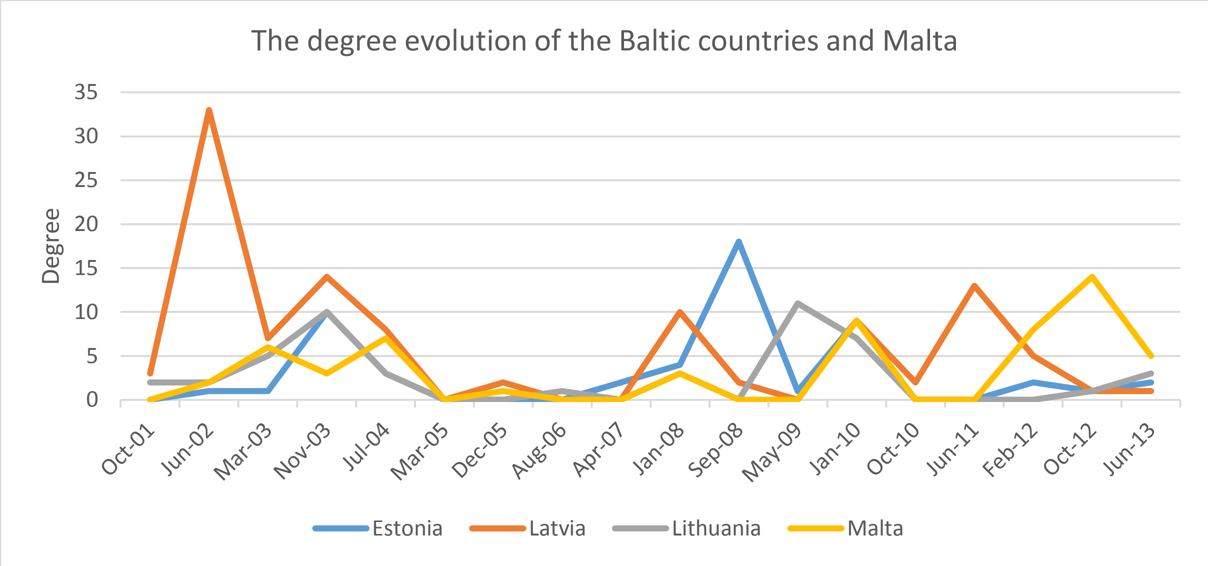
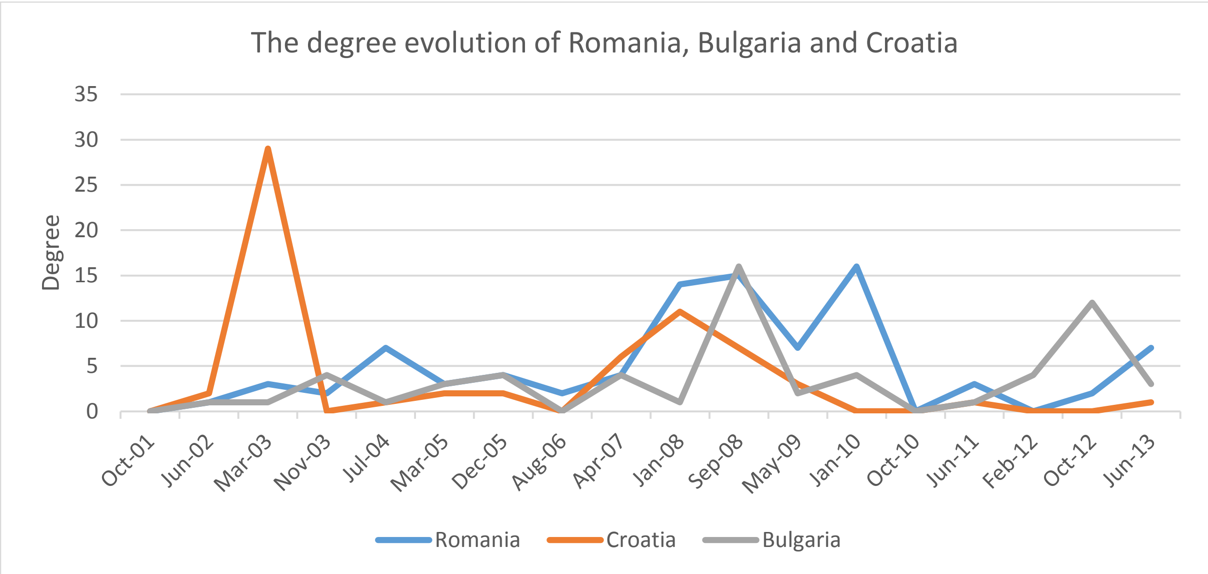


Figure 3 shows the degree evolution of the three Baltic countries and Malta. In case of **Estonia** there is a peak in late 2003 of 10 links and another peek in the period 2008-2010, both driven by links to new members. Beside these periods, there is no sign of stock market integration based on the number of cointegrating relationships. In **Lithuania** there were two peaks in the number of degrees: the first one in late 2003 with 10 links and the second one in the period 2009-2010 with 11 and 7 links, both driven by links to new members. Between the two peaks and after the last one, there is no sign of deep stock market integration. **Latvia** presents strange behavior in Period two as it connects to all of the other countries. After checking the evolution of the market index in this period, it became clear that due to a large structural break, the ADF test is most probably not producing appropriate results. The stock market of Latvia experienced the burst of a financial market bubble in this period. In the other periods, Latvia shows a similar level of stock market integration to the other three countries in this group. In the period of the accession there is an increased level of integration, driven exclusively by new member states while in later periods the weight of new and old members is the same. In case of **Malta** there are signs of pre-accession and post crisis integration. In both periods there are higher numbers of links but this is driven by links to new members in the first

case and by links to old members in the second case. Malta seems not to be so much integrated during the outburst of the 2007/2008 financial crisis, but it shows increased integration during the sovereign debt crisis and afterwards, especially in the last periods. These last periods are characterized mostly by links to old EU member states. These findings are mostly in line with the findings of Nikkinen et al. (2012).

Romania and Bulgaria were the two countries that joined the EU in 2007, shortly before the outbreak of the interbank lending and the global financial and economic crisis. Croatia was the last to join the EU (in 2013) among the analyzed countries. This makes it difficult to assess the effect of EU membership on the integration of their stock markets as markets overall became more integrated in this period due to the financial turmoil. However, it is informative to check whether these countries had shown signs of integration prior to their accession. **Figure 4** presents the time evolution of their degree. In case of **Romania** there is an increasing trend in the degree until the end of 2008, with an initial peak in June 2004. After the degree reaches its maximal value of 16 in the beginning of 2010, it decreases dramatically to zero in the subsequent period. Afterwards, a slight increase is beginning. In all of these periods, links to old member states are in majority. It is hard to conclude that the high level of integration of Romania around the date of its accession to the EU is due to the accession process, because in this period, due to the worldwide financial and economic crisis there are many cointegrating links observable in the network. **Bulgaria** shows a sign of integration even after the financial crisis, mainly driven by cointegration with old members. Before September 2008, the number of degrees varies between 0 and 4. In September 2008 there is a peak of 16 links. After this, contrary to other countries, there is another peak in late 2012. This might indicate an increased level of integration of the Bulgarian stock market even after the financial crisis of 2008. **Croatia** in the third period shows similar behavior to that of Latvia in the second period. The reasons behind this are the same: there is a large structural break in the index series. In other periods the degree mostly fluctuates in the interval 0-3, however there is a period of increased integration between 2007 and 2009 reaching 11 cointegrating relationships. All of these links are equally driven both by new and old members. The stock market integration of these countries were previously analyzed by Kenourgios and Samitas (2011) and Guidi and Ugur (2014) who found evidence for integration. Furthermore they found that the stock market integration of these countries increased during the crisis and there were structural breaks in the cointegrating relationships in 2002 and in 2007-2008. These results are in line with the above comments based on the degree evolution of these states.

Figure 4 The time evolution of the degree in case of Romania, Bulgaria and Croatia



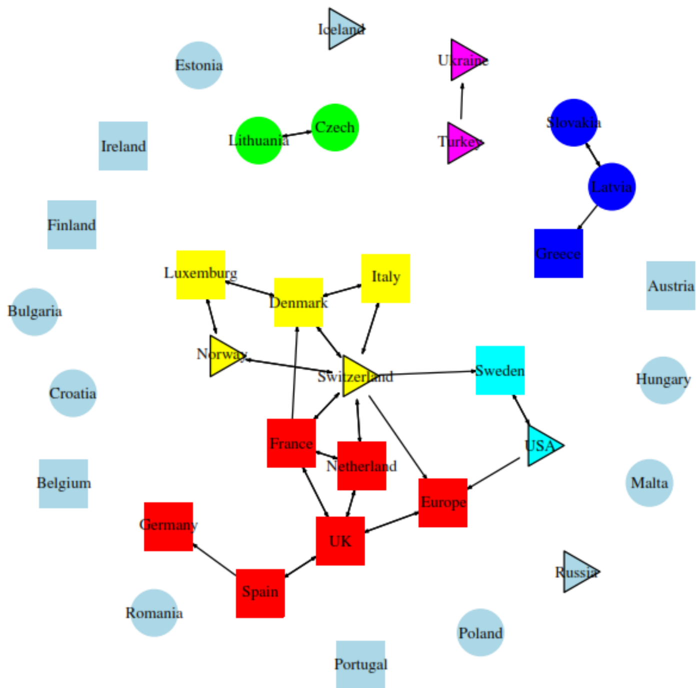
5.2.3. The evolution of communities

In order to find out whether old members are more integrated among themselves or with new member states, the results of the "Infomap" community detection algorithm gives a better overview than the simple analysis of degrees and the degree structure. The characterization of the structure of the resulting communities are summarized in **Table 4**. In the following I present the evolution of these communities during three different time intervals: before the accession of the EU 10 countries; between the accession of the EU 10 countries and the beginning of the financial crisis and after the beginning of the financial crisis. The membership vector of each community in each period is presented in **Appendix C**. while the plots of those networks that are not presented in this subchapter can be found in **Appendix D**.

Before the EU accession in 2004

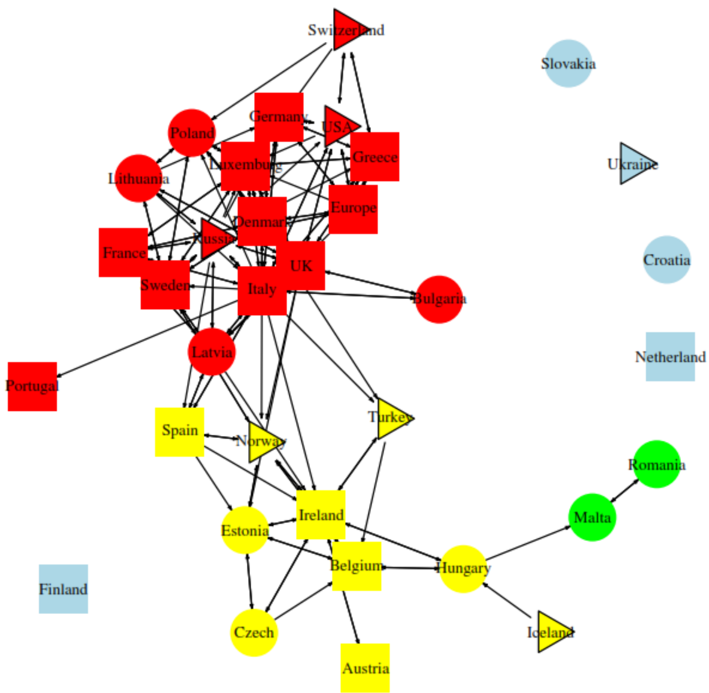
In the first period there are 6 communities with at least two members. There is only one single community in which new and old member states are mixed (Latvia, Greece and Slovakia). The fragmented nature of this network can be perfectly seen on **Figure 5**. Colors represent different communities while shapes represent different country groups: square for old EU members, circles for new EU members and triangles for non members. The giant component contains only old members while the number of isolated nodes is striking on the figure.

Figure 5 The cointegration network in the first period (November 2000 - October 2002)



All the other communities contain either only old or only new member states. In period two there are four communities. Two of them is built up by only old members, one has only new members while the fourth has nearly all the new member states together with Greece, Norway, Finland and Austria. The presence of Greece and Austria in this community is not surprising as both countries have important economic relationships with the new member states. In the third period, ranging from February 2002 to February 2004 there are still two homogenous communities but there is a large community of 20 members where seven new members are mixed with nine old members. In period four the two biggest communities are a mixture of old and new states. In period five, besides a large and a smaller mixed community (consisting of 18 states) there is one homogenous community. Based on these, there is a clear sign of increased integration of the new member states with the old ones as the number of homogenous communities decreases steadily and large, mixed communities emerge in the last two periods (see **Table 4**). This increased level of integration can be seen if we compare **Figure 5** with **Figure 6**. In case of the figure below, the number of isolated nodes is very low and there are two large mixed communities.

Figure 6 The cointegration network in the fourth period (November 2002 - October 2004)



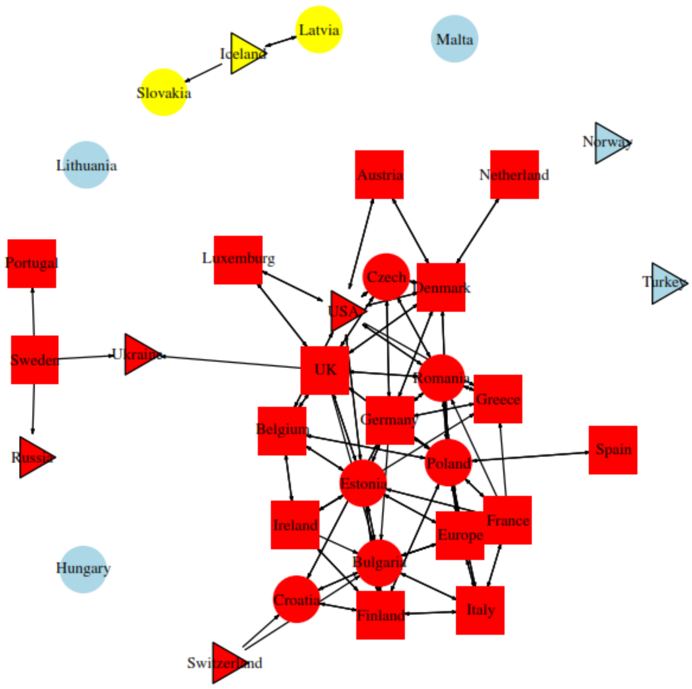
After the EU accession in 2004

In period six, which is the first complete period after the accession of the “EU 10” countries, there are 10 isolated communities consisting of only one single country. Furthermore, there are also two homogenous communities (one of them with old and another one with new member states) while there is a large mixed community. Period seven is dominated by three mixed communities, however there are two small homogenous communities as well. Period eight is the last complete period before the interbank lending crisis that began in the summer of 2007 and the outbreak of the global financial-economic crisis starting with the bankruptcy of Lehman Brothers in September 2008. There is a change in the level of integration in period eight as the communities in this case are dominated by homogenous and nearly homogenous communities. Based on the structure of the communities a certain level of post-accession integration can be observed, however the size of mixed communities became smaller and the percentage of new members states inside these communities decreased compared to the periods right before accession.

The interbank lending crisis, the global financial economic crisis and the European sovereign debt crisis

Periods nine and ten are dominated by a large mixed community and many communities with only one single member. This is a sign of a group of integrated countries and a considerable number of countries (10 and 9) that are isolated. Period eleven (**Figure 7**) is the first complete period after the outbreak of the interbank-lending crisis and this period is characterized by a very large community consisting of 26 nodes (out of the totally examined 34 nodes). This shows that in this period the financial markets were highly integrated throughout the whole Europe. By checking the behavior of the index time series in this period, it is observable that there was a considerable decrease in case of all indices examined. Period twelve is again characterized by a large mixed community and numerous isolated nodes while the community structure of period thirteen is very similar to that of period elven. The community structure of these three period shows clearly that stock markets become deeply integrated during the financial crisis.

Figure 7 The cointegration network in the eleventh period (September 2007 - August 2009)



Period fourteen is characterized by a very low number of links, this shows that there was a restructuring of the cointegration network between periods thirteen and fifteen. Beginning with period fifteen the number of links starts to increase but the existence of one single large community (like in the cases of periods eleven and thirteen) is not observable in the subsequent periods. However, with period fifteen a new cycle of growing integration can be observed as there are less and less isolated nodes and more and more mixed communities. The size of these communities, however is at most twelve.

To sum up the results of the community detection, I can state that in the beginning of the analyzed time period, starting with 2000, stock market integration was a characteristic of homogenous groups that were formed either by old or by new member states. The presence of mixed groups was first observable in later periods and became general around the accession of the EU 10 countries. Between the accession and the outbreak of the financial crisis, there was a period of lower integration, more homogenous groups can be observed. During the crisis large communities emerged that contained most of the analyzed countries. This might very well be the effect of the financial crisis and not EU membership as all the stock exchanges fell dramatically and together in this period. After a period with a very low number of cointegrating relationships between June 2010 and May 2012 I observed again an increasing level of stock market integration between old and new member states through the presence of numerous small, but mixed communities.

Table 4 Summary of community size and components

Nr	Interval	Nr. of Comm.	Isolated nodes	2-4 memb.	5-15 memb.	>15 memb.	Hom. Comm.	Mixed comm. (size)	% new member in mixed
Before the EU accession in 2004									
1	11/2000 10/2002	20	14	4	2	0	5	1 (3)	66%
2	7/2001 6/2003	4	0	1	2	1	3	1 (16)	56%
3	3/2002 2/2004	5	1	2	1	1	2	2 (3, 22)	66%, 31%
4	11/2002 10/2004	8	5	1	1	1	1	2 (17, 10)	23%, 30%
5	8/2003 7/2004	8	5	2	1	1	1	2 (18, 5)	38%, 80%
After the EU accession in 2004									
6	4/2004 3/2006	14	10	2	2	0	2	2 (11, 2)	18%, 50%
7	12/2004 11/2006	10	5	2	3	0	2	3 (13, 7, 2)	15%, 57%, 50%
8	8/2005 8/2007	14	9	3	2	0	2	3 (12, 5, 2)	8%, 40%, 50%
The interbank lending crisis, the global financial economic crisis and the European sovereign debt crisis									
9	5/2006 4/2008	14	11	1	2	0	1	2 (16, 5)	25%, 40%
10	1/2007 12/2008	13	10	2	0	1	0	3 (17, 4, 3)	47%, 25%, 33%
11	9/2007 8/2009	7	5	1	0	1	1	1 (26)	23%
12	6/2008 5/2010	15	10	4	0	1	3	2 (16, 2)	31%, 50%
13	2/2009 1/2011	5	3	1	0	1	0	2 (27, 4)	29% , 25%
14	10/2009 9/2011	25	19	6	0	0	4	2 (3, 2)	33%, 50%
15	6/2010 5/2012	19	14	3	2	0	2	3 (7, 6, 3)	16%, 50%, 33%
16	3/2011 2/2013	15	10	2	3	0	3	2 (9, 5)	33%, 60%
17	11/2011 10/2013	12	6	3	3	0	3	3 (7, 6, 6)	28%, 16%, 33%
18	7/2012 4/2014	10	4	4	2	0	2	4 (12, 7, 4, 3)	58%, 28%, 25%, 33%,

Notes: 2-4 memb: the number of communities with size between 2 and 4; 5-15 memb: the number of communities with size between 5 and 15; >15 memb: communities with more than 15 members;

6. Limitations and possible extensions

The results presented in the previous section show that it is possible to track changes in the stock market integration of multiple countries based on a cointegration network analysis. However, there are a few limitations and possible extensions of this methodology.

First of all, by building a cointegration network of n countries, the Engle-Granger cointegration test is repeated $n * (n - 1)$ times. Suppose that in all the $n * (n - 1)$ cases the null hypothesis is true. If each test is evaluated based on a critical value associated to a specific p-value α, then the null hypothesis will be incorrectly rejected $n * (n - 1) * \alpha$ times. In case of my analysis this would mean 56 erroneous rejections. A solution to this issue would be to use the Bonferroni correction method, which is easy to apply but very conservative. The Bonferroni correction modifies the p-value by dividing the original p-value by the number of tests conducted. In this case, by assuming an original significance level of 5%, the new p-value would be $\frac{\alpha}{n*(n-1)} = 0.045 * 10^{-3}$. However, I was not able to find critical values associated with so low p-values for the Augmented Dickey Fuller test. The lowest critical values reported in the literature are for the 1% significance level. As a result I used the critical values associated with this significance level, as a transient solution. This means around 11 erroneous rejections in case of each network if it is supposed that all the null hypotheses are originally true.

Another important point to consider is the choice of the currency. As I already mentioned, indices in this study are all denominated in local currencies. Another option is using a common currency, like the US Dollar or the Euro. It is more feasible to choose the US Dollar as many companies publish indices in this currency. In order to check for the stability of my results, I built a shorter dataset of 31 MSCI country stock market indices denominated in US Dollars for the period 12/2006-4/2014. Unfortunately, for many of the new EU member states I was not able to find the appropriate index series for earlier time periods. Simultaneously I built a dataset based on my original data for the same time period and for the same countries in order to compare the results. I applied the same rolling-window analysis with 500 days window width and 180 days roll. I found that while the number of links is very similar for the networks based on different currencies, there is a fairly limited number of links that appear in the same period in both networks. This means that the results are not completely robust to the currency choice. This phenomenon is not unique in the literature as it can be observed by comparing the results for the periods that coincide in the studies of Gilmore et al. (2008) and Voronkova (2004). The two papers present different results for the same countries, using the same methodology but different currencies.

An important extension to this study and to the papers of Tu (2014) and Yang et al. (2014) would be constructing a measure that captures the strength of the cointegrating relationship between two countries. Once there is a reliable measure, this could be applied to build a weighted network. The advantage of a weighted network is that more detailed analysis can be conducted on it.

7. Conclusion

My goal in this thesis was to check whether stock markets of those countries that became members of the European Union after 2004 became more integrated with the stock markets of countries that were members of the Union previously. The European Union has a strong political will to reach a high level of financial integration among its member states and stock market integration is an important cornerstone of overall financial integration.

As a method to examine this question I have chosen to build cointegration networks using a rolling-window approach. Specifically, I used the cointegration test proposed by Engle and Granger in order to define links between national stock market indices. This procedure was previously used by Yang et al. (2014) and Tu (2014) on other datasets. Based on this cointegration test I built 18 networks that cover the period between 2000 and 2014.

By analyzing the structure of the networks, the evolution of the degree of each country in the 18 periods and the results of the Infomap community detection algorithm I can confirm the results of previous studies showing the time-varying nature of stock market integration. According to my results, the new member states went through a period of increased stock market integration right before their accession to the EU. This shows the ability of financial markets to process information about the future membership of most of the new member states.

In general stock markets showed a very high degree of integration beginning with the outburst of the interbank lending market and throughout the first years of the world economic and financial crisis. Therefore the effect of EU membership on the integration of countries that joined the EU in this period can not be unambiguously inferred from this kind of analysis. In the autumn of 2009 a re-shuffling of the network takes place, in this period there are very few links observable among the analyzed countries. After this period an increasing amount of integration can be observed again.

Appendix A – ADF test results for the analyzed series

Appendix A Table 1 ADF test statistics for the level values for each period

Midpoint	Germany	UK	France	Spain	Italy	Portugal	Ireland	Netherland	Belgium	Luxemburg	Denmark	Finland
10/16/2001	1.9550	1.1231	1.7129	1.2834	1.6066	2.0854	0.7778	1.5735	0.9068	1.8552	1.6515	0.6232
6/25/2002	0.2087	-0.2294	0.0293	-0.5469	-0.0970	-0.2686	0.2639	0.3160	-0.2142	0.2397	0.0055	-0.8528
3/4/2003	-0.3052	-0.4131	-0.4336	-0.6869	-0.4016	-0.4735	-0.7533	-0.2139	-0.6551	-0.4528	-0.5673	-0.5387
11/11/2003	-0.7155	-0.8590	-0.8406	0.0097	-0.9413	1.1108	0.5519	-1.3877	-0.0183	0.6332	0.9757	-1.1853
7/20/2004	0.5349	1.2312	1.2227	1.3104	0.9970	1.5154	1.6514	0.1556	1.9615	1.7451	2.4278	0.2147
3/29/2005	1.7479	1.9741	2.0691	1.9960	1.7767	3.7976	2.1961	1.2822	3.0733	2.9603	2.4776	1.7233
12/6/2005	1.6861	1.2873	1.6358	2.7679	1.3793	2.7442	1.5665	1.4231	1.7738	2.3154	1.5622	1.1043
8/15/2006	1.4660	0.2518	0.6962	1.2566	0.2207	3.7902	0.1275	0.9192	0.7499	1.7358	1.4725	1.1568
4/24/2007	-0.6184	1.2652	-1.2541	-0.4943	-0.6586	-0.3305	-0.6004	-1.3202	-1.2913	-0.5106	-0.7555	-1.1055
1/1/2008	-0.2254	-0.0415	0.9843	0.3080	1.9875	1.2355	2.3839	1.5477	2.2362	1.8473	1.4470	1.0525
9/9/2008	-0.2616	-0.4049	-0.0067	-0.4943	0.1865	-0.1324	0.4790	0.2027	0.2023	0.2851	0.0515	0.4379
5/19/2009	-0.6190	-0.6966	-0.3447	-0.4207	-0.0511	-0.1573	0.0223	-0.1961	-0.1146	-0.0571	-0.4197	-0.1648
1/26/2010	0.5548	0.4478	-0.1250	-0.7564	-1.1392	-0.2417	-0.7643	0.1306	0.0105	0.4070	1.1338	0.3307
10/5/2010	-1.2008	-1.6122	-1.5628	-0.4514	0.7881	-0.5638	-0.3208	-1.6040	-1.5365	-0.5999	-0.7267	-1.0582
6/14/2011	-1.3942	-0.8243	-1.5969	-0.1508	-0.1608	-0.1680	-1.8438	-1.7171	-1.3579	-0.2718	-1.2106	-0.9603
2/21/2012	-1.5346	-1.9118	-1.0139	-0.4870	-0.3522	-0.5156	-0.8311	-0.9408	-0.8824	-0.4640	-0.8286	-0.5241
10/30/2012	0.7115	-0.0771	0.5977	-1.4180	-1.2786	-0.5711	1.3918	0.3359	0.6195	-0.5451	1.2736	-0.5843
6/5/2013	0.8721	0.2175	1.0296	0.7979	1.0719	1.1071	1.5783	0.4303	1.0120	0.8560	1.5460	0.7482

The table above (continued on the next page) presents the resulting ADF test statistics for the level values of the index series in each period. All the values are above the 5% critical value -1.95. This means that the null hypothesis of the existence of a unit root can not be rejected.

Midpoint	Norway	Austria	Greece	USA	Europe	Russia	Ukraine	Turkey	Switzerland	Iceland	Sweden
10/16/2001	1.7063	-1.0796	1.2604	0.9170	1.5477	-0.4016	-0.9804	-0.9956	0.8563	-0.4035	1.6792
6/25/2002	-0.1243	-1.1299	-0.1136	-0.5306	0.0868	0.9953	-0.9948	-1.7344	-0.1785	2.3365	-0.0843
3/4/2003	-0.3918	2.1769	-0.6246	-0.6777	-0.3430	0.9474	1.8834	0.0810	-0.5945	5.7137	-0.5105
11/11/2003	2.0277	2.4763	0.0998	0.0567	-1.5635	0.5838	1.7254	0.2461	-1.2388	3.9071	-0.0493
7/20/2004	2.9561	3.3991	0.8593	0.5942	0.6450	-0.0744	2.4323	1.0697	0.6519	2.4666	1.5861
3/29/2005	2.4986	2.5224	1.9444	0.0094	1.4121	0.8530	1.8460	1.5466	2.2406	2.3543	2.4362
12/6/2005	1.4453	1.1712	1.1469	0.3260	1.3660	1.6094	0.9204	0.1793	2.2616	1.2918	1.6673
8/15/2006	0.8832	0.4640	0.9079	0.3919	0.6491	0.8731	2.7607	0.6400	0.6628	1.6916	1.0813
4/24/2007	-1.4033	-1.4066	-1.1468	-1.1112	-1.2904	-1.6767	0.7834	-1.4220	-1.1869	-0.6188	-1.0955
1/1/2008	0.6780	1.6536	2.5347	0.5431	0.9080	0.5604	0.0865	-0.6247	0.6200	2.5348	0.9227
9/9/2008	-0.2302	-0.0822	0.2809	-0.0948	-0.0104	-0.5839	0.0654	-0.6067	-0.1444	1.2870	-0.3373
5/19/2009	-0.3573	-0.1234	0.5531	-0.5272	-0.2956	-0.5553	-0.4370	-0.5691	-0.6116	0.4858	-0.8043
1/26/2010	0.8785	0.2687	-0.8438	0.7025	-0.5523	0.9329	1.4335	1.6355	-0.0191	-0.9349	1.1245
10/5/2010	-1.2187	-0.5677	1.9168	-0.8515	-0.4194	-1.0041	-0.8994	-0.6946	-1.4357	-0.2677	-1.0227
6/14/2011	-0.5685	-0.9718	1.7318	0.0107	-1.3565	-0.9839	0.7648	-1.2821	-1.1997	0.2977	-1.4924
2/21/2012	-1.5045	-0.5907	-0.1772	-1.2675	-0.8518	-0.8195	1.1568	-0.2865	-1.1278	0.2999	-1.3217
10/30/2012	0.3995	-0.0542	-0.4991	0.9063	0.1390	-0.5805	0.7060	-0.0195	1.0106	1.1954	0.4426
6/5/2013	1.2947	0.0160	0.6245	1.2326	0.8109	-1.7059	-1.1903	-0.5617	0.7297	0.7653	1.0038

Midpoint	Hungary	Romania	Croatia	Estonia	Latvia	Lithuania	Bulgaria	Malta	Poland	Czech	Slovakia
10/16/2001	-0.9613	2.9590	-0.2033	-0.4441	-1.2239	-0.8070	-1.0115	1.8567	-0.0912	-0.6372	-0.4409
6/25/2002	-0.6150	1.7289	-0.4287	1.2528	-0.6645	3.3004	1.5852	0.4820	0.0336	0.5195	0.3892
3/4/2003	-0.2151	2.5035	-1.1261	1.3635	1.6674	3.5048	2.5614	-0.1412	-0.3361	1.9531	0.4453
11/11/2003	1.6295	2.7429	-0.7115	1.7504	2.3569	3.0031	2.8265	2.3176	0.3162	2.3426	2.5191
7/20/2004	2.6065	1.3502	0.8978	2.6325	3.1193	3.6879	1.3970	1.5977	0.5385	2.1663	2.9951
3/29/2005	1.2376	1.2953	1.4923	1.9206	1.2932	1.1439	1.1469	3.4907	0.8017	1.4702	1.3949
12/6/2005	0.2855	0.4127	2.4863	2.1128	1.0650	0.7282	1.4495	0.5254	0.6780	0.6086	-0.1452
8/15/2006	-0.4163	1.2457	3.7877	1.1471	0.6946	-0.0775	2.8453	-0.0116	0.6334	0.1560	-0.2854
4/24/2007	-1.3869	-0.9979	0.0829	-0.5960	-0.6687	-0.5783	-0.0025	0.5021	-1.7027	-1.2251	-0.0169
1/1/2008	0.9516	2.1316	0.5950	3.7797	3.4789	4.2167	4.1090	3.2235	0.6954	0.7074	-0.3306
9/9/2008	-0.3980	0.1821	0.5196	0.7643	1.2755	0.3691	1.2103	1.1826	-0.1137	-0.3029	0.3324
5/19/2009	-0.8095	-0.2776	0.1502	-0.4793	-0.1977	-0.2736	0.8513	-0.2740	-0.6122	-0.4365	1.4038
1/26/2010	0.4404	0.9312	-0.4133	1.8762	0.6992	1.2804	-0.0259	-0.0379	0.3766	0.3093	0.1382
10/5/2010	-0.9410	-1.1956	-0.4032	-0.2852	-0.5981	-0.2905	0.2877	-0.8368	-1.3462	-0.6464	-0.0125
6/14/2011	-0.8129	-1.1134	-0.7286	-0.6241	-0.7589	-0.6531	-0.1336	-0.2082	-1.0100	-0.3734	-0.9152
2/21/2012	-0.6034	-0.8565	-0.1667	-0.7023	-0.5917	-0.6352	-0.1596	-0.1297	-0.7075	-0.3289	0.6864
10/30/2012	-0.9865	0.2929	-1.3740	1.5326	0.1679	0.3816	0.9270	0.2474	-0.5821	-1.1618	-0.4979
6/5/2013	-1.2671	1.3901	-0.5378	0.5212	-0.4649	1.7095	3.0045	0.1071	-0.6138	-0.5048	-1.0713

Appendix A Table 2 ADF test statistics for the level values for each period

Midpoint	USA	Europe	Germany	Hungary	Romania	UK	Croatia	France	Russia	Ukraine	Estonia	Latvia
10/16/2001	-16.913	-16.849	-16.386	-16.689	-15.869	-17.589	-15.462	-16.342	-15.217	-17.673	-14.447	-11.481
6/25/2002	-16.166	-16.320	-16.089	-14.804	-15.595	-16.308	-14.691	-15.593	-15.112	-19.672	-13.968	-11.400
3/4/2003	-16.049	-16.129	-16.136	-15.157	-16.147	-15.863	-18.647	-15.464	-16.807	-18.493	-13.611	-16.107
11/11/2003	-17.042	-15.535	-15.704	-16.400	-14.046	-15.465	-19.744	-15.440	-16.722	-18.083	-14.588	-16.748
7/20/2004	-16.234	-15.334	-14.790	-15.977	-14.603	-15.113	-18.449	-15.426	-16.526	-14.843	-14.599	-16.248
3/29/2005	-16.822	-16.376	-15.350	-16.342	-15.035	-16.022	-13.981	-16.775	-16.057	-14.689	-15.249	-14.580
12/6/2005	-17.362	-16.571	-15.461	-14.965	-15.420	-15.923	-12.962	-16.144	-16.163	-14.270	-13.315	-13.833
8/15/2006	-16.985	-15.993	-15.173	-14.974	-16.211	-15.222	-13.676	-15.448	-16.058	-13.212	-14.029	-14.209
4/24/2007	-17.861	-15.953	-14.981	-14.954	-15.700	-16.247	-13.600	-15.773	-16.472	-13.638	-13.451	-16.099
1/1/2008	-20.962	-18.195	-17.590	-17.249	-14.739	-18.584	-16.442	-18.136	-15.190	-13.533	-12.691	-14.894
9/9/2008	-19.735	-17.505	-17.131	-17.070	-15.236	-17.901	-16.148	-17.463	-15.835	-13.323	-12.952	-15.476
5/19/2009	-19.788	-17.807	-17.545	-17.250	-15.007	-18.040	-16.492	-17.673	-15.735	-12.957	-13.797	-15.621
1/26/2010	-15.879	-17.038	-16.768	-17.105	-15.919	-16.036	-15.292	-16.468	-17.211	-12.895	-14.837	-16.981
10/5/2010	-15.041	-16.575	-15.473	-17.035	-16.247	-15.620	-15.410	-15.961	-15.922	-13.688	-14.251	-16.369
6/14/2011	-15.413	-16.756	-16.164	-16.457	-15.445	-16.253	-15.320	-16.415	-15.913	-13.061	-14.964	-16.474
2/21/2012	-14.942	-15.908	-15.553	-16.124	-14.955	-15.834	-14.736	-15.745	-15.637	-12.702	-15.012	-15.106
10/30/2012	-15.559	-15.366	-15.065	-16.604	-13.507	-15.542	-14.364	-15.348	-16.237	-12.860	-15.568	-16.594
6/5/2013	-15.817	-15.506	-14.828	-14.032	-13.719	-14.727	-14.044	-15.415	-15.653	-15.429	-14.724	-16.151

The table above (continued on the next page) presents the resulting ADF test statistics for the first differences of the index series in each period. All the values are below the 1% critical value -2.58. This means that the null hypothesis of the existence of a unit root can be rejected.

Midpoint	Lithuania	Bulgaria	Turkey	Malta	Spain	Switzerland	Italy	Portugal	Ireland	Iceland	Netherland
10/16/2001	-14.212	-16.854	-15.603	-10.931	-17.002	-15.858	-16.509	-15.782	-15.359	-15.008	-16.554
6/25/2002	-12.509	-15.523	-15.802	-14.064	-16.672	-15.027	-15.898	-14.670	-14.708	-15.812	-15.459
3/4/2003	-12.288	-15.095	-15.891	-14.236	-16.599	-14.597	-15.711	-15.225	-14.948	-12.893	-15.221
11/11/2003	-12.186	-13.192	-15.789	-12.686	-15.745	-14.546	-14.986	-15.455	-14.550	-13.010	-14.863
7/20/2004	-13.152	-12.781	-15.346	-13.041	-14.784	-15.992	-14.925	-15.020	-13.803	-12.543	-14.567
3/29/2005	-13.216	-12.468	-16.557	-13.107	-15.888	-16.489	-15.774	-15.235	-14.621	-12.946	-15.280
12/6/2005	-14.507	-12.042	-15.577	-14.223	-15.626	-16.205	-16.235	-13.722	-15.148	-14.845	-15.402
8/15/2006	-14.871	-13.630	-14.674	-14.702	-15.799	-15.698	-15.798	-12.931	-14.810	-15.014	-14.488
4/24/2007	-15.375	-14.766	-15.386	-17.335	-16.242	-15.935	-15.816	-14.608	-15.659	-12.957	-15.140
1/1/2008	-13.869	-12.324	-15.098	-14.368	-17.535	-18.345	-17.461	-15.799	-15.771	-15.373	-17.249
9/9/2008	-13.226	-12.649	-14.981	-12.582	-16.771	-17.861	-16.146	-15.552	-15.598	-15.355	-16.755
5/19/2009	-13.655	-11.885	-14.641	-12.472	-16.976	-18.481	-16.134	-15.711	-15.703	-15.469	-16.928
1/26/2010	-13.803	-13.766	-15.184	-13.388	-16.658	-16.848	-15.726	-15.509	-16.941	-15.852	-15.532
10/5/2010	-14.550	-15.171	-14.466	-14.092	-16.616	-15.486	-16.142	-16.143	-16.350	-17.072	-15.457
6/14/2011	-14.414	-14.939	-14.952	-14.873	-16.950	-15.841	-16.363	-15.922	-16.652	-18.013	-15.932
2/21/2012	-14.848	-14.741	-14.170	-15.435	-15.828	-15.213	-15.646	-14.983	-16.068	-15.302	-15.152
10/30/2012	-20.652	-15.367	-14.985	-15.838	-15.306	-15.501	-15.522	-14.602	-16.652	-15.028	-14.766
6/5/2013	-16.044	-14.331	-14.987	-15.558	-14.726	-14.799	-15.536	-13.822	-16.053	-13.841	-14.520

Midpoint	Denmark	Finland	Norway	Sweden	Austria	Greece	Poland	Czech	Slovakia	Belgium	Luxemburg
10/16/2001	-14.859	-16.204	-15.578	-16.683	-15.821	-15.290	-15.095	-15.777	-17.226	-14.923	-13.366
6/25/2002	-15.007	-15.864	-14.764	-15.489	-15.341	-13.800	-15.570	-15.869	-15.923	-14.326	-12.549
3/4/2003	-14.816	-15.368	-14.431	-14.584	-15.812	-14.722	-15.555	-14.834	-15.380	-14.490	-12.683
11/11/2003	-14.971	-14.767	-14.430	-14.334	-15.543	-15.336	-15.237	-15.009	-16.424	-14.571	-14.130
7/20/2004	-14.934	-14.842	-14.287	-14.445	-14.757	-15.783	-14.968	-14.757	-12.604	-14.043	-14.867
3/29/2005	-14.731	-14.526	-16.056	-15.330	-14.723	-15.184	-15.830	-15.422	-13.172	-15.272	-15.377
12/6/2005	-14.970	-15.749	-16.583	-17.168	-14.178	-14.422	-15.115	-14.432	-13.441	-15.282	-15.006
8/15/2006	-15.232	-15.532	-16.776	-17.118	-14.492	-14.442	-15.273	-14.802	-15.882	-14.913	-15.567
4/24/2007	-15.846	-16.152	-16.785	-17.008	-15.204	-15.127	-15.107	-16.021	-17.064	-15.539	-16.214
1/1/2008	-15.496	-17.639	-17.076	-17.079	-16.188	-15.219	-15.926	-16.696	-14.093	-16.534	-15.740
9/9/2008	-15.237	-16.720	-16.734	-16.778	-16.339	-15.325	-16.280	-16.101	-14.173	-15.927	-15.768
5/19/2009	-15.524	-16.807	-16.828	-17.201	-16.523	-15.978	-16.697	-16.169	-14.395	-16.004	-15.631
1/26/2010	-15.512	-15.726	-16.277	-17.216	-16.949	-16.087	-17.438	-15.892	-15.288	-15.557	-16.900
10/5/2010	-15.328	-14.753	-14.527	-15.420	-15.265	-16.645	-17.111	-15.549	-16.064	-16.233	-16.055
6/14/2011	-15.103	-15.345	-15.189	-15.781	-15.311	-16.896	-16.422	-16.534	-17.867	-17.250	-16.160
2/21/2012	-14.636	-15.015	-15.188	-15.543	-14.770	-16.601	-16.343	-16.216	-19.276	-16.366	-15.130
10/30/2012	-14.990	-15.060	-16.517	-16.080	-15.142	-15.499	-15.017	-15.992	-20.625	-15.826	-15.695
6/5/2013	-14.529	-13.917	-16.823	-14.826	-14.873	-13.880	-14.644	-14.884	-19.326	-15.022	-15.779

Appendix B – ADF results of the cointegration test

Appendix B Table 1 Excerpt from the matrix containing the results of the Engle-Granger cointegration tests in period 1

	Germany	Hungary	Romania	UK	France	Latvia	Lithuania	Bulgaria	Spain	Italy	Portugal	Netherland	Belgium	Austria	Greece	Poland	Czech	Slovakia
Germany	N/A	-1.69	-2.21	-3.29	-3.05	-2.77	-0.70	-2.25	-3.48	-1.73	-2.11	-3.36	-2.69	-1.31	-2.32	-1.87	-1.49	-1.39
Hungary	0.30	N/A	0.74	-0.24	0.02	-2.26	-1.54	-1.15	0.11	-0.61	0.30	-0.02	0.31	-1.53	-1.13	-1.14	-1.92	-1.37
Romania	-2.33	-1.81	N/A	-3.08	-2.55	-2.50	-1.33	-2.76	-2.81	-2.82	-2.06	-2.77	-2.13	-0.77	-3.11	-1.84	-1.96	-1.21
UK	-3.10	-1.71	-2.80	N/A	-3.88	-2.80	-0.88	-2.40	-3.58	-3.05	-2.69	-3.65	-2.52	-1.19	-2.59	-2.12	-1.55	-1.64
France	-2.94	-1.70	-2.36	-3.93	N/A	-2.94	-0.72	-2.29	-3.14	-2.63	-1.95	-3.45	-2.61	-1.24	-2.71	-1.94	-1.48	-1.53
Latvia	-1.15	-1.83	-0.42	-1.58	-1.51	N/A	-1.80	-1.77	-1.05	-2.00	-1.93	-1.11	-0.54	-1.21	-2.80	-1.91	-2.13	-3.80
Lithuania	0.95	-1.84	1.05	0.31	0.70	-2.70	N/A	-1.01	0.26	0.22	1.30	0.51	0.37	-1.22	-0.45	-1.03	-4.32	-1.53
Bulgaria	-1.51	-1.82	-2.28	-1.90	-1.74	-2.88	-1.51	N/A	-2.12	-2.18	-1.51	-1.77	-1.65	-1.14	-2.49	-1.53	-2.04	-1.92
Spain	-3.34	-1.70	-2.70	-3.62	-3.15	-2.20	-0.77	-2.53	N/A	-2.49	-1.93	-3.11	-2.58	-1.26	-2.88	-2.03	-1.51	-1.59
Italy	-1.24	-1.71	-2.03	-2.88	-2.41	-3.24	-0.63	-2.23	-2.26	N/A	-2.75	-2.13	-1.63	-1.16	-3.10	-2.12	-1.48	-1.69
Portugal	-1.92	-1.68	-1.75	-2.33	-1.84	-3.23	-0.43	-2.03	-1.81	-2.82	N/A	-1.84	-1.55	-1.06	-3.16	-2.45	-1.42	-1.69
Netherland	-3.24	-1.69	-2.53	-4.05	-3.46	-2.72	-0.80	-2.24	-3.10	-2.37	-1.93	N/A	-2.72	-1.27	-2.51	-2.10	-1.55	-1.50
Belgium	-2.81	-1.64	-2.34	-2.69	-2.66	-2.52	-1.02	-2.16	-2.66	-2.03	-1.79	-2.76	N/A	-1.43	-2.17	-2.13	-1.69	-1.55
Austria	-0.06	-1.99	1.72	-0.37	-0.17	-2.21	-1.32	-0.83	-0.20	-0.69	0.15	-0.24	0.03	N/A	-0.82	-1.21	-1.90	-1.32
Greece	-1.72	-1.82	-2.52	-2.22	-1.96	-3.56	-0.99	-2.37	-2.54	-2.97	-2.75	-2.12	-1.43	-1.00	N/A	-2.19	-1.59	-2.01
Poland	-0.89	-1.59	-0.51	-1.26	-0.97	-2.75	-1.04	-1.17	-1.38	-1.72	-1.88	-1.22	-1.51	-1.16	-1.98	N/A	-1.55	-1.94
Czech	0.99	-1.80	0.93	0.39	0.72	-2.53	-4.02	-1.10	0.62	0.27	1.00	0.37	0.39	-1.19	-0.45	-0.94	N/A	-1.61
Slovakia	-0.15	-1.76	0.12	-1.27	-0.61	-4.06	-1.24	-1.50	-0.71	-1.11	-0.83	-0.90	-0.29	-1.18	-1.84	-1.75	-2.07	N/A

The table above presents the test statistics of the ADF test on the cointegrating residuals (the "results" of the Engle-Granger test) in case of some country pairs. Shaded values are lower than the 1% critical value proposed by Phillips and Oularis (1990), which is -3.3865. These country pairs are cointegrated and in the adjacency matrix they will enter with a value equal to one. Other results are not presented due to space limitations.

Appendix C – Cummunity membersips in each period

Period	Group type	Com.	Nr. Nodes	Members										
1	Community	1	6	Europe	Germany	UK	France	Spain	Netherland					
		2	5	Switzerland	Italy	Luxemburg	Denmark	Norway						
		3	2	Lithuania	Czech									
		4	2	USA	Sweden									
		5	3	Latvia	Greece	Slovakia								
		6	2	Ukraine	Turkey									
	Isolated		14	Russia	Poland	Austria	Finland	Belgium	Iceland	Ireland	Portugal	Malta	Bulgaria	Estonia
				Romania	Croatia	Hungary								

Period	Group type	Com.	Nr. Nodes	Members									
2	Community	1	7	Europe	Germany	France	Switzerland	Netherland	Belgium	Luxemburg			
		2	8	USA	UK	Spain	Italy	Portugal	Ireland	Denmark	Sweden		
		3	16	Hungary	Romania	Croatia	Ukraine	Estonia	Latvia	Bulgaria	Turkey	Malta	Iceland
				Finland	Norway	Austria	Greece	Poland	Slovakia				
		4	3	Russia	Lithuania	Czech							

Period	Group type	Com.	Nr. Nodes	Members									
3	Community	1	3	Ukraine	Malta	Denmark							
		2	6	Europe	Germany	UK	France	Switzerland	Belgium				
		3	20	USA	Hungary	Romania	Croatia	Estonia	Bulgaria	Turkey	Spain	Italy	Portugal
				Ireland	Iceland	Luxemburg	Finland	Norway	Sweden	Austria	Greece	Poland	Slovakia
		4	4	Russia	Latvia	Lithuania	Czech						
	Isolated		1	Netherland									

Period	Group type	Com.	Nr. Nodes	Members									
4	Community	1	17	USA	Europe	Germany	UK	France	Russia	Latvia	Lithuania	Bulgaria	Switzerland
				Italy	Portugal	Luxemburg	Denmark	Sweden	Greece	Poland			
		2	10	Hungary	Estonia	Turkey	Spain	Ireland	Iceland	Belgium	Norway	Austria	Czech
		3	2	Romania	Malta								
	Isolated		5	Slovakia	Finland	Netherland	Ukraine	Croatia					

Period	Group type	Com.	Nr. Nodes	Members										
5	Community	1	18	USA	Romania	Croatia	Ukraine	Bulgaria	Turkey	Malta	Spain	Ireland	Iceland	
				Belgium	Denmark	Norway	Sweden	Austria	Poland	Czech	Slovakia			
		2	6	Europe	Germany	France	Italy	Luxemburg	Greece					
		3	5	Hungary	UK	Estonia	Latvia	Lithuania						
	Isolated		5	Russia	Switzerland	Portugal	Netherland	Finland						

Period	Group type	Com.	Nr. Nodes	Members										
6	Community	1	8	Europe	UK	France	Denmark	Finland	Norway	Sweden	Austria			
		2	11	USA	Romania	Turkey	Spain	Italy	Ireland	Netherland	Belgium	Luxemburg	Greece	Czech
		3	2	Germany	Poland									
		4	3	Croatia	Ukraine	Bulgaria								
	Isolated		10	Russia	Estonia	Latvia	Lithuania	Malta	Switzerland	Portugal	Iceland	Slovakia	Hungary	

Period	Group type	Com.	Nr. Nodes	Members										
7	Community	1	13	Europe	Germany	Romania	UK	France	Russia	Iceland	Netherland	Finland	Norway	Sweden
				Greece	Poland									
		2	5	USA	Italy	Ireland	Belgium	Luxemburg						
		3	2	Latvia	Czech									
		4	7	Croatia	Ukraine	Bulgaria	Malta	Spain	Portugal	Slovakia				
		5	2	Hungary	Denmark									
	Isolated		5	Estonia	Lithuania	Turkey	Switzerland	Austria						

Period	Group type	Com.	Nr. Nodes	Members										
8	Community	1	12	USA	Europe	Germany	UK	France	Portugal	Netherland	Luxemburg	Finland	Norway	Greece
				Poland										
		2	4	Switzerland	Italy	Ireland	Belgium							
		3	5	Hungary	Romania	Ukraine	Iceland	Austria						
		4	2	Denmark	Czech									
		5	2	Lithuania	Slovakia									
	Isolated		9	Estonia	Croatia	Latvia	Bulgaria	Turkey	Malta	Spain	Sweden	Russia		

Period	Group type	Com.	Nr. Nodes	Members										
9	Community	1	16	USA	Europe	Hungary	Romania	UK	France	Portugal	Iceland	Netherland	Luxemburg	
				Denmark	Norway	Austria	Greece	Poland	Czech					
		2	5	Germany	Croatia	Bulgaria	Turkey	Finland						
		3	2	Estonia	Sweden									
	Isolated		11	Ukraine	Latvia	Lithuania	Malta	Spain	Switzerland	Italy	Ireland	Belgium	Slovakia	Russia

Period	Group type	Com.	Nr. Nodes	Members									
10	Community	1	17	USA	Germany	Hungary	Romania	Croatia	Estonia	Latvia	Lithuania	Bulgaria	Turkey
				Iceland	Netherland	Denmark	Finland	Austria	Greece	Czech			
		2	4	Europe	France	Portugal	Poland						
		3	3	UK	Malta	Spain							
	Isolated		10	Slovakia	Sweden	Norway	Luxemburg	Belgium	Ireland	Italy	Switzerland	Ukraine	Russia

Period	Group type	Com.	Nr. Nodes	Members									
11	Community	1	26	USA	Europe	Germany	Romania	UK	Croatia	France	Russia	Ukraine	Estonia
				Bulgaria	Spain	Switzerland	Italy	Portugal	Ireland	Netherland	Belgium	Luxemburg	Denmark
				Finland	Sweden	Austria	Greece	Poland	Czech				
		2	3	Latvia	Iceland	Slovakia							
	Isolated		5	Norway	Malta	Turkey	Lithuania	Hungary					

Period	Group type	Com.	Nr. Nodes	Members									
12	Community	1	16	USA	Europe	Germany	Romania	France	Estonia	Lithuania	Switzerland	Netherland	Belgium
				Luxemburg	Denmark	Norway	Austria	Poland	Czech				
		2	2	Croatia	Bulgaria								
		3	2	Turkey	Sweden								
		4	2	Hungary	UK								
		5	2	Ireland	Finland								
	Isolated		10	Malta	Spain	Italy	Portugal	Iceland	Greece	Slovakia	Russia	Ukraine	Latvia

Period	Group type	Com.	Nr. Nodes	Members									
13	Community	1	27	USA	Europe	Germany	Hungary	Romania	UK	France	Russia	Ukraine	Estonia
				Latvia	Lithuania	Turkey	Malta	Switzerland	Iceland	Netherland	Belgium	Luxemburg	Denmark
				Finland	Norway	Sweden	Austria	Greece	Poland	Czech			
		2	4	Bulgaria	Spain	Italy	Portugal						
	Isolated		3	Croatia	Ireland	Slovakia							

Period	Group type	Com.	Nr. Nodes	Members									
14	Community	1	3	France	Netherland	Austria							
		2	3	Germany	Sweden	Poland							
		3	3	USA	Russia	Norway							
		4	2	Latvia	Iceland								
		5	2	Hungary	Belgium								
		6	2	Europe	Portugal								
	Isolated		19	Croatia	UK	Slovakia	Czech	Greece	Finland	Denmark	Luxemburg	Ireland	Italy
				Switzerland	Spain	Malta	Turkey	Bulgaria	Lithuania	Estonia	Ukraine	Romania	

Period	Group type	Com.	Nr. Nodes	Members									
15	Community	1	6	Europe	Hungary	Turkey	Italy	Belgium	Luxemburg				
		2	2	Poland	Czech								
		3	7	Croatia	Russia	Ukraine	Latvia	Bulgaria	Portugal	Austria			
		4	3	Romania	France	Sweden							
		5	2	UK	Denmark								
	Isolated		14	Slovakia	Greece	Norway	Finland	Netherland	Iceland	Ireland	Switzerland	Spain	Malta
				Lithuania	Estonia	Germany	USA						

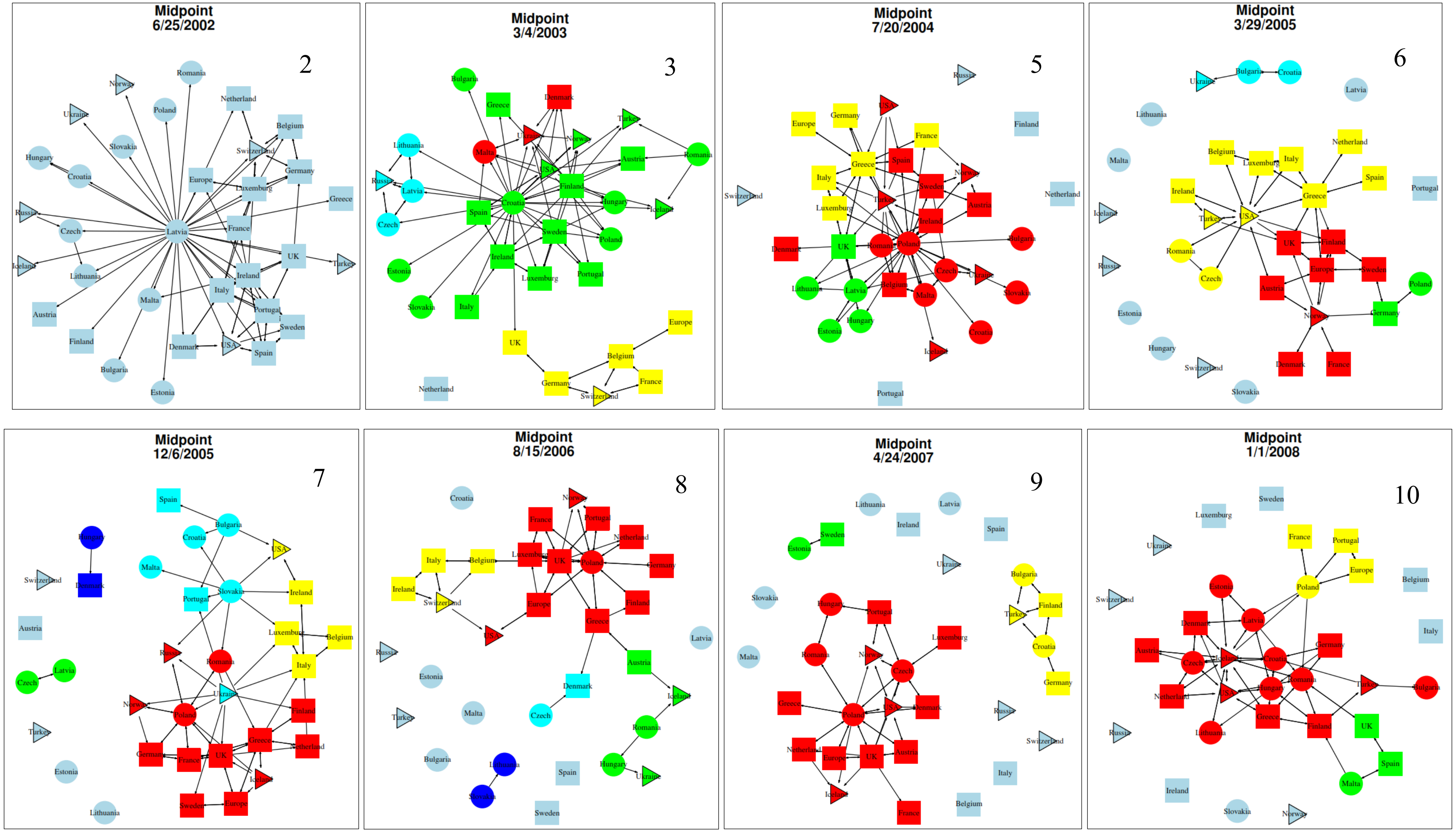
Period	Group type	Com.	Nr. Nodes	Members									
16	Community	1	9	Hungary	Russia	Latvia	Spain	Italy	Luxemburg	Finland	Austria	Czech	
		2	5	USA	Germany	Ireland	Denmark	Norway					
		3	5	Bulgaria	Malta	Portugal	Greece	Poland					
		4	3	UK	Netherland	Sweden							
		5	2	Estonia	Turkey								
	Isolated		10	Slovakia	Belgium	Iceland	Switzerland	Lithuania	Ukraine	Croatia	Romania	France	Europe

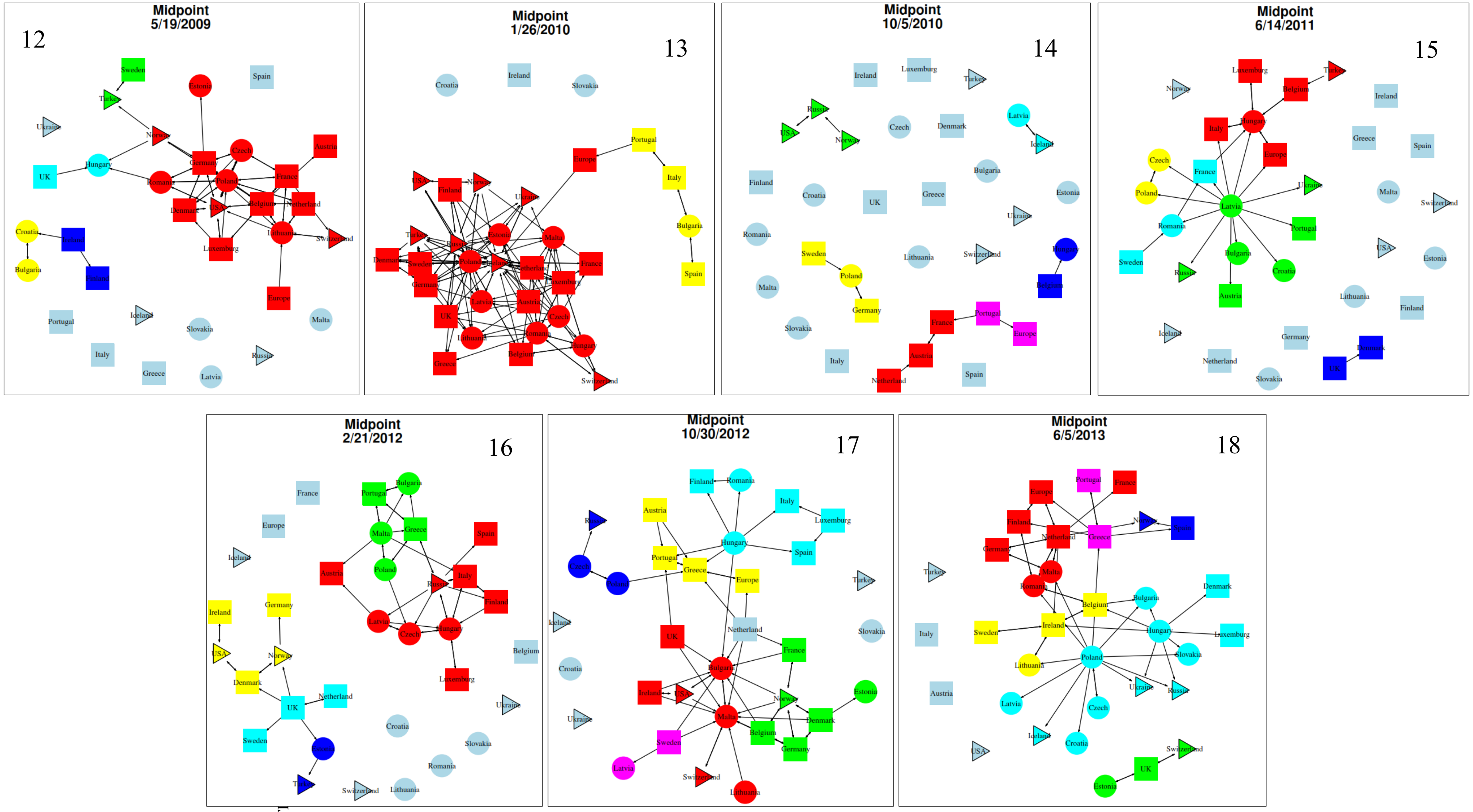
Period	Group type	Com.	Nr. Nodes	Members						
17	Community	1	7	USA	UK	Lithuania	Bulgaria	Malta	Switzerland	Ireland
		2	4	Europe	Portugal	Austria	Greece			
		3	6	Germany	France	Estonia	Belgium	Denmark	Norway	
		4	6	Hungary	Romania	Spain	Italy	Luxemburg	Finland	
		5	3	Russia	Poland	Czech				
		6	2	Latvia	Sweden					
	Isolated		6	Netherland	Ukraine	Turkey	Iceland	Slovakia	Croatia	

Period	Group type	Com.	Nr. Nodes	Members											
18	Community	1	7	Europe	Germany	Romania	France	Malta	Netherland	Finland					
		2	4	Lithuania	Ireland	Belgium	Sweden								
		3	3	UK	Estonia	Switzerland									
		4	12	Hungary	Croatia	Russia	Ukraine	Latvia	Bulgaria	Iceland	Luxemburg	Denmark	Poland	Czech	Slovakia
		5	2	Spain	Norway										
		6	2	Portugal	Greece										
	Isolated		4	USA	Turkey	Italy	Austria								

Appendix C Table 1 The membership vectors of the communities in each period

Appendix D – Plots of cointegration networks





The figures above show the networks that are not included in the body of the thesis. Different colors mean different communities while different shapes are different country groups: circle: new member, square: old member; triangle: non members.

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