Identification of Asset Price Misalignments on Financial Markets with Extreme Value Theory

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Abstract

This paper examines the potential for concurrence of crises in the foreign exchange, stock, and government bond markets as well as identifying asset price misalignments from equilibrium for three Central European countries and the euro area. Concurrence is understood as the joint occurrence of extreme asset changes in different countries and is assessed with a measure of the asymptotic tail dependence among the distributions studied. However, the main aim of the paper is to examine the potential for concurrence of misalignments from equilibrium among financial markets. To this end, representative assets are linked to their fundamentals using a cointegration approach. Next, the extreme values of the differences between the actual daily exchange rates and their monthly equilibrium values determine the episodes associated with large departures from equilibrium. Using tools from Extreme Value Theory, we analyze the transmission of both standard crisis and misalignment-from-equilibrium formation events in the foreign exchange, stock, and government bond markets examined. The results reveal significant potential for co-alignment of extreme events in these markets in Central Europe. The evidence for bubble formation is found to be very weak for the exchange rates, but is stronger for the stock markets and bond markets in some periods.

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Nontechnical summary

This paper analyzes extreme movements in daily exchange rates, five-year government bond indices, and equity indices in the Czech Republic, Hungary, Poland, and the euro area. The aim is to uncover crisis episodes and to assess the degree of concurrence of such crises in the above-mentioned financial markets. In this respect, clusterings of extreme asset value changes offers evidence of crisis occurrences. Extremes values occur with low frequencies and, consequently, are found in the tails of the empirical distributions. Concurrence of crises is formalized as clustering of joint extreme events. Tools borrowed from Extreme Value Theory (EVT) are used to assess the degree of co-alignment of such crises.

The standard crisis approach is supplemented with an analysis of extreme departures from equilibrium values in the above-mentioned markets. The intention is to determine episodes of significant departure from equilibrium on the excessive buying side of each market, reflecting strong investor interest in owning the assets over and above what the economic fundamentals would suggest. Equilibrium is determined based on cointegration relationships estimated at a monthly level. The quest for fundamentals starts with a money-income model for the exchange rates and uses the same set of fundamentals for the government bond and equity markets.

The degree of concurrence of extreme movements is assessed with bilateral asymptotic (tail) dependence measures between the pairs of empirical distributions. Asymptotic dependence is formalized as the limit of the conditional probability that one random variable takes extreme values given that the other random variable is taking such values. The standard approach of Poon et al. (2004) is employed. It describes the asymptotic dependence structure with two measures, the first of which being a limit of the type defined above and the second being a measure of the speed of convergence of the conditional probabilities to zero.

The results show that crisis episodes in exchange rates and equity markets predominantly took place during the recent global crisis and seem quite coordinated. Extreme increases in five-year government bond yields are much more country specific compared with the other two markets. Extreme departures from equilibrium on the appreciation side were practically uniformly distributed in all the exchange rate markets studied. As an exception, a short episode of clustering can be observed at the beginning of 2009 in the Czech case. Extreme upward movements from equilibrium in equity indices also show a rather uniform distribution. The government bond market is again much more heterogeneous, displaying clear and less coordinated clusters of extreme downward movements from equilibrium in bond yields.

The estimated asymptotic dependence measures are significantly high in the majority of cases studied. This, however, hinders two potential explanations. On the one hand, crises show a clear coordinated pattern in certain cases and this is reflected in the estimated tail dependence measures. On the other hand, the evidence for crises or extreme departures from equilibrium is weak in other cases and extreme events are quite uniformly distributed. The high asymptotic values in these cases are, paradoxically, a consequence of the absence of crises and rather reflect coordinated extreme movements over long horizons. Nevertheless, it is worth noting that the asymptotic dependence measures detect heterogeneity in the government bond markets. The only cases where asymptotic independence was found were in this market, and this result is fully concordant with the informal empirical evidence contained in the graphical representations.

Our results imply that financial stability policy makers should take into account the interlinkages identified between different parts of national financial markets. These interlinkages may manifest themselves only in the "tails," as during the financial crisis. Similarly, the potential for increased cross-border linkages could be strong in crisis periods. Therefore, policy makers should closely monitor not only their own national financial markets, but also financial markets in other relevant countries.

1. Introduction

Recent developments in financial markets have shown that crises can have quick and often devastating effects in areas far beyond their epicenter. The speed with which the recent U.S. sub-prime crisis reached a global dimension took the majority of economists and policy makers by surprise. It proved that the global nature of the current market interlinkages makes the transmission of disequilibria across markets and regions a very likely outcome.

In this paper we look at disequilibrium transmission within the foreign exchange, government bond, and stock markets of three Central European countries (Hungary, the Czech Republic, and Poland) and the euro area. We analyze the *potential* for co-alignment of crises in this region. However, the main aim of the paper is to extend the standard analysis of financial crises by looking at alignment during episodes of significant departure from equilibrium asset values. This offers an insight into how likely it is that this type of disequilibrium will be transmitted in a coordinated manner across the above-mentioned markets in this area.

Concurrence during the disequilibrium formation process is examined using tools from cointegration and Extreme Value Theory (EVT). Concurrence is viewed as the occurrence of joint extreme events in different markets and is assessed with a measure of asymptotic tail dependence among the distributions studied. Crisis concurrence among financial markets is assessed in a standard way by focusing on the extremes of asset return distributions. The potential for disequilibrium concurrence is examined by firstly linking representative assets to their fundamentals using a cointegration approach. This gives the equilibrium values of assets at a coarser (monthly) frequency. Next, the data are considered at daily frequency and the extreme values of the differences between the actual daily asset values and their monthly equilibrium values determine the episodes associated with large departures from equilibrium. Consequently, an EVT-based approach is applied to these departures from equilibrium distributions.

The results reveal significant potential for extreme value alignment among the financial markets in Central Europe in terms of both crisis and disequilibrium formation. We examine both the right tail (upward movements) and the left tail (downward movements) of the asset distributions, with the tail threshold initially delimiting the 5% most extreme values on each side of the distribution. As a consistency check, all results are replicated by going further into the tails, i.e., with a threshold value of 3%. In the majority of cases our results reveal asymptotic dependence values close to one, which proves that the co-alignment of extremes in these markets is very high. In a certain sense, these results come as no surprise. The time horizon considered in this research paper contained the recent global financial crisis as the main crisis event. And even if the recent crisis might have affected the countries considered in different financial segments and with different intensities, one can *a priori* expect highly coordinated extreme changes and misalignments from equilibrium.

The paper is organized as follows. Section 2 briefly discusses studies relating to analogous analyses focused on Central European countries. Section 3 offers a brief summary of some empirical approaches available in the literature for the identification and alignment assessment of extreme events by means of the Extreme Value Theory. The next section focuses on data description. Section 5 identifies the main crisis periods for exchange rate markets, stock markets, and government bond markets in Central Europe (the Czech Republic, Hungary, and Poland) and the euro area. Section 6 sheds light on the methodology employed – Extreme Value Theory. The main results of the empirical analysis are presented in Section 7. The main conclusions of the paper are contained in Section 8.

2. Extreme events and misaligned asset prices

The recent financial crisis has again turned the attention of economists to co-movement across different countries and markets over time, i.e., among (i) the same segment of the financial market in various countries (for example, the European stock market is affected by the U.S. stock market, and both have an influence on Czech stock market), or (ii) different segments of financial markets (for example, shocks in the FX market are propagated to the stock, government bond, and money markets). The primary objective of such research is to study extreme events where asset prices correspond to their fundamental values. The fact that asset prices move away from their fundamentals is not necessarily a sign of a "bubble." Such an observation can be easily rationalized by investors' expectations of future risk premia. Observationally, Cochrane (2013) showed that the explanation of bubble formation and rationally motivated behavior about the future risk premium are equivalent.

Whereas correlations and co-movements[1] are well defined through linkages based on fundamentals, the definition of contagion varies across the literature. Calvo and Reinhart (1996) term the transmission of shocks among countries due to real financial linkages as "fundamentals-based" contagion, whereas "pure" contagion describes the transmission of shocks among countries in excess of what should be ascribed to fundamental factors, i.e., it is characterized by excessive co-movements (see Gallegati, 2012). This type of contagion is usually caused by loss of confidence and panic in financial markets after the arrival of important negative news. Forbes and Rigobon (2002) define contagion in a similar way as a significant increase in cross-market linkages after a shock.

The occurrence of extreme market movements in different asset markets and potential spillovers were analyzed by Brunnermeier and Pedersen (2009), who developed a theoretical framework similar in spirit to Grossman and Miller (1988) for thinking about extreme market movements in different asset markets and potential spillovers. They link an asset's market liquidity and traders' funding liquidity, because traders provide market liquidity, which depends on the availability of funding. Their model explains, among other things, that market liquidity can suddenly dry up and has commonality across securities. They also showed that market liquidity has a strong influence on volatility, is subject to "flight to quality," and co-moves with the market. Our analysis assesses the common movements or spillovers from extreme events in the foreign exchange market to other asset markets, i.e., the stock market and the government bond market, as well as cross-country spillovers.

2.1 Effect of heavily misaligned asset prices

Both heavily misaligned asset prices and asset price bubbles are phenomena which are highly deleterious to the real economy and can appear even in a low-inflation environment. The formation and collapse of a heavily misaligned asset price (bubble) leads to distortion of the economic decisions made in all sectors of the economy. Firstly, household consumption is affected through the wealth channel, i.e., growth in financial asset and property prices held by households is perceived as growth in wealth and as a source of finance for consumption. Secondly, firms' investment decisions are incorrectly influenced in that the capital available for investment becomes cheaper as a result of growth in market equity prices. This, in the case of a growing asset price misalignment, implies an excessive decrease in the price of capital, and hence inefficient investments with negative effects in the future may be made. Thirdly, the banking sector balance sheet suffers due to unsustainable growth in prices of property,

[1] Co-movement can be seen as the correlated or similar movement of two or more assets. In comparison, spillover can be seen as the transmission of liquidity shocks from one asset to another.

which often serves as collateral in lending operations. These effects of growing and especially subsequently bursting heavily misaligned asset prices (bubbles differ in strength over time and across economies, but they affect the real economy in the same direction). The issue of whether the performance of the economy will be affected when a bubble bursts does not depend solely – as we say in this article – on asset prices. Other important factors are the economic environment, the state of the financial sector, its ability to absorb shocks, its vulnerability and its fragility, and the subsequent likelihood and strength of a monetary or fiscal policy response.

The primary question relates to the process of formation of these extreme events and heavily misaligned asset prices (bubbles). On the one hand, each asset price can be theoretically decomposed into components arising from fundamental factors (e.g. indicators from the real economy and financial markets) and components affected by non-fundamental factors (e.g. euphoria or over-optimistic investment sentiment). On the other hand, empirically identified motivations explicitly featuring both components, i.e., fundamental and non-fundamental, are hard to identify. In cases where non-fundamental factors account for a major part of the asset price growth, identifying a bubble is more complicated, since non-fundamental factors are not directly measurable. The empirical literature suggests that neither ex post nor ex ante identification of heavily misaligned.

In the literature there are plenty of definitions of heavily misaligned asset prices and approaches to identifying them. DeMarzo, Kaniel, and Kremer (2007) tighten up the definition of a bubble by specifying three components: (i) the market price of an asset is higher than the discounted sum of its expected cash flows, with the discount factor being equal to the risk-free interest rate; (ii) cash flows have a non-negative correlation with aggregate risk; (iii) risk-averse investors rationally choose to hold the asset, despite their knowledge of (i) and (ii). In an attempt to estimate the fundamental value more realistically, Ofek and Richardson (2003) define a range for the fundamental value of an asset, with the upper boundary of the range being more significant. The upper boundary is formed on the basis of an estimate of the maximum achievable future cash flows of a company in a given sector and the minimum possible discount factor. Subsequently, if the market value of the asset is still higher than the fundamental value estimated in this way, a bubble in the price of the asset can be assumed.

Siegel (2003) proposes an operational definition of an asset price bubble as any time the realized asset return over a given future period is more than two standard deviations from its expected return. He argues that a bubble cannot be identified immediately, but one has to wait a sufficient amount of time to determine whether the previous prices can be justified by subsequent cash flows. Kubicová and Komárek (2011) define an asset price bubble as an explosive and asymmetric deviation of the market price of an asset from its fundamental value, with the possibility of a sudden and significant reverse correction.[2] Developing countries are most liable to higher asset price growth and volatility, which arise mainly from underdeveloped segments of the financial market. Therefore, we argue that for a final assessment of the risks of the presence of asset price bubbles or heavily misaligned asset prices, we have to bear market and country specifics in mind. Furthermore, the theories of asset price bubbles have not been sufficiently investigated for small open economies.

[2] See Kubicová and Komárek (2011).

2.2 Empirical investigation

Analyses of influences across countries in each segment of the financial market (the foreign exchange, stock, bond, or money market) are relatively common even for Central European countries, but analyses of the relationship between markets remain relatively scarce. The largest part of the literature examines the interdependence between the U.S. and countries of Western Europe. Baele (2005) and Baele and Inghelbrecht (2010) apply switching models to show that the intensity of co-movements and spillovers increased during the 1980s and 1990s with no evidence of significant contagion other than a small effect during the 1987 crash. Connolly et al. (2007) research co-movements between the U.S., UK, and German stock and bond markets and show that during high (low) implied volatility periods, the co-movements are stronger (weaker), whereas stock-bond co-movements tend to be positive (negative) following low (high) implied volatility days. Morana and Beltratti (2008) examine the stock markets of the U.S., the UK, Germany, and Japan between 1973 and 2004 and find increasing co-movements for all markets.

Frank and Hesse (2009) deal with the transmission of stress between advanced and emerging stock and bond markets using a GARCH model. They find that during the peak of the last crisis the increase in global risk aversion spilled rapidly to emerging economies and investors resorted to safe and liquid assets in their home markets. Pappas, Ingham, and Izzeldin (2013) examines the synchronization between the EU financial markets before and during the recent financial crisis. They adopt both a Dynamic Conditional Correlation-GARCH and a Markov-Switching regime approach, applied to stock market indices from 27 EU countries. They find evidence of integration between these economies.

Cappiello et al. (2006) carry out an analysis of returns on equity market indices. The results suggest that the integration of the new EU member states with the euro area increased during the process of EU accession. The Czech Republic, Hungary, and Poland are found to exhibit return co-movements both between themselves and with the euro area. The co-movements between stock markets in these three Central and Eastern European countries (CEECs) on the one hand, and between the CEECs and Western European countries on the other, are also researched by Égert and Kočenda (2005). Evidence from intraday data reveals no robust co-integration relationship for either intra-CEEC or CEEC–Western European stock market linkages. The results suggest that it is transmission of volatility of returns, not linkages in the levels of returns, which occurs in reality.

For the CEE region, Hanousek and Filer (2000) identify interconnections between fluctuations in equity market returns and economic variables in selected CEE countries. An application of conditional heteroskedasticity (GARCH) analysis to stock market indices in the CEE region in relation to the G-7 is reported by Égert and Kouba (2004). Stock markets in the CEE region are found to exhibit more asymmetry and volatility as compared to the G-7. Chmielwska (2010) provides an application of contagion for the stock and bond markets over the period from 2008 to 2010. Her results show some similarity factor among the CEE countries, but at the same time confirm that asset prices in the Czech Republic tend to follow the mature markets, while Polish and Hungarian assets can still be treated as a separate, relatively unified category. Babecký, Komárková, and Komárek (2013) primarily analyze financial integration in terms of convergence of returns on, among others, the Czech, Hungarian, and Polish financial markets (the money, foreign exchange, government bond, and equity markets) with those on the financial market of the euro area (or Germany for the government bond market) at times of financial instability. Their empirical analysis – based on the price-based and news-based methods – reveals that the financial crisis caused temporary price divergence of the Czech, Hungarian, and Polish financial markets from the markets of the euro area (in the cases of the equity, money, and foreign exchange markets) and Germany (in the case of the government bond market).

3. Literature review for crisis identification and alignment assessment

The empirical analysis undertaken in this paper draws intensively on cointegration and the vast amount of EVT literature relating to financial crises and contagion. In the EVT approach, financial crises are viewed as rare and extreme events whose occurrence is governed by different laws than those governing the entire domain of asset return distributions studied. The focus is on the tails of the distributions. This allows the avoidance of some typical misassumptions, of which the most commonly made are that (a) the analyzed empirical distributions follow normal distributions, and (b) the Pearson correlation is a good measure of crisis dependence.

In fact, it is a common finding in the economic literature that asset returns significantly depart from the normal distribution in the majority of markets and asset types studied. As a rule, empirical asset returns display fat tails, implying that the probability of extreme events is higher than what studies based on the normal distribution usually assume. Additionally, asymptotic dependence or tail-based dependence measures are usually quite different from linear dependence measures proxied by Pearson correlation. Embrechts et al. (2002) and de Vries (2005), for instance, proved that tail dependence may still be significant among variables with a zero Pearson correlation. It is also true that asymptotic dependence is zero in the case of bivariate normal distributions with a non-zero but less than one Pearson correlation.

This paper draws inspiration from several papers employing EVT in the crisis context. Cumperayot and Kouwenberg (2011) used EVT to search for asymptotic dependence between exchange rates and several macroeconomic variables in an attempt to find early warning systems for currency crises. From a rather comprehensive list of macroeconomic variables, asymptotic dependence was found only between domestic real interest rates and exchange rates. Their methodology was based on the approach of Poon et al. (2004), who were the first to formalize two measures of asymptotic dependence/independence for two random variables – these will be used in this paper too.

The first measure is rather intuitive. Asymptotic dependence is examined based on the conditional probability that one variable takes extreme values given that the second variable is taking such values. If the limit of such a conditional probability goes to zero when we move more deeply into the tails of the distributions, then the two variables are said to be asymptotically independent. Otherwise, if the limit is non-zero, they are considered to be asymptotically dependent.

The second measure is the measure of extreme association in the tails. It shows the speed at which the above-mentioned conditional probability decays to zero. It has been proven (Ledford and Tawn, 1996) that this second measure equals one for all asymptotically dependent variables but is less than one for asymptotically independent ones. Consequently, the decision about asymptotic dependence is taken based on a test of equality to one of the second measure. If this hypothesis cannot be rejected, the two variables are said to be asymptotically dependent and the limiting conditional probability is computed. If the above hypothesis can be rejected, the two variables are said to be asymptotically independent and the conditional probability is zero at the limit.

Poon et al.'s approach was discussed and applied in a comparative manner by Schmuki (2008), who also provided a Matlab code, which was modified by the authors of this paper, for its practical implementation. In this paper, we employ Poon et al.'s approach and a slightly adjusted version of Schmuki's code to compute the two measures of asymptotic dependence.

Contagion in other markets, using tools from EVT, has been studied by Hartmann et al. (2004). Focusing on the co-movement of extreme returns in bond and stock markets in the G5 countries, these authors found that the potential for co-crashes in stock markets and bond markets was substantial. Moreover, contagion from stock to bond markets was as frequent as flight to quality from stocks to bonds at times of stock market crises. International crisis linkages were similar to those found in the national context, a result that underscored the downside risk of financial integration. Hartmann et al. (2010) focused on contagion in exchange rate markets in relation to the statistical properties of exchange rate fundamentals. Although interesting insights are gained from these papers, their methodological approach is different from the one used in this paper and will not be further commented on here.

4. Data

Data from the financial markets (the exchange rate market, stock market, and government bond market for the Czech Republic, Hungary, Poland, and the euro area) were collected at daily frequency from Thomson Reuters. We collected data from January 1, 2001 through July 26, 2013 at daily[3] frequency (Table 1). The length of our data sample is a compromise between our attempts to achieve as long a data series as possible and the availability of data. For example, information on long-term Czech government bond yields is missing for older periods, as these bonds were not available.[4] Our sample period necessarily includes several structural breaks such as the change of currency regime in Hungary, intervention periods, and institutional changes on stock markets. Consequently, the results should be taken with caution.

Table 1: Financial market data sources

	Foreign exchange market	Stock market	Government bond market
CZ	PRUSDSP	CZPXIDX	BMCZ05Y
EA	USECBSP	DJES50I	BMBD05Y
HU	HNUSDNB	BUXINDX	BMHN05Y
PL	POUSDSP	POLWIGI	BMPO05Y

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area (data for Germany were used in the case of the government bond market). The abbreviations are the Thomson Reuters codes of the series.
Source: Thomson Reuters.

[3] There is a small possibility that, in some events indicated in the empirical analysis, the result – especially for the stock market – was affected by lower market liquidity or trading activity. Deev and Linnertová (2012) found the Czech equity market to be (i) the most efficient after accession to the EU and until the beginning of the global financial crisis, and (ii) less efficient at the beginning of the new millennium and in its most recent developments. However, contradictory results of authors using different models indicate that the efficiency of the Czech market is slowly recovering to its previous level.

[4] This is also why we used 5-year government bond indices instead of 10-year ones, which could be linked to the Maastricht criteria. In the Czech Republic, 10-year government bonds were first issued in 2004, so using them would shorten our data sample further.

A similar time length was chosen for the monthly variables (Appendix 7) which were used in the cointegration analysis (section 6.1). They were collected from the national central banks, national statistical offices, Eurostat, OECD, and Bloomberg.

5. Developments on financial markets and crisis episodes in Central Europe

In this section we identify the main crisis periods for the markets considered in the paper. A summary of the in-sample extreme exchange rate movements is displayed in Table 2.

Table 2: Extreme values and tail-defining thresholds of the exchange rates

	Left tail – Appreciation				Right tail – Depreciation			
	Minimum	**Date**	**Tail**	**Date**	**Maximum**	**Date**	**Tail**	**Date**
CZ	-5.74%	10/29/08	-1.27%	10/19/11	4.99%	04/04/02	1.29%	05/15/13
EA	-3.89%	12/18/08	-0.99%	09/08/09	4.74%	12/19/08	1.08%	06/22/10
HU	-5.52%	10/29/08	-1.53%	06/21/11	6.97%	10/10/08	1.65%	01/10/07
PL	-21.49%	01/05/09	-1.37%	01/26/09	23.06%	01/02/09	1.53%	06/13/05

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area.

Table 2 shows the lowest/highest daily changes of the exchange rates over the period January 1, 2001–July 26, 2013, together with the specific dates when these values occurred. For example, the maximum daily appreciation and depreciation values of the Czech crown were 5.74% (October 29, 2008) and 4.99% (April 4, 2002), respectively. To get a better glimpse of how crisis events are identified in the paper, the threshold values defining the 5% tails are also shown. For example, in the Czech case, extreme depreciation changes are those exceeding the 1.29% daily value, which is the 95% quintile of the empirical distribution of the Czech daily exchange rate changes.

It has to be noted that extreme events in our approach are also linked with administrative changes on the exchange rate markets, such as central bank interventions. For example, the maximum depreciation level in the Czech case mentioned above is clearly linked to an intervention episode (see Égert and Komárek, 2005). Similarly, the developments in Hungary were influenced until May 2001 by a different foreign currency regime (crawling band) and subsequently by its abandonment. Similarly, the other markets may have been influenced by other types of interventions by central banks or governments, such as changes to dividend tax rates with a clear impact on the stock markets. We tried to estimate our model using sub-samples of the data series excluding these intervention periods, but the results were not substantially different from those presented here in the paper.

Looking at the time of occurrence of events exceeding the tail-defining threshold values, it became evident that these events occurred mainly during the period 2008–2011 for all the exchange rates considered. It was also interesting to note that extreme depreciation and appreciation events tended to alternate and that this took place in a very coordinated manner across countries.

Table 3 contains similar estimations for the stock markets.

Table 3: Extreme values and tail-defining thresholds of the stock exchange indices

	Left tail – Downward movement				Right tail – Upward movement			
	Minimum	**Date**	**Tail**	**Date**	**Maximum**	**Date**	**Tail**	**Date**
CZ	-16.19%	10/10/08	-2.15%	08/16/01	12.36%	10/29/08	2.07%	03/06/07

EA	-12.65%	10/10/08	-2.52%	03/07/03	13.18%	10/13/08	2.31%	10/13/10
HU	-8.29%	10/15/08	-2.41%	08/13/08	6.08%	10/29/08	2.51%	12/05/03
PL	-8.21%	10/10/08	-2.01%	01/18/05	10.44%	10/29/08	2.10%	07/26/01

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area.

It is worth noting the coincidence of the dates when the minimum and maximum values occurred for these indices. At the same time, the extreme values exceeding the 5% thresholds on both sides of the distributions are clustered roughly during September 2008–November 2009, May 2010, and August–November 2011 for all indices. Unlike the exchange rates, a period of extreme movement occurrences in the stock indices was also visible during June–November 2002.

Table 4 displays a similar analysis for the government bond indices.

Table 4: Extreme values and tail-defining thresholds of the 5Y government bond indices

	Left tail – Downward movement				**Right tail – Upward movement**			
	Minimum	**Date**	**Tail**	**Date**	**Maximum**	**Date**	**Tail**	**Date**
CZ	-17.42%	11/01/12	-2.49%	03/05/04	34.72%	05/01/13	2.22%	08/30/11
EA	-23.76%	02/26/13	-4.45%	03/21/12	31.31%	01/02/13	4.28%	04/25/12
HU	-42.63%	03/01/01	-1.79%	07/11/02	31.33%	06/20/03	1.60%	01/10/11
PL	-8.86%	02/26/09	-1.97%	06/07/05	10.17%	06/20/13	1.92%	03/28/07

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area.

The government bond indices showed changes of the highest magnitude among the asset segments studied. The periods of clustering of extreme values were August 2008–March 2009, April–May 2010, August–December 2011, and March–July 2013.

Appendix 1 provides a more detailed graphical visualization of the timing of the crises at the country level. We were interested in uncovering events of extreme depreciation in exchange rates, extreme decreases in stock prices, and extreme increases in bond yields.

As a rule, extreme depreciations were clustered around September 2008–January 2009 and September–December 2011 for all countries. Periods of stress in the stock markets appeared equally coordinated and were visible during the two to three months before and after the end of 2008 and in August–November 2011. Only in the euro area can one see a period of turbulence in the stock market at the end of 2002/beginning of 2003. The situation is not so clear for the government bond markets. In this case one cannot identify a common pattern in the extreme upward movements in yields across the countries considered.

We are aware that this “crisis” identification method may rely considerably on in-sample information. However, perfectly objective guidelines for identifying asset crises are rarely available in empirical work. We think that our method is still superior to crisis identification criteria of the type “plus/minus two standard deviations,” which, besides the fact that they exploit the same in-sample information, may be subject to additional and often neglected limitations.[5] The analysis undertaken here should be viewed just as an attempt to analyze coordinated extreme movements, offering policy makers in the countries concerned an indication of the potential for synchronized crises.

[5] To mention only one, there is the fact that the fat-tail properties of some empirical distributions might not even allow their second moment to be computed. In these cases, the “plus/minus two standard deviations” rule is completely flawed.

6. Methodology

In terms of EVT, a relatively standard approach is followed in this paper. At the univariate level we assess the degree of tail fatness of the distributions using the tail index. A distribution has heavy tails if it varies slowly at infinity, in other words if a positive parameter α exists such that:

$$\lim_{t\to\infty}\frac{1-F(t\cdot x)}{1-F(t)}=x^{-\alpha}, \qquad x>0, \tag{1}$$

where F denotes the cumulative distribution function, x is a positive observation, and α is the tail index. This means that in the case of a distribution with a fat tail, the tail probabilities decrease according to a power law. This is much slower than the exponential decay followed by the normal distribution.

The parameter α is called the tail index and is customarily estimated with the Hill estimator:

$$\alpha=\left[\frac{1}{K}\sum_{I=1}^{K}\ln\frac{X_{N-I+1}}{X_{N-K}}\right]^{-1}. \tag{2}$$

Here, K represents the number of observations in the right tail and the values in the sum are the values above the chosen tail threshold, i.e., X_{N-I+1} are the values of the empirical distribution higher than the tail threshold, and X_{N-K} is the value of the right threshold.

The inverse of the parameter α (γ, or the shape parameter) describes the shape of the tail. Positive values of γ are characteristic for distributions with fat tails, while a γ value of zero is representative for the normal distribution. For a positive γ, the number of moments of the distribution is determined with the tail index α. The number of moments that can be reliably computed for a distribution with fat tails equals the greatest integer that is less than or equal to α.

Turning to multivariate EVT, a measure of asymptotic dependence can be derived starting from conditional probabilities of the type:

$$P\left(X>F_X^{-1}(q)\,|\,Y>F_Y^{-1}(q)\right) \tag{3}$$

This gives the probability that the random variable X takes an extreme value given the occurrence of an extreme event in Y. Here, extremeness is defined with the q quintile, which is in general bounded by the 10% value on both ranges of the distribution. Asymptotic dependence in the right tail is the limit of such a conditional probability when q tends to one:

$$\chi=\lim_{q\to 1}P\left(X>F_X^{-1}(q)\,|\,Y>F_Y^{-1}(q)\right). \tag{4}$$

We follow the approach of Poon et al. (2004), who describe the asymptotic dependence structure in the bivariate case with the help of the two previously mentioned measures $(\chi,\overline{\chi})$, the first of which is a limit of the type defined above and the second is a measure of the speed of convergence of the conditional probabilities to zero. If χ is non-zero, the variables are said to be asymptotic dependent and the limit χ measures the degree of such dependence. If χ is zero, the variables are asymptotic independent but the parameter $\bar{\chi}$ measures the amount of extreme association or the speed with which extreme events converge to zero for both tails.

In this paper the approach of Poon et al. (2004) is closely followed. We first apply unit Fréchet transformations to the original data in order to eliminate the impact of the marginal distributions on the bivariate distribution function but to preserve the original dependence structure. The parameters χ and $\bar{\chi}$ are computed for the transformed series and the decision regarding asymptotic dependence/independence involves the following steps: (1) test the null hypothesis $\bar{\chi} = 1$ ($\bar{\chi}$ follows a normal distribution), (2) if this hypothesis is rejected the series are asymptotic independent (χ = 0), (3) if $\bar{\chi} = 1$ cannot be rejected, the variables are asymptotic dependent and compute χ, the final asymptotic dependence measure.

7. Empirical findings

The representative assets are the exchange rates vis-à-vis the U.S. dollar (FX), the 5Y government bond yield indices (GB), and the equity price indices (SE) of the three Central European countries mentioned above and the euro area. The quest for fundamentals for the exchange rates is based on a money-income model (see, for example, Engel and West, 2003) that is summarized by the following equation:

$$s_t = \alpha_0 + \alpha_1 \cdot (m_t - m_t *) + \alpha_2 \cdot (y_t - y_t *) + \alpha_1 \cdot (p_t - p_t *) + \alpha_1 \cdot (i_t - i_t *) + \varepsilon_t . \qquad (5)$$

Here, s_t is the logarithm of the nominal exchange rate versus the dollar, m_t is a measure of the money supply (M1), y_t is a proxy for output (industrial production, IP), p_t is the Consumer Price Index (CPI), and i_t is the money market interest rate (IR). Excepting the interest rates, which enter the regression as differences from the U.S. interest rate values, all the variables are expressed in logarithmic form and are measured relative to the corresponding U.S. variables.

Dividing the variables by the corresponding U.S. values offers a convenient way to isolate common external shocks affecting the variables. Relationship (5) can be viewed as a combination of different simple exchange rate determination models, i.e., purchasing power parity, interest parity conditions, and the asset view of the exchange rates, perceiving the ratio of two monetary stocks as a significant factor for the determination of the equilibrium level of exchange rates.

The same set of fundamentals is employed for government bond and equity indices, although the limitations of this approach are obvious. It is clear that important factors affecting these variables, such as measures of debt levels at the country level, are missing and this negatively impacts the reliability of our estimations. We could not include this sort of information in the models because these variables are usually available at quarterly or annual frequency. Using them would have necessitated either running cointegration tests with a small number of observations or, if using linear interpolations to fill the gaps at the monthly level, having to accept the negative implications for the stationary nature of the variables. The positive side of things is that we have a homogeneous set of fundamentals for all assets. Moreover, they prove to be relevant factors in the equilibrium model, as cointegration holds in almost all cases.

7.1 Cointegration

The variables mentioned in equation (5) were I(1) for all the countries and markets studied. The existence of cointegration relationships of the type described in (5) was tested using the standard Johansen methodology. Cointegration was found in all cases with the exception of the Polish equity index. For this reason, this variable will not be further considered in the EVT estimations. A summary of the cointegration tests based on the Johansen methodology is contained in Appendix 2.

The cointegration relationships were estimated by the Canonical Cointegration Regression (CCR) method. The equilibrium exchange rates were computed as the fitted values from these CCRs. A graphical representation of the actual daily exchange rates and their monthly equilibrium levels is contained in Appendix 3. The deviations from equilibrium variables were obtained by subtracting the corresponding monthly equilibrium values from the daily values of the asset variables.

From the graphs included in Appendix 3 one can easily remark that the biggest departures from equilibrium for the exchange rates took place between 2008 and 2011. In the stock markets the deviations from equilibrium appear more prominently during 2006–2008 for the Czech Republic and the euro area, and slightly earlier, during 2004–2006, for Hungary. The evidence for government bond market disequilibrium is less obvious, partly due to the imperfections of the cointegration estimations mentioned above.

As in the standard crisis case, Appendix 4 provides a more detailed picture of the extreme departures from equilibrium formation in the markets examined. We focus on phenomena reflecting buyers' interest, i.e., extreme departures from equilibria on the appreciation side for the exchange rates, on the upturn side for stock indices, and on the downturn side for government bond yields.

The graphs in the exchange rate section show the time spots of the 5% strongest exchange rate values relative to their equilibrium values at the country level. It is worth remarking that these extreme exchange rate values are almost uniformly distributed in all cases and show a very weak clustering tendency.

For the stock exchange indices, one can observe periods of clustering of extreme upward deviations from equilibrium during 2005 in the Czech Republic, 2005–2006 in Hungary, and 2003 in the euro area. However, excepting these episodes, the remaining extreme values are also rather uniformly distributed.

Periods of clustering can be discovered in the bond case too – at the beginning of the period for Poland and the Czech Republic, in 2009 for the Czech Republic, the euro area and Hungary, at the end of 2011 in the euro area, and during the first part of 2013 in Hungary. We would like to point out again that the cointegration estimations were less reliable in the bond case; all these conclusions should therefore be accepted with care.

7.2 Extreme Value Theory

Implementing the EVT approach requires variables that are identically and independently distributed. However, the correlograms of the deviation from the equilibrium series obtained so far[6] at daily frequency showed strong evidence of first-order autocorrelation and in some

[6] These residuals should not be confounded with the residuals from the cointegration tests, which should satisfy the i.i.d. condition if enough lagged terms are included in their specifications.

cases of second-order autocorrelation. Additionally, the variance of these series was not constant over time, implying that the assumption of homoskedasticity was also not met. For these reasons, we filtered out autocorrelation and heteroskedacity from the deviation series by estimating GARCH regressions in which the mean equation contained lagged terms of the required orders. In order to account for error term distributions with heavy tails, the error distributions in these regressions were assumed to follow Student's *t*-distribution. In the case of the asset return series only the homoskedasticity assumption was not met. Thus, in this case the GARCH modeling employed only a constant in the mean equation and used more complex formulations for volatility.

The tail index parameters computed for the filtered residuals from these GARCH regressions are provided in Table 5. It is obvious that all γ parameters are positive, proving that all these empirical distributions do indeed have fat tails. This outcome allows us to implement the multivariate EVT approach, which will provide the final asymptotic dependence measures.

Table 5: Tail index estimations

		Left tail				Right tail			
		CZ	**EA**	**HU**	**PL**	**CZ**	**EA**	**HU**	**PL**
Asset returns	**Exchange rates**	3.572	4.074	4.101	4.011	3.435	4.003	3.787	3.366
	Government bonds	2.847	3.951	0.448	2.435	2.248	3.282	0.448	2.163
	Equity	3.252	3.958	3.706	3.233	3.636	4.012	4.619	4.124
Deviations from equilibrium	**Exchange rates**	3.166	2.953	3.063	2.806	2.843	3.056	2.907	2.625
	Government bonds	1.451	1.812	1.560	2.020	1.220	1.737	1.443	1.895
	Equity	2.138	2.644	1.840	-	2.443	2.387	2.069	-

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area.

The above-mentioned EVT tools in the multivariate case were applied to assess the degree of asymptotic dependence among different distributions. The analysis took into account both the left and the right tails of asset returns and the deviations from equilibrium distributions. Extremeness was defined with the q quintiles set at the 5% and 3% levels. Unless evidence for a lack of asymptotic dependence was found under both tail-defining scenarios, we concluded that co-alignment of extremes was present.

Bilateral country asymptotic dependence measures were computed when examining concurrence across the three financial markets – bonds, equity, and exchange rates. Additionally, cross-asset concurrence within individual countries was considered, and this separately envisaged the co-movement and flight to quality scenarios as in Hartman et al. (2004).

The estimations of parameters χ and $\bar{\chi}$ for the exchange rate variables are shown in Table 6. The results suggest that significant tail dependence is present among all the pairs of exchange rate variables considered in this paper.

Table 6: Measures of bilateral asymptotic dependence for exchange rates at the 5% tail threshold

a) Deviations from equilibrium series

Depreciation (right tail)	Appreciation (left tail)

	$\bar{\chi}$	Hypothesis $\bar{\chi}=1$	χ	$\bar{\chi}$	Hypothesis $\bar{\chi}=1$	χ
CZ_EA	0.8445	Rejected	-	0.8789	Not rejected	0.9323
CZ_HU	0.8900	Not rejected	0.9431	0.888	Not rejected	0.9323
CZ_PL	0.9384	Not rejected	0.9431	0.8816	Not rejected	0.9323
HU_EA	0.9537	Not rejected	0.9408	0.9724	Not rejected	0.9478
PL_EA	0.9307	Not rejected	0.9408	0.9613	Not rejected	0.9469
HU_PL	0.9501	Not rejected	0.948	0.9654	Not rejected	0.9469

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area.

b) Exchange rate return series

	Depreciation (right tail)			**Appreciation (left tail)**		
	$\bar{\chi}$	Hypothesis $\bar{\chi}$ =1	χ	$\bar{\chi}$	Hypothesis $\bar{\chi}$ =1	χ
CZ_EA	0.9846	Not rejected	0.9343	0.9569	Not rejected	0.9374
CZ_HU	0.9547	Not rejected	0.9425	0.9643	Not rejected	0.94
CZ_PL	0.9257	Not rejected	0.8928	0.9584	Not rejected	0.9374
HU_EA	0.9464	Not rejected	0.9343	0.9472	Not rejected	0.9381
PL_EA	0.8994	Not rejected	0.8928	0.9433	Not rejected	0.9381
HU_PL	0.9573	Not rejected	0.8928	0.9623	Not rejected	0.9455

Notes: CZ – Czech Republic, HU – Hungary, PL – Poland, EA – euro area.

All the other estimations assessing crisis concurrence are contained in Appendix 5 and those of a disequilibrium type in Appendix 6. The entries of the tables included in these two appendices provide estimations for the extreme association parameters $\bar{\chi}$ and, where parameters $\bar{\chi}$ are not significantly different from one, the corresponding asymptotic dependence measures χ. Where the $\bar{\chi}$ s are significantly different from one, no χ estimations are provided and the corresponding entries are empty.

As can be seen from those tables, the evidence for co-alignment of extremes was strong in the majority of the cases examined. This conclusion did not hold in just a few cases. Firstly, crises in government bond markets appeared to be uncoordinated between the Czech Republic and Hungary (Appendix 5, case A). Similarly, extreme upward changes in bond yields did not seemed synchronized in Poland and Hungary. The two cases of a disequilibrium type in which concurrence did not manifest were again found in the government bond segment, namely, between the euro area and Hungary and between the euro area and Poland (Appendix 6, case A). It seems that extreme upward movements in government bond yields relative to fundamentals in the euro area are not transmitted in a coordinated manner to Poland and Hungary and extreme downward movements of the same variable are not transmitted to Poland. The overall conclusion is that the evidence for concurrence in extreme changes and extreme deviations from equilibrium in foreign exchange and stock markets is strong in this region. However, the evidence is less strong in government bond markets.

8. Conclusion

The goal of this paper was to empirically analyze the potential for crisis and disequilibrium formation co-alignment within three asset markets in Central Europe and the euro area. Tools pertaining to Extreme Value Theory offered a suitable methodological approach and were used in conjunction with cointegration.

The main finding of the paper is that the potential for co-alignment in terms of crises and departures from equilibrium in this region is particularly high across both countries and markets. In almost all cases we found high values of asymptotic dependence on both the upward/depreciation and downward/appreciation side.

Another interesting result of the paper is that support for cointegration was found, as a rule, among the asset variables and the small set of macro variables that we proposed as fundamentals. This result shows that these markets function in accordance with basic theoretical models, if not on a standalone basis, then at least as the interplay of multiple factors. Based on cointegration we were also able to distinguish episodes of extreme misalignments from equilibrium. It is worth noting that the evidence for persistent disequilibrium formation in the exchange rates was very weak. However, such evidence was stronger in the equity markets, predominantly in 2005–2006 for Hungary and the Czech Republic and in 2003 for the euro area. Such evidence was also found in the government bond markets, although the misalignment was much less synchronized in these markets.

Our results imply that financial stability policy makers should take into account the interlinkages identified between different parts of national financial markets. These interlinkages may manifest themselves only in the “tails,” as during the financial crisis. Similarly, the potential for increased cross-border linkages could be strong in crisis periods. Therefore, policy makers should closely monitor not only their own national financial markets, but also financial markets in other relevant countries.

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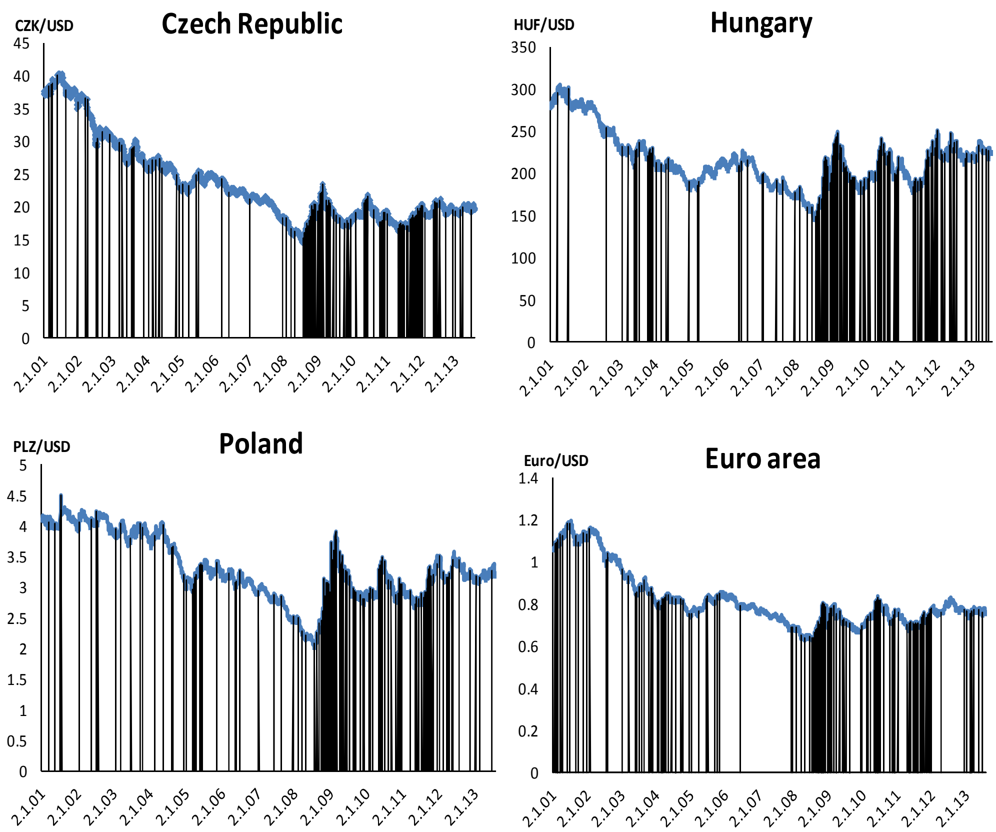
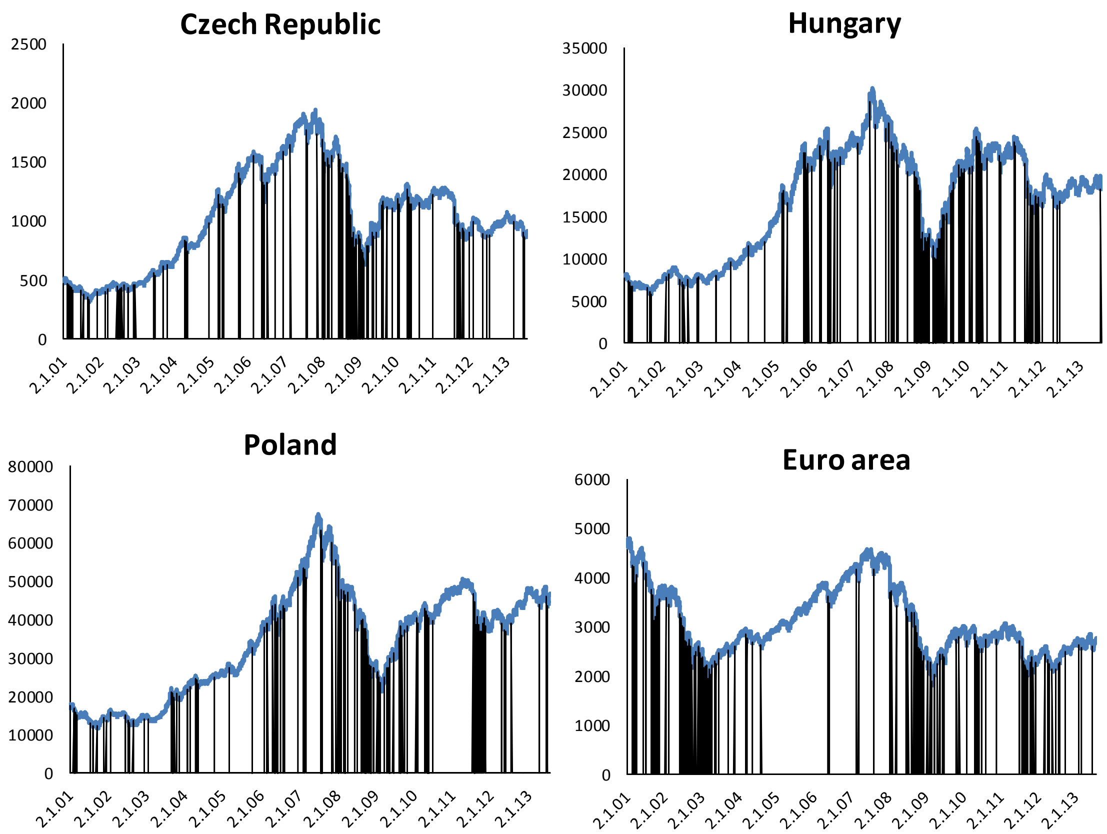
Appendix 1. Crisis identification at the country level

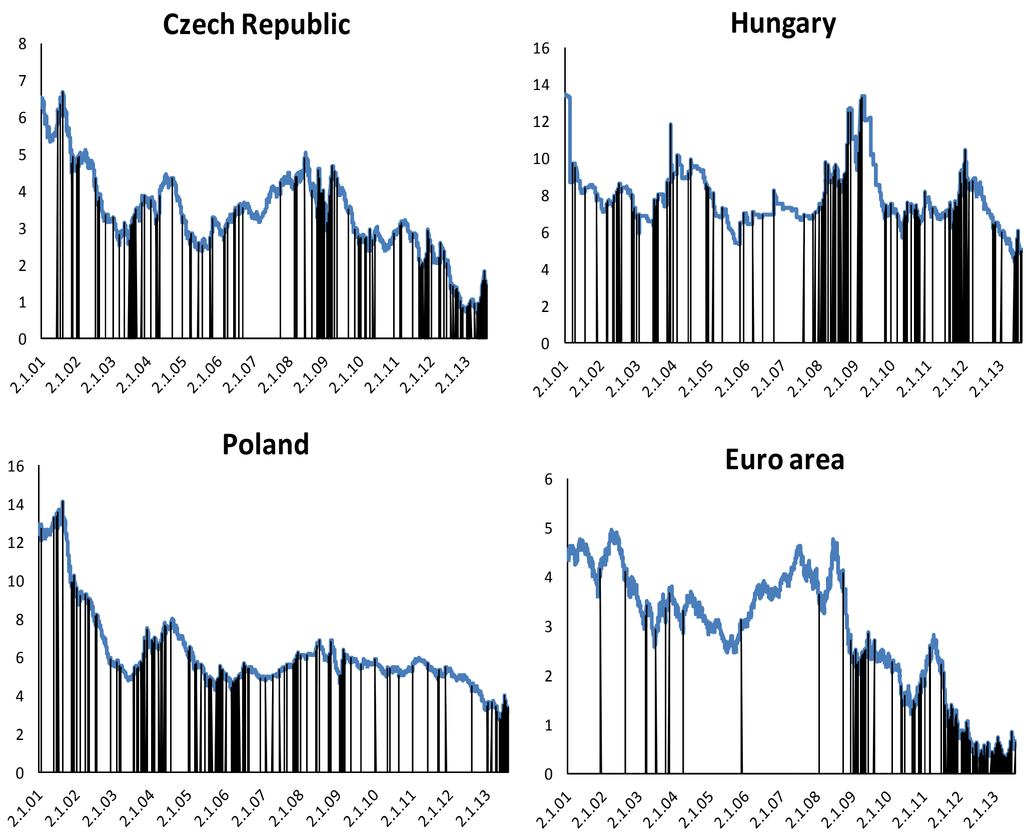
A. Extreme depreciation



B. Extreme downturn movements in stock indices



C. Extreme upward movements in bond yields



Appendix 2. Results of the cointegration tests - Johansen methodology

A. Exchange rates

Czech Republic									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.213	80.736	76.973	0.025	None *	0.213	35.499	34.806	0.041
At most 1	0.131	45.237	54.079	0.241	At most 1	0.131	20.803	28.588	0.353
At most 2	0.088	24.434	35.193	0.435	At most 2	0.088	13.670	22.300	0.493
At most 3	0.049	10.764	20.262	0.565	At most 3	0.049	7.367	15.892	0.625
At most 4	0.023	3.396	9.165	0.509	At most 4	0.023	3.396	9.165	0.509
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				
Euro area									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.278	99.057	88.804	0.008	None *	0.278	47.230	38.331	0.004
At most 1	0.146	51.827	63.876	0.336	At most 1	0.146	22.850	32.118	0.429
At most 2	0.084	28.978	42.915	0.563	At most 2	0.084	12.752	25.823	0.822
At most 3	0.075	16.225	25.872	0.475	At most 3	0.075	11.277	19.387	0.485
At most 4	0.034	4.948	12.518	0.604	At most 4	0.034	4.948	12.518	0.604
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				
Hungary									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.267	114.531	88.804	0.000	None *	0.267	46.361	38.331	0.005
At most 1 *	0.165	68.170	63.876	0.021	At most 1	0.165	26.891	32.118	0.190
At most 2	0.155	41.279	42.915	0.072	At most 2	0.155	25.151	25.823	0.061
At most 3	0.083	16.128	25.872	0.482	At most 3	0.083	12.840	19.387	0.341
At most 4	0.022	3.288	12.518	0.841	At most 4	0.022	3.288	12.518	0.841
Trace test indicates 2 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				
Poland									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.200	95.190	88.804	0.016	None	0.200	32.788	38.331	0.189
At most 1	0.144	62.402	63.876	0.066	At most 1	0.144	22.804	32.118	0.433
At most 2	0.105	39.598	42.915	0.103	At most 2	0.105	16.277	25.823	0.520
At most 3	0.092	23.321	25.872	0.101	At most 3	0.092	14.178	19.387	0.243
At most 4	0.060	9.143	12.518	0.172	At most 4	0.060	9.143	12.518	0.172
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates no cointegration at the 0.05 level				

* denotes rejection of the hypothesis at the 0.05 level

B. Government bonds

Czech Republic									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.271	102.392	88.804	0.004	None *	0.271	46.805	38.331	0.004
At most 1	0.185	55.587	63.876	0.204	At most 1	0.185	30.303	32.118	0.082
At most 2	0.086	25.283	42.915	0.775	At most 2	0.086	13.385	25.823	0.774
At most 3	0.050	11.898	25.872	0.819	At most 3	0.050	7.538	19.387	0.861
At most 4	0.029	4.360	12.518	0.690	At most 4	0.029	4.360	12.518	0.690
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				

Euro area									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.255	101.940	88.804	0.004	None *	0.255	43.774	38.331	0.011
At most 1	0.180	58.166	63.876	0.138	At most 1	0.180	29.558	32.118	0.100
At most 2	0.099	28.608	42.915	0.586	At most 2	0.099	15.612	25.823	0.579
At most 3	0.058	12.995	25.872	0.739	At most 3	0.058	8.831	19.387	0.742
At most 4	0.028	4.164	12.518	0.718	At most 4	0.028	4.164	12.518	0.718
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				

Hungary									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.234	95.073	88.804	0.016	None *	0.234	39.456	38.331	0.037
At most 1	0.148	55.617	63.876	0.203	At most 1	0.148	23.678	32.118	0.370
At most 2	0.114	31.939	42.915	0.392	At most 2	0.114	17.872	25.823	0.387
At most 3	0.066	14.067	25.872	0.652	At most 3	0.066	10.052	19.387	0.613
At most 4	0.027	4.015	12.518	0.740	At most 4	0.027	4.015	12.518	0.740
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				

Poland									
Trace Test					**Max-Eigenvalue Test**				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.193	74.316	69.819	0.021	None	0.193	31.672	33.877	0.090
At most 1	0.111	42.644	47.856	0.142	At most 1	0.111	17.463	27.584	0.540
At most 2	0.089	25.181	29.797	0.155	At most 2	0.089	13.810	21.132	0.381
At most 3	0.064	11.372	15.495	0.190	At most 3	0.064	9.753	14.265	0.229
At most 4	0.011	1.619	3.841	0.203	At most 4	0.011	1.619	3.841	0.203
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates no cointegration at the 0.05 level				

* denotes rejection of the hypothesis at the 0.05 level

..

C. Equity indices

Czech Republic									
Trace Test					Max-Eigenvalue Test				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.287	92.944	88.804	0.024	None *	0.287	49.983	38.331	0.002
At most 1	0.111	42.961	63.876	0.738	At most 1	0.111	17.434	32.118	0.836
At most 2	0.084	25.528	42.915	0.763	At most 2	0.084	13.017	25.823	0.802
At most 3	0.058	12.510	25.872	0.775	At most 3	0.058	8.903	19.387	0.734
At most 4	0.024	3.608	12.518	0.798	At most 4	0.024	3.608	12.518	0.798
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level									

Euro area									
Trace Test					Max-Eigenvalue Test				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.222	83.374	69.819	0.003	None *	0.222	37.242	33.877	0.019
At most 1	0.157	46.133	47.856	0.072	At most 1	0.157	25.255	27.584	0.097
At most 2	0.079	20.878	29.797	0.365	At most 2	0.079	12.175	21.132	0.530
At most 3	0.057	8.703	15.495	0.394	At most 3	0.057	8.627	14.265	0.319
At most 4	0.001	0.076	3.841	0.783	At most 4	0.001	0.076	3.841	0.783
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 leve				

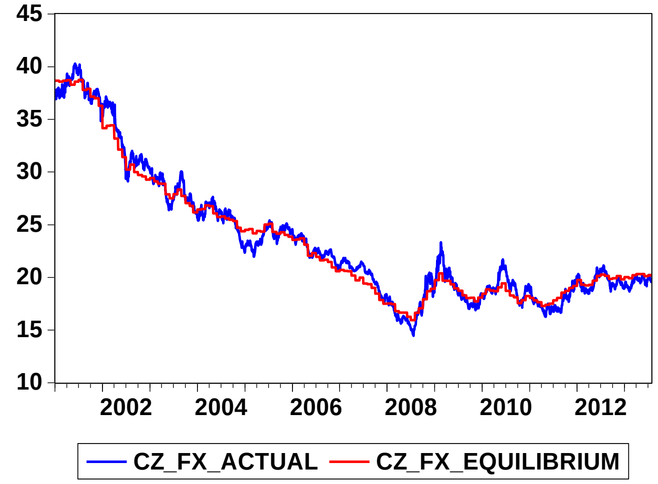
Hungary									
Trace Test					Max-Eigenvalue Test				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.319	110.096	88.804	0.001	None *	0.319	57.184	38.331	0.000
At most 1	0.146	52.912	63.876	0.294	At most 1	0.146	23.447	32.118	0.386
At most 2	0.095	29.466	42.915	0.534	At most 2	0.095	14.840	25.823	0.649
At most 3	0.071	14.625	25.872	0.606	At most 3	0.071	10.940	19.387	0.520
At most 4	0.024	3.686	12.518	0.787	At most 4	0.024	3.686	12.518	0.787
Trace test indicates 1 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 leve				

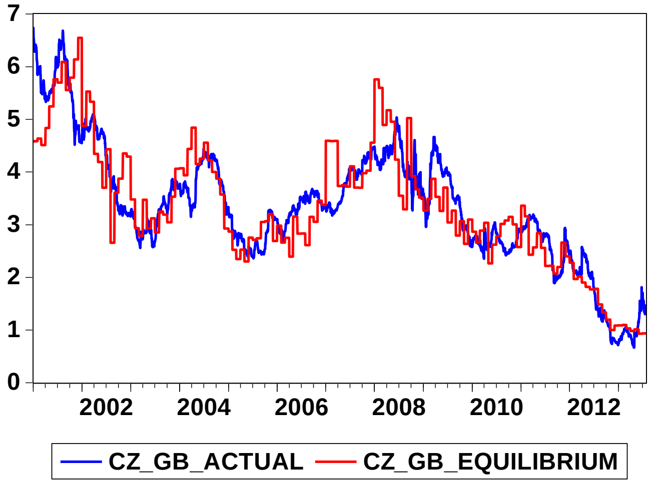
Poland									
Trace Test					Max-Eigenvalue Test				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.256	111.895	88.804	0.000	None *	0.256	43.707	38.331	0.011
At most 1 *	0.165	68.187	63.876	0.021	At most 1	0.165	26.747	32.118	0.197
At most 2	0.118	41.440	42.915	0.070	At most 2	0.118	18.537	25.823	0.337
At most 3	0.080	22.903	25.872	0.112	At most 3	0.080	12.314	19.387	0.387
At most 4	0.069	10.589	12.518	0.103	At most 4	0.069	10.589	12.518	0.103
Trace test indicates 2 cointegrating eqn(s) at the 0.05 level					Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 leve				

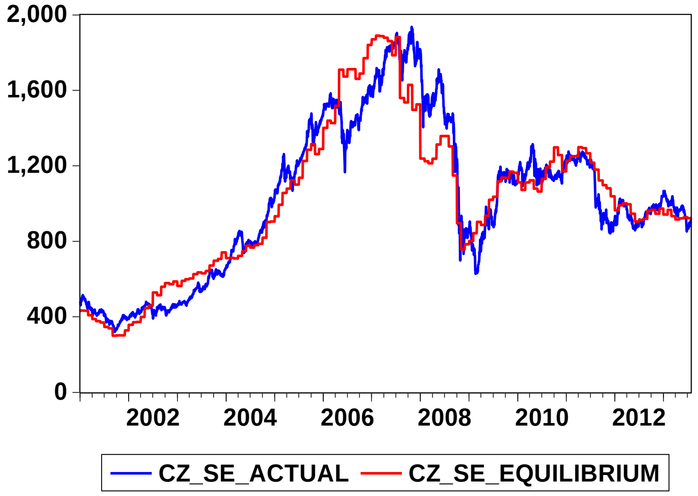
* denotes rejection of the hypothesis at the 0.05 level

Appendix 3. Actual and equilibrium asset values

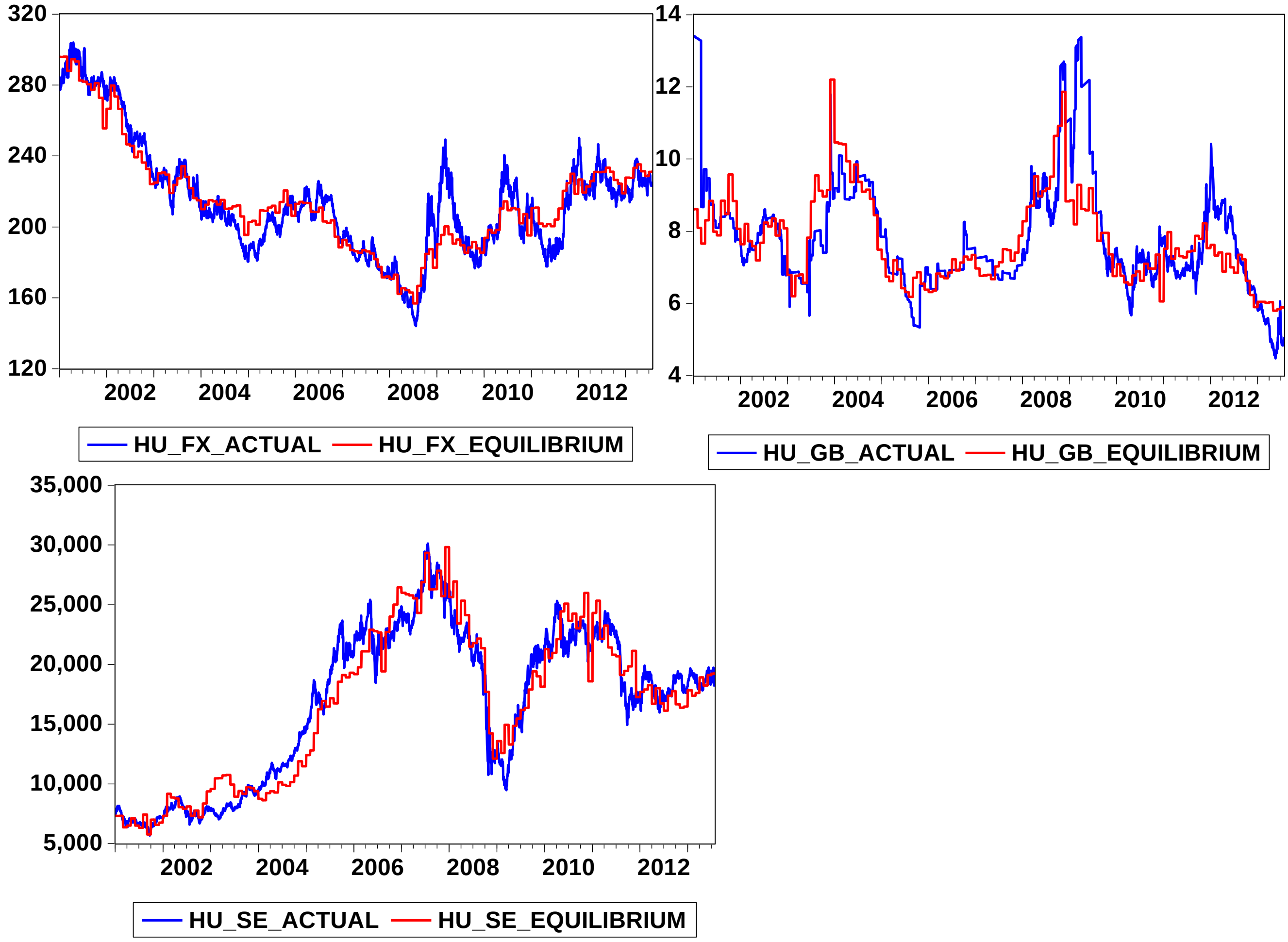
A. Czech Republic





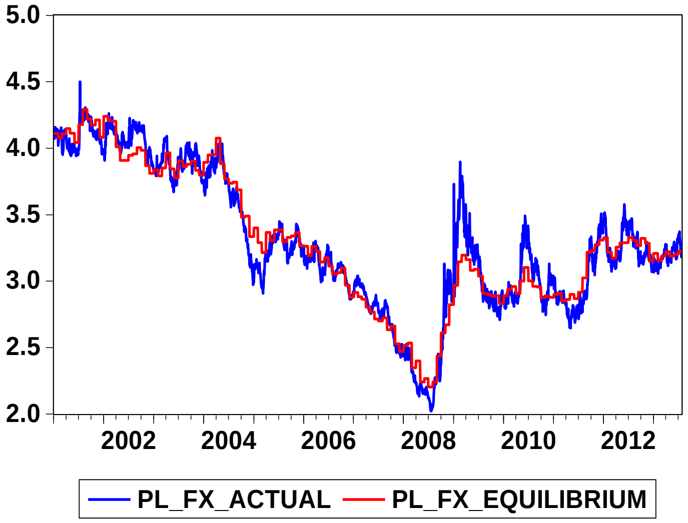


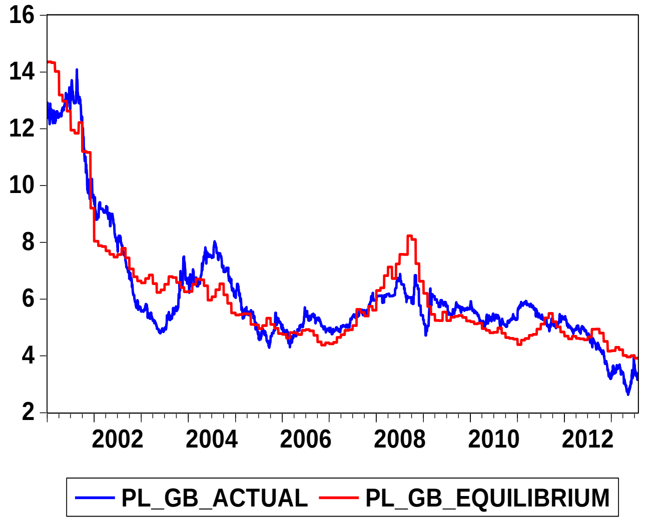
B. Hungary



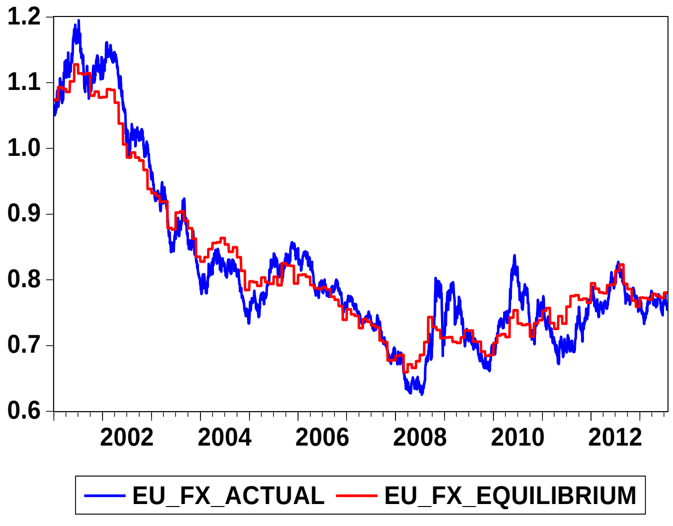
320
280
240
200
160
120
2002
2004
2006
2008
2010
2012
HU_FX_ACTUAL
HU_FX_EQUILIBRIUM
14
12
10
8
6
4
2002
2004
2006
2008
2010
2012
HU_GB_ACTUAL
HU_GB_EQUILIBRIUM
35,000
30,000
25,000
20,000
15,000
10,000
5,000
2002
2004
2006
2008
2010
2012
HU_SE_ACTUAL
HU_SE_EQUILIBRIUM

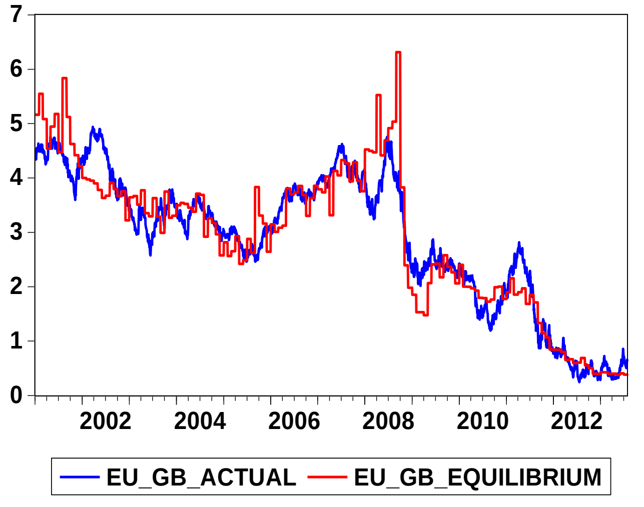
C. Poland

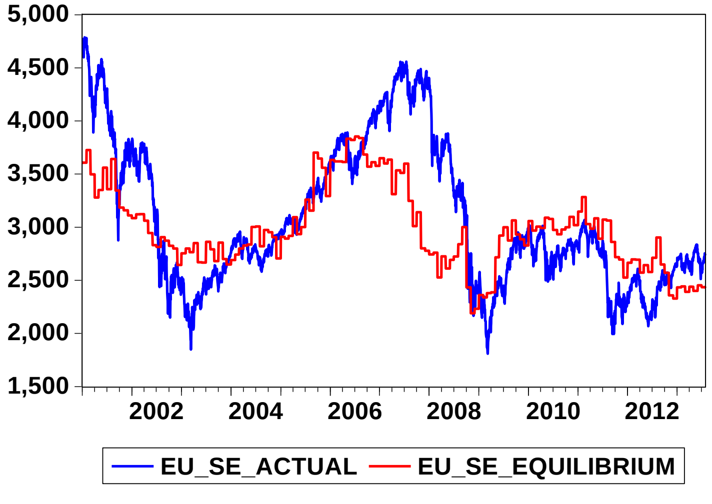




D. Euro area

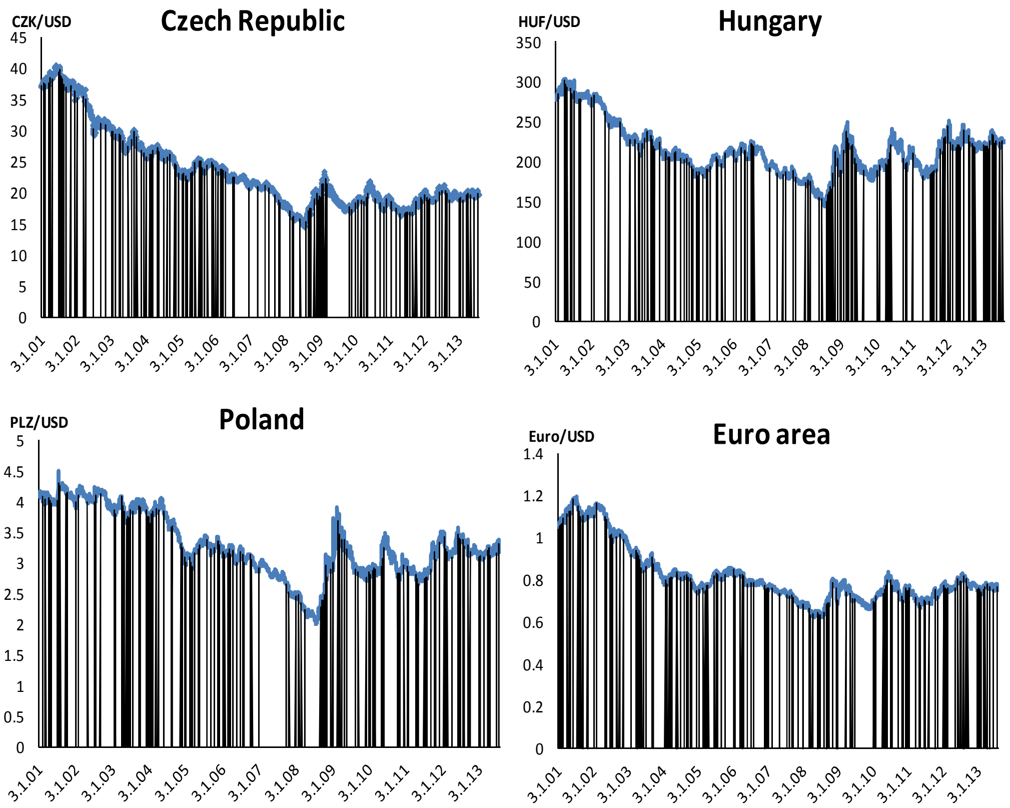




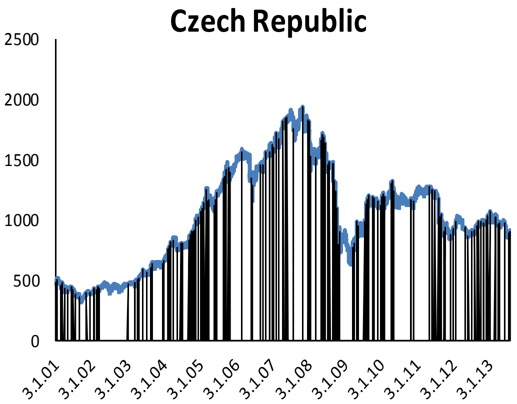


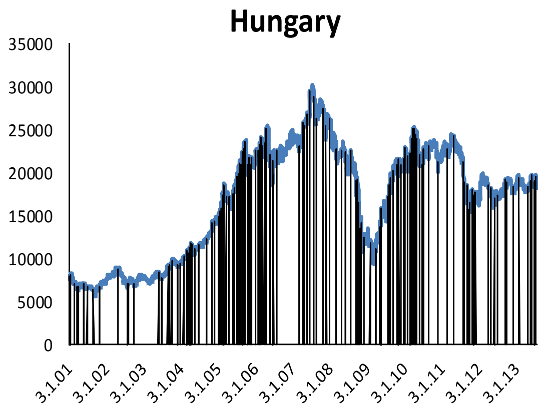
Appendix 4. Extreme deviations from equilibrium identification at country level

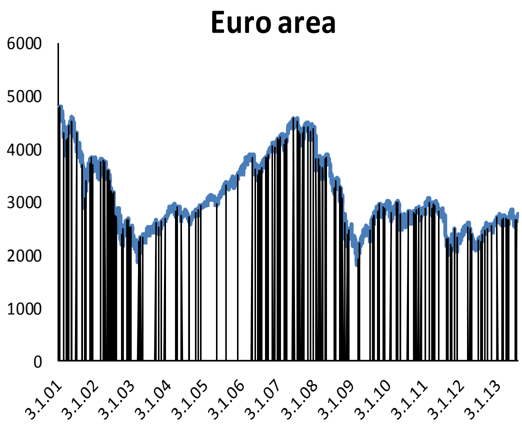
A. Exchange rates on the appreciation side



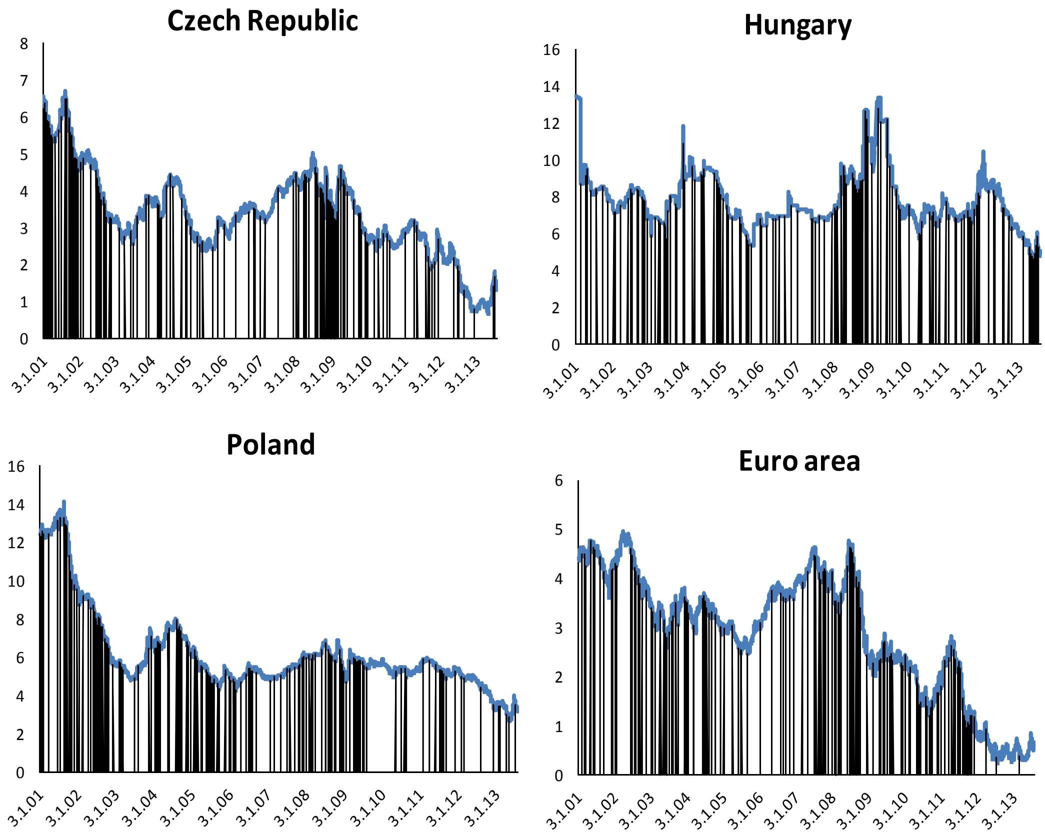
B. Extreme upward movements from equilibrium in stock indices







C. Extreme downward movements from equilibrium in bond yield indices



Appendix 5. Asymptotic dependence for asset return series – standard crisis approach

A. Cross-country

ASSET RETURN ASSYMPTOTIC DEPENDENCE

Exchange rates returns - 5% quantile / **Exchange rates returns - 3% quantile**

	Depreciation		Apreciation			Depreciation		Apreciation	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
CZ_EU	0.985	0.934	0.957	0.937	CZ_EU	0.942	0.940	0.920	0.932
CZ_HU	0.955	0.943	0.964	0.937	CZ_HU	0.889	0.940	0.932	0.934
CZ_PL	0.926	0.893	0.958	0.937	CZ_PL	0.965	0.832	0.940	0.934
EU_HU	0.946	0.934	0.947	0.938	EU_HU	0.889	0.946	0.921	0.932
EU_PL	0.899	0.893	0.943	0.938	EU_PL	0.963	0.832	0.934	0.932
HU_PL	0.957	0.893	0.962	0.946	HU_PL	0.944	0.832	0.924	0.947

Government bond yield returns - 5% quantile / **Government bond yield returns - 3% quantile**

	Upward movements		Downward movement			Upward movements		Downward moveme	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
CZ_EU	0.897	0.941	0.976	0.921	CZ_EU	0.787	-	0.922	0.923
CZ_HU	0.803	-	0.917	0.878	CZ_HU	0.628	-	0.885	0.901
CZ_PL	0.898	0.945	0.915	0.940	CZ_PL	0.853	0.917	0.870	0.944
EU_HU	0.907	0.899	0.924	0.878	EU_HU	0.861	0.883	0.894	0.901
EU_PL	0.937	0.941	0.898	0.921	EU_PL	0.931	0.937	0.837	0.923
HU_PL	0.894	0.899	0.810	-	HU_PL	0.826	0.883	0.764	-

Stock Exchange returns - 5% quantile / **Stock Exchange returns - 3% quantile**

	Upward movements		Downward movement			Upward movements		Downward movemen	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
CZ_EU	0.950	0.942	0.962	0.942	CZ_EU	0.926	0.939	0.922	0.942
CZ_HU	0.987	0.942	0.954	0.942	CZ_HU	0.952	0.939	0.913	0.941
CZ_PL	0.963	0.938	0.973	0.932	CZ_PL	0.945	0.939	0.956	0.934
EU_HU	0.966	0.943	0.916	0.945	EU_HU	0.940	0.945	0.890	0.941
EU_PL	0.973	0.938	0.963	0.932	EU_PL	0.899	0.945	0.893	0.934
HU_PL	0.969	0.938	0.930	0.932	HU_PL	0.938	0.947	0.913	0.934

B. Cross-market in individual countries

Czech Republic

5% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.897	0.942	0.963	0.940
SE_FX	0.940	0.942	0.997	0.937
FX_GB	0.893	0.943	0.967	0.937

3% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.784	-	0.937	0.942
SE_FX	0.914	0.939	0.971	0.934
FX_GB	0.847	0.917	0.955	0.934

5% quantile

	Boom in the first var		Crash of the first var	
	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.960	0.940	0.900	0.942
SE_FX	0.984	0.937	0.937	0.942
FX_GB	0.972	0.940	0.893	0.937

3% quantile

	Boom in the first var		Crash of the first var	
	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.934	0.939	0.807	-
SE_FX	0.962	0.934	0.911	0.940
FX_GB	0.927	0.940	0.775	-

Euro area

5% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.927	0.941	0.966	0.921
SE_FX	0.984	0.934	0.930	0.938
FX_GB	0.924	0.934	0.937	0.921

3% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.892	0.937	0.879	0.923
SE_FX	0.940	0.945	0.887	0.932
FX_GB	0.953	0.937	0.962	0.923

5% quantile

	Boom in the first var		Crash of the first var	
	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.972	0.921	0.938	0.941
SE_FX	0.929	0.938	0.984	0.934
FX_GB	0.986	0.921	0.974	0.938

3% quantile

	Boom in the first var		Crash of the first var	
	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.903	0.923	0.908	0.937
SE_FX	0.901	0.932	0.948	0.944
FX_GB	0.942	0.923	0.934	0.932

Hungary

5% quantile / **3% quantile**

	Comovements					Comovements			
	Boom Episodes		**Crashes Episodes**			**Boom Episodes**		**Crashes Episodes**	
	chi bar	**chi**	**chi bar**	**chi**		**chi bar**	**chi**	**chi bar**	**chi**
SE_GB	0.906	0.899	0.829	-	SE_GB	0.860	0.883	0.833	0.901
SE_FX	0.972	0.948	0.923	0.946	SE_FX	0.897	0.946	0.893	0.941
FX_GB	0.882	0.899	0.898	0.878	FX_GB	0.751	-	0.882	0.901

5% quantile / **3% quantile**

	Boom in the first var		Crash of the first var			Boom in the first var		Crash of the first var	
	Flight to quality		**Flight to quality**			**Flight to quality**		**Flight to quality**	
	chi bar	**chi**	**chi bar**	**chi**		**chi bar**	**chi**	**chi bar**	**chi**
SE_GB	0.866	0.878	0.874	0.899	SE_GB	0.862	0.901	0.810	-
SE_FX	0.979	0.946	0.954	0.946	SE_FX	0.953	0.947	0.908	0.941
FX_GB	0.870	0.878	0.907	0.899	FX_GB	0.772	-	0.861	0.883

Poland

5% quantile / **3% quantile**

	Comovements					Comovements			
	Boom Episodes		**Crashes Episodes**			**Boom Episodes**		**Crashes Episodes**	
	chi bar	**chi**	**chi bar**	**chi**		**chi bar**	**chi**	**chi bar**	**chi**
SE_GB	0.993	0.938	0.913	0.932	SE_GB	0.962	0.947	0.855	0.934
SE_FX	0.924	0.893	0.959	0.932	SE_FX	0.949	0.832	0.929	0.934
FX_GB	0.939	0.893	0.948	0.946	FX_GB	0.949	0.832	0.9111	0.947

5% quantile / **3% quantile**

	Boom in the first var		Crash of the first var			Boom in the first var		Crash of the first var	
	Flight to quality		**Flight to quality**			**Flight to quality**		**Flight to quality**	
	chi bar	**chi**	**chi bar**	**chi**		**chi bar**	**chi**	**chi bar**	**chi**
SE_GB	0.920	0.9375	0.9783	0.9315	SE_GB	0.923	0.947	0.926	0.934
SE_FX	0.964	0.9375	0.9191	0.8928	SE_FX	0.956	0.947	0.928	0.832
FX_GB	0.971	0.8928	0.9703	0.9445	FX_GB	0.9446	0.8316	0.9396	0.9471

Appendix 6. Asymptotic dependence for deviation from equilibrium series

A. Cross-country

Exchange rates returns - 5% quantile

	Depreciation		Apreciation	
	chi bar	chi	chi bar	chi
CZ_EU	0.845	-	0.879	0.932
CZ_HU	0.890	0.943	0.888	0.932
CZ_PL	0.938	0.943	0.882	0.932
EU_HU	0.954	0.941	0.972	0.948
EU_PL	0.931	0.941	0.961	0.947
HU_PL	0.950	0.948	0.965	0.947

Exchange rates returns - 3% quantile

	Depreciation		Apreciation	
	chi bar	chi	chi bar	chi
CZ_EU	0.891	0.939	0.798	-
CZ_HU	0.929	0.944	0.822	0.934
CZ_PL	0.920	0.947	0.829	0.934
EU_HU	0.913	0.939	0.956	0.938
EU_PL	0.937	0.939	0.921	0.938
HU_PL	0.928	0.944	0.944	0.939

Government bond yield returns - 5% quantile

	Upward movements		Downward movements	
	chi bar	chi	chi bar	chi
CZ_EU	0.856	0.936	0.869	0.910
CZ_HU	0.924	0.929	0.907	0.944
CZ_PL	0.912	0.941	0.903	0.942
EU_HU	0.772	-	0.766	-
EU_PL	0.791	-	0.758	-
HU_PL	0.979	0.929	0.986	0.942

Government bond yield returns - 3% quantile

	Upward movements		Downward movements	
	chi bar	chi	chi bar	chi
CZ_EU	0.761	-	0.852	0.922
CZ_HU	0.974	0.929	0.922	0.940
CZ_PL	0.929	0.929	0.900	0.940
EU_HU	0.768	-	0.807	-
EU_PL	0.822	0.934	0.776	-
HU_PL	0.932	0.934	0.953	0.944

Stock Exchange returns - 5% quantile

	Upward movements		Downward movements	
	chi bar	chi	chi bar	chi
CZ_EU	0.945	0.936	0.924	0.940
CZ_HU	0.964	0.936	0.936	0.941
CZ_PL	-	-	-	-
EU_HU	0.964	0.941	0.888	0.940
EU_PL	-	-	-	-
HU_PL	-	-	-	-

Stock Exchange returns - 3% quantile

	Upward movements		Downward movements	
	chi bar	chi	chi bar	chi
CZ_EU	0.908	0.940	0.919	0.936
CZ_HU	0.926	0.942	0.932	0.932
CZ_PL	-	-	-	-
EU_HU	0.955	0.940	0.830	0.932
EU_PL	-	-	-	-
HU_PL	-	-	-	-

B. Cross-market in individual countries

Czech Republic

5% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.869	0.936	0.942	0.945
SE_FX	0.828	-	0.932	0.932
FX_GB	0.922	0.941	0.882	0.932

3% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.816	-	0.936	0.940
SE_FX	0.896	0.942	0.885	0.934
FX_GB	0.923	0.929	0.871	0.934

5% quantile

Boom in the first var Crash of the first var

	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.911	0.936	0.930	0.941
SE_FX	0.810	-	0.954	0.943
FX_GB	0.878	0.943	0.946	0.932

3% quantile

Boom in the first var Crash of the first va

	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.870	0.940	0.873	0.929
SE_FX	0.826	0.934	0.918	0.947
FX_GB	0.891	0.940	0.971	0.929

Euro area

5% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.972	0.936	0.879	0.910
SE_FX	0.957	0.941	0.951	0.940
FX_GB	0.951	0.936	0.854	-

3% quantile

	Comovements			
	Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi
SE_GB	0.939	0.934	0.847	0.922
SE_FX	0.926	0.939	0.923	0.936
FX_GB	0.909	0.934	0.840	0.922

5% quantile

Boom in the first var Crash of the first var

	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.915	0.910	0.935	0.936
SE_FX	0.931	0.942	0.961	0.940
FX_GB	0.909	0.910	0.905	0.936

3% quantile

Boom in the first var Crash of the first va

	Flight to quality		Flight to quality	
	chi bar	chi	chi bar	chi
SE_GB	0.883	0.922	0.893	0.934
SE_FX	0.889	0.938	0.937	0.936
FX_GB	0.874	0.922	0.860	0.934

Hungary

5% quantile / **3% quantile**

	Comovements					**Comovements**			
	Boom Episodes		Crashes Episodes			Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
SE_GB	0.796	-	0.928	0.941	SE_GB	0.870	0.934	0.940	0.932
SE_FX	0.948	0.941	0.895	0.941	SE_FX	0.947	0.944	0.836	0.932
FX_GB	0.868	0.929	0.917	0.944	FX_GB	0.871	0.934	0.894	0.942

5% quantile / **3% quantile**

	Boom in the first var		Crash of the first var			Boom in the first var		Crash of the first va	
	Flight to quality		**Flight to quality**			**Flight to quality**		**Flight to quality**	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
SE_GB	0.841	-	0.888	0.929	SE_GB	0.926	0.947	0.927	0.932
SE_FX	0.914	0.941	0.959	0.941	SE_FX	0.935	0.942	0.924	0.932
FX_GB	0.911	0.944	0.881	0.929	FX_GB	0.934	0.944	0.821	0.934

Poland

5% quantile / **3% quantile**

	Comovements					**Comovements**			
	Boom Episodes		Crashes Episodes			Boom Episodes		Crashes Episodes	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
SE_GB	-	-	-	-	SE_GB	-	-	-	-
SE_FX	-	-	-	-	SE_FX	-	-	-	-
FX_GB	0.932	0.941	0.894	0.942	FX_GB	0.898	0.947	0.861	0.939

5% quantile / **3% quantile**

	Boom in the first var		Crash of the first var			Boom in the first var		Crash of the first va	
	Flight to quality		**Flight to quality**			**Flight to quality**		**Flight to quality**	
	chi bar	chi	chi bar	chi		chi bar	chi	chi bar	chi
SE_GB	-	-	-	-	SE_GB	-	-	-	-
SE_FX	-	-	-	-	SE_FX	-	-	-	-
FX_GB	0.944	0.942	0.886	0.941	FX_GB	0.883	0.944	0.879	0.939

Appendix 7. Data sources

Country	Variable	Ticker	Description of time series	Source
CZ	M1	CZNMSM1.A	Czech Republic, M1 money supply, CZK millions	Czech National Bank
CZ	CPI	CZCONPRCF	Czech Republic, consumer prices, total, index, 1995=100	Czech National Bank
CZ	Industrial production	CZIPTOT.G	Czech Republic, production, total, SA, index, 2010=100	Czech National Bank
CZ	Money market rate	CZINTER3	Czech Republic, Prague interbank offer rate – 3-month (EP)	Czech National Bank
HU	M1	HNM1....A	Money supply: M1 (HUF billions)	National Bank of Hungary
HU	CPI	HNCONPRCF	Hungary, consumer prices, by commodity, all items, total, index, 1990=100	Hungarian Central Statistical Office (HCSO)
HU	Industrial production	HNIPTOT.G	Hungary, production, gross output, excluding water and waste management, volume, cal adj, SA, index, 2010=100	Hungarian Central Statistical Office (HCSO)
HU	Money market rate	HNINTER3	Hungary, 3-month interbank rate	National Bank of Hungary
HU	Money market rate	HNIBK3M	Hungary, 3-month interbank rate	National Bank of Hungary
PL	M1	POM1....A	Poland, M1, PLN millions	National Bank of Poland
PL	CPI	POCONPRCF	Poland, consumer prices, by commodity, total, index, 1998=100	Central Statistical Office, Poland
PL	Industrial production	POESINXCG	Poland, industry production index (NACE Rev. 2), industry production index, monthly data (2005=100) (NACE Rev. 2), mining; mfg; elecy, gas, steam and AC, industrial production excluding construction, SA, index, 2010=100	Eurostat
PL	Money market rate	POOIR076R	Poland, 3-month or 90-day rates and yields, interbank rates, total, 3-month WIBOR	OECD
USA	M1	USM1....B	United States, M1 money supply, SA, USD	Federal Reserve, United States
USA	CPI	USCONPRCF	United States, all urban consumers, U.S. city average, consumer prices, all items, index, 1982–1984=100	U.S. Bureau of Labor Statistics (BLS)
USA	Industrial production	USIPTOT.G	United States, production, overall, total, volume, SA, index, 2007=100	Federal Reserve, United States
USA	Money market rate	USGBILL3	United States, Treasury bill rate – 3-month (EP)	Federal Reserve, United States
EA	M1	EMM1....B	Eurozone, M1, amount outstanding, SA, EUR	European Central Bank (ECB)
EA	CPI	EMCPHARMF	Eurozone, HICP – monthly data (index), CP00, CPI – all items (harmonized, NSA), index, 2005=100	Eurostat
EA	Industrial production	EKIPTOT.G	Eurostat, Eurozone, production, overall, NACE Rev. 2, B–D, Total, excluding construction, linked and rebased, SA, index, 2010=100	Eurostat
EA	Money market rate	EIBOR3M	3-month Euribor	European Banking Federation/The Financial Markets Association