Gábor Dávid KISS

Defining Contagion and Divergence Based on the Extremity of Daily Returns

- on the networks of the East-Central European stock, bond and currency markets

Theses of doctoral dissertation

2012

University of Szeged
Faculty of Economics and Business Administration
Doctoral School in Economics

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Szeged, 2012

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1. INTRODUCTION

Present days the actors on the capital markets as well as central bankers have to face with the following question due to the international free flow of liquidity: what happens with the inter-market correlations under extreme trading days? To ask this question the hypothesis of market efficiency has to be rejected at first, but diversification strategies will be inefficient under these circumstances – what is more than a simple theoretical problem.

This study has two main novelties: at first, there was no more comprehensive analysis in the region to study contagion both on stock, bond and currency markets, as well as the applied method to define the subset of extreme trading days is also new. This work applies the theory of scale-free networks by Albert Barabási as well as the tool of dynamic conditional correlation by Robert Engle, keeping in mind that this region has a unique model of capitalism as Beata Farkas suggests.

In my opinion, the loss of financial stability is caused both by global imbalances and flow of liquidity – but they are expressible trough the dynamic and statistic properties of extreme events.

2. AIMS OF THE DISSERTATION, DEFINITIONS AND HYPOTHESES

The aim of this study is to analyze the following: assuming a network of capital markets in East-Central Europe, Euro-zone and the US, how collective market behaviors are able to bias market prices under extreme days? To answer this question, it is necessary to define at first the set of data, then to define forms of collective behaviors.

This study focuses on the 3 month and the 10 year maturities of bond, currency, and stock market developments between January 1 2002 and August 31 2011 using logarithmic differentials as returns, calculated from daily closing values.

Bonanno et al. (2001) defined the three statistical consequences of complexity in financial market: first of all time series have short range and long range memories and only asymptotic stationary, second, their sectoral intraday cross-correlations are high, and for third they proved collective market behavior during extreme market events. The terms of contagion, divergence and interdependence are consistent with the latest two consequences – while interdependence rules out any significant changes in the common movement between markets, contagion counts with significant increase as well as divergence with decrease of the cross market correlation.

Contagions could be broadly defined as the cross-country transmission of shocks or the general cross-country spillover effects, which does not need to be related to crises. This paper uses the World Bank's very restrictive definition[1] on the contagions, as a cross-country correlations increase during "crisis times" relative to correlations during "tranquil times". We can talk about interdependence, when the difference between correlations under extreme and normal conditions is insignificant.

Definition: Contagion (1) occurs between $m_k m_j$ markets, when the $\rho^{m_k m_j}$ cross-market correlation became significantly higher due to a shock derived from one market ($r_{n/x}^{m}$) to others or other external factors (Forbes and Rigobon, 2002; Campbell et al., 2002; Bekaert et al., 2005):

$$r_{n/x}^{m_i} \neq 0 \rightarrow \rho_n^{m_k m_j} < \rho_x^{m_k m_j}, \tag{1}$$

Definition: Interdependence (2) occurs between $m_k m_j$ markets, when the $\rho^{m_k m_j}$ cross-market correlation not became significantly different, but the level of correlation is constantly high (Forbes and Rigobon, 2002):

$$r_{n/x}^{m_i} \neq 0 \rightarrow \rho_n^{m_k m_j} \approx \rho_x^{m_k m_j}, \tag{2}$$

Definition: Divergence (3) occurs between $m_k m_j$ markets, when the $\rho^{m_k m_j}$ cross-market correlation became significantly lower due to a shock derived from one market ($r_{n/x}^{m}$) to others or other external factors (Bearce 2002):

$$r_{n/x}^{m_i} \neq 0 \rightarrow \rho_n^{m_k m_j} > \rho_x^{m_k m_j}, \tag{3}$$

The necessity to define "shocks" or extreme events and correlations is nested in the upper definitions.

Definition: Extreme event is a $w_x \in W$ event for a W stochastic variable with a $w_x >> w_n$ *or* $w_x << w_n$*)* significant higher impact than the expected, in a limited time and space with a $p(w_x) << p(w_n)$ significant lower probability than the expected, providing a uniqueness (Jentsch et al. 2006). Extreme events have both statistical and dynamic properties. Their statistical property comes from their occurrence on the tails of probability distribution – defining both negative and positive extreme events as well as pointing on the importance of fat tailed distributions. Extreme events are built in features of complex systems (like the scale-free networks of Barabási-Albert (1999)), where the power-law degree distributed structure defines the error tolerance and attack vulnerability as well as easy synchronicity (Clauset et al. 2009).

Capital market returns are also power law distributed in ideal cases as Gabaix et al. (2003) suggest or at least fat-tailed. Therefore it is reasonable to define extreme returns on the basis

[1] see: http://go.worldbank.org/JIBDRK3YC0, cited also by Forbes, Rigobon (2002)

of the extreme event definition – to state that "shocks" came from the transition from normal to extreme return subset.

Definition: Extreme return (5) is the extreme change of the m_j market on the fat tails of the r^{m_j} return's probability distribution. This occurrence is in connection with the skewness of the distribution, while their probability and value differ starkly from the *E(r)* expected.

$$r_x \gg E(r),\ or\ E(r) \gg r_x,\ where\ p_{r_x} \ll p_{E(r)} \tag{5}$$

Definition: Normal returns fit well on the projected theoretical normal distribution – therefore they are signed in the study with r_n.

Definition: Capital market shock means the $r_{n/x}$ transition of the return from the r_n.normal subset to r_x.extreme subset. The $r_{n/x}\neq 0$ existence of this transition defines both subsets (6) while the totally normal distributed return indicates an $r_{n/x}=0$ efficient market (7):

$$r_{n/x}^{m_i} \neq 0 \ \rightarrow r^{m_i} = \begin{cases} r_n^{m_i} \\ r_x^{m_i}, \end{cases} \tag{6}$$

$$r_{n/x}^{m_i} = 0 \ \rightarrow \ r^{m_i} = r_n^{m_i}. \tag{7}$$

The entire time series can be separated on extreme and normal subsets according to the upper definitions:

$$r \begin{cases} \qquad r_x \begin{cases} r_x^{+}: r_{empirical\ ,l} > \mathrm{r_{theoretical\ \ normal\ \ ,l}} \\ r_x^{-}: r_{empirical\ ,i} < \mathrm{r_{theoretical\ \ normal\ \ ,i}} \end{cases} \\ r_n: \mathrm{r_{theoretical\ \ normal\ \ ,i}} < \ r_{empirical\ ,k} < \mathrm{r_{theoretical\ \ norm\ ál,l}} \end{cases} \tag{8}$$

where $r_{empirical\ ,i}$ is the *i*th element of the empirical distribution, as well as the $\mathrm{r_{theoretical\ \ normal\ \ ,i}}$ denotes the projected normal distribution, $i<k<l$.

Leaning on the definition of QQ plots the upper separation can be expressed on the following way:

$X_i = \phi_1^{-1}(P_i) = \phi_1^{-1}(i/T)$ for all $i<T$, therefore,

$$r_n \approx \mu_2 + \sigma_2 X_i,$$

$$r_x^{+} > \mu_2 + \sigma_2 X_i,$$

$$r_x^{-} < \mu_2 + \sigma_2 X_i, \tag{9}$$

where X_i denotes the theoretical empirical standard normal distribution, what is represented in the QQ plot by a line with $\mu_2 + \sigma_2 X_i$ slope.

Contagions, divergences and interdependence initiated by one market's extreme days have to be detected on 10 inter-market correlations (6 for currencies). At first it is necessary to decide between interdependence (nonsignificant change of correlations) and forms of significant correlation changes (as divergence and contagion) – it could be expressed by the overall weight of significant different correlations (10):

$$\frac{\Sigma(s_{m_1m_2}, s_{m_1m_3}, \ldots, s_{m_jm_k}, \ldots, s_{m_{n-1}m_n})}{N}\begin{cases} > 50\%, where\ is\ contagion\ or\ divergence \\ \leq 50\%, where\ is\ interdependence \end{cases}, \quad (10)$$

where $s = \begin{cases} 1, when\ correlations\ are\ significant\ different \\ 0, when\ correlations\ are\ nonsignificant\ different \end{cases}$, N denotes the number of involved market pairs. Contagions are characterized by significant higher, as well as divergences by significant lower correlations according to the definitions (11). To choose between these two form the following algorithm was used:

$$g = \begin{cases} 1, if\ (\rho_{na} = \begin{cases} 0, if\ s = 0 \\ \rho_n, if\ s = 1 \end{cases} < \ \rho_{xa} = \begin{cases} 0, if\ s = 0 \\ \rho_x, if\ s = 1 \end{cases}) \\ 0, if\ (\rho_{na} = \begin{cases} 0, if\ s = 0 \\ \rho_n, if\ s = 1 \end{cases} \geq \ \rho_{xa} = \begin{cases} 0, if\ s = 0 \\ \rho_x, ifs = 1 \end{cases}) \end{cases},$$

than $\frac{\Sigma(g_{m_1m_2}, g_{m_1m_3}, \ldots, g_{m_jm_k}, \ldots, g_{m_{n-1}m_n})}{N}\begin{cases} > 50\%, where\ is\ contagion \\ \leq 50\%, where\ is\ divergence \end{cases}.$ (11)

So the contagion was expressed by weighting against the entire set of correlations, what is a strict rule.

The definition of basic formulas supports the expression of my dissertation's hypotheses.

Hypothesis 1.: There is an m_V *capital market, what is capable to identify the contagions on the East-Central European capital markets(12):*

$$r_{n/x}^{m_V} \neq 0 \ \rightarrow \rho_n^{m_km_j} < \rho_x^{m_km_j}. \quad (12)$$

Hypothesis 2.: *Assuming an US (m_{V_1}) and a Euro-zone (m_{V_2}) capital market, contagion will be* ***not*** *detected upon the strength (13) of external trade ($\frac{X_{CEE}^{V_1}}{X_{CEE}} < \frac{X_{CEE}^{V_2}}{X_{CEE}}, \frac{IM_{CEE}^{V_1}}{IM_{CEE}} < \frac{IM_{CEE}^{V_2}}{IM_{CEE}}$):*

$$r_{n/x}^{m_{V_1}} \neq 0 \ \rightarrow \rho_n^{m_km_j} < \rho_x^{m_km_j}, while\ r_{n/x}^{m_{V_2}} \neq 0 \ \rightarrow \rho_n^{m_km_j} \approx \rho_x^{m_km_j}. \quad (13)$$

Hypothesis 3.: *Monetary policy have to face with unwanted autonomy under extreme days on the bond markets – caused by contagions (14):*

$$r_{n/x}^{m_i} \neq 0 \ \rightarrow \rho_n^{m_km_j} > \rho_x^{m_km_j}. \quad (14)$$

3. STRUCTURE OF THE DISSERTATION

The extremity of an event is directly linked to the extremity of a dynamical state of the underlying system as Jentsch et al. (2006) suggest. The second chapter of the dissertation describes an alternative model which is capable to provide extreme jumps and collective behaviors. A market model which allows collective behaviors is more heterogeneous and hierarchic than it should be according to the efficient market hypothesis. Therefore the null hypothesis of efficient markets will be tested against the alternative hypothesis of complex markets.

To model the network structure of one market (n) (15) it is necessary to define the actors (a), their interactions (c), and the shape of the network (sh):

$$n(a, c, sh). \qquad (15)$$

The mainstream model of efficient markets (16) has the following structure:

$$r_n(a_r, sh_r, s_b, h_{e-k}), \qquad (16)$$

where r_n denotes the normal distributed returns, while a_r signs the rational actors, sh_r is random networks, s_b random-walk in the case of time series, as well as $h_{e\text{-}k}$ is the sign of market efficiency. The Erdősi-Rényi random networks are capable to model competitive and efficient markets with dynamic recombination and fast information propagation, but they are unable to describe preferential connectivity. From statistic view, it involves the requirements of normal distributed, homoscedastic and not autocorrelated returns.

If extreme returns represent a higher mass than from normal distribution it could be expected, capital market should be modeled as the dynamic properties of extreme events suggest – as a complex system (17):

$$r_{n/x}(a_{kr}, sh_s, s_{a-h}, h_{gy}), \qquad (17)$$

where $r_{n/x}$ denotes shock on capital markets due to the fat-tailed distribution of returns, a_{kr} signs bounded rational actors, sh_s means scale-free network, $s_{a\text{-}h}$ point on autocorrelated and heteroskedastic time series, as well as h_{gy} denotes the lack of efficiency. Scale-free complex networks were described by Barabási-Albert (1999), what is able to explain internal heterogeneity through preferential connections which could be responsible for spontaneous synchronisations ("large cooperative phenomena") or phase transitions. These systems are far from equilibrium as self-organized criticality (SOC) describes – therefore extreme events are inherent properties of the system and indicated by power law distribution.

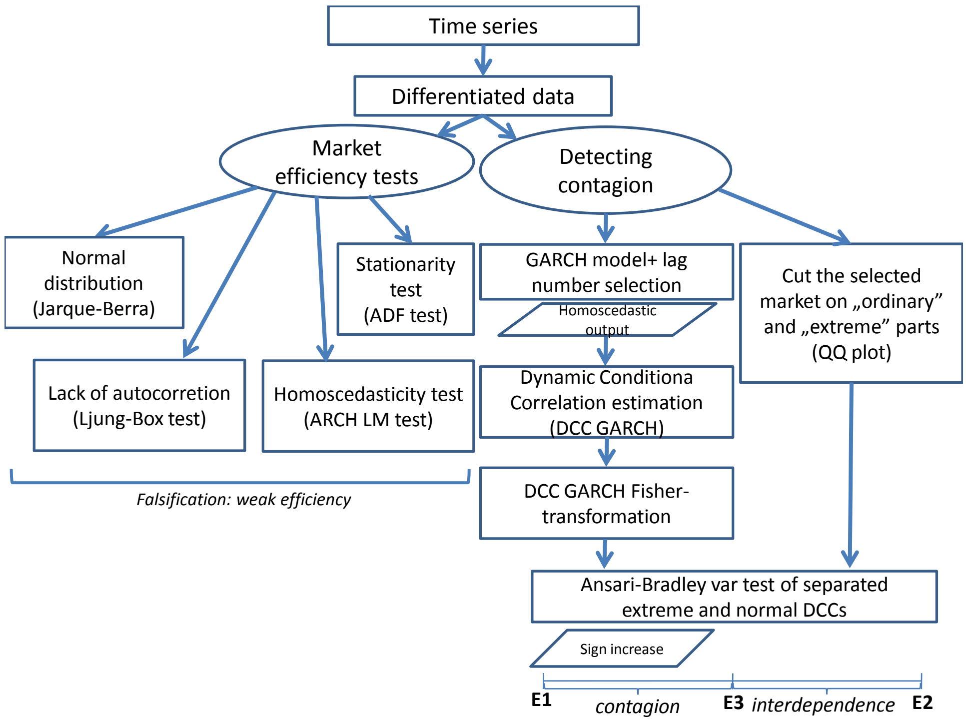
The third chapter of my dissertation describes the applied methodology: the rejection of market efficiency is followed by the calculation of GARCH-based dynamic conditional correlation based on the article of Cappiello, Engle and Sheppard (2006). These correlations were analyzed in the light of extreme events to detect interdependence, divergence and correlations. This chapter summarizes several rejected alternative ways to answer the hypotheses.

The fourth chapter contains the results of the dissertation. Market efficiency was clearly rejected, due to the autocorrelation and heteroscedasticity and the lack of normal distribution in the case of analyzed returns. Returns seemed to be weak (covariant) stationary, what is the pre requirement for the further analysis. Heteroscedasticity was ruled out by the application of APARCH(p,o,q) model, as well as kurtosis was reduced too. 3M maturity on the bond markets seemed to be uncorrelated, while common movement between 10Y maturities declined from weak/medium correlation to no/weak correlation after 2006. The correlation of stock markets increased after 2006 – but East-Central European and German markets tended to move stronger together than with US market. Currencies showed a tight common movement. Contagion was detected only in the case of Dow Jones Industrial Average from the stock markets and partially in the case of EUR/USD exchange rate, while divergence occurred on the 10Y market. These results were analyzed also according to the interest rate policy of the ECB, as well as the impact of the time-lag on the US market (it showed no bias). There was a test for alternative detection of contagions: to separate extreme returns trough probabilities (from 1% to 10%), but the distributions were too different and asymmetric.

4. METHODOLOGY

To prove the existence of contagions it is necessary at first to reject the efficiency of the selected markets. To meet the efficiency requirements, markets have to look like as the random walk and Wiener-process describes them – the distribution of returns should be normal, without autocorrelation, heteroscedasticity and unit root. The rejection of market efficiency allows us to estimate contagions trough dynamic conditional correlation after ruling out heteroscedasticity with GARCH-models (Figure 1).

Figure 1: Chart of methodology



Source: own construction

According to the very restrictive definition of contagion, significant increase in the correlation has to detect between some kind of “ordinary” and “extreme” intervals. There is no general rule to define the turning point between extreme and ordinary, so this study applies fat tailness of the distribution. The set of days according to one market’s extreme and ordinary fluctuation is possibly able to split up the correlation of 10 market pairs, therefore contagion requires more than 5 market pairs with significant higher correlation as well as divergence with its demand for more than 5 significant lower correlation under extreme days.

To prove the existence of contagions it is necessary at first to reject the efficiency of the selected markets. To meet the efficiency requirements, markets have to look like as a random walk process describes it.

The normal distribution of the logarithmic returns is the precondition of efficient market hypothesis – the exponential shape means fast falloff of the returns and the central tendencies are close together. Therefore extreme amplitudes are very improbable. This study applies Jarque-Berra test, where $P<5\%$ value means the rejection of normality. Current study applies Ljung-Box test to provide autocorrelations in the residuals. ARCH LM tests for ARCH effects with the null hypothesis of no conditional heteroscedasticity in the residuals. The rejection of

H_0 supports the idea of volatility clustering, which bias could be ruled out by GARCH models.

Under the assumption of weak market efficiency time series are mostly biased by autocorrelation and heteroscedasticity due to the fat tails of the return distributions and volatility clustering. The different versions of Generalized Autoregression and Heteroscedasticity (GARCH) models are widely used methods to provide homoscedastic standardized residuals, which is necessary to estimate Engle's (2002) Dynamic Conditional Correlation (DCC).

The Asymmetric Power GARCH (APARCH)[2] model by Ding, Granger and Engle (1993) is maybe the most powerful tool to handle the bias of heteroscedasticity due to the asymmetric, fat-tailed assumptions of the distribution. There parameters of APARCH have to be defined, "*p*" and "*q*" determines the lag number of residuals and volatility, while "*o*" is a non-negative scalar integer representing the number of asymmetric innovations. Further advantage of the APARCH model is the flexibility – it is easy to convert both on GJR GARCH and TARCH as well as the basic GARCH form too. The lag length was optimized on a 1-to-4 scale and selected according to the estimation's Akaike Information Criteria (AIC).

Ordinary cross-correlation is not the suitable tool to specify the common movement of markets due to the heteroscedasticity as Forbes and Rigobon (2002) suggest. Cointegration is ruled out too, because it is better to analyze long-term processes, so BEKK-GARCH or DCC-GARCH could be an adequate solution after the APARCH step.

This study applies **DCC-GARCH**[3], to analyze the daily common movements of the selected markets. Cross market correlation is compared both with Ansari-Bradley and two-sided t-test, because the variance test is not based on the assumption of normal distribution – as happens in the case of the widely used t-tests.

The Ansari-Bradley test of the hypothesis that two independent samples, in the vectors x and y, come from the same distribution, against the alternative that they come from distributions that have the same median and shape but different variances. The result is $h = 0$ if the null hypothesis of identical distributions cannot be rejected at the 5% significance level, or $h = 1$ if the null hypothesis can be rejected at the 5% level.

[2]The estimation based on the UCSD toolbox, developed by Kevin Sheppard: http://www.kevinsheppard.com/wiki/UCSD_GARCH

[3]The estimation based on the Oxford MFE toolbox, developed by Kevin Sheppard: http://www.kevinsheppard.com/wiki/MFE_Toolbox

Before the Ansari-Bradley test of significant variance difference of the ordinary and extreme correlation intervals, it is necessary to run a Fischer-transformation (8) on the computed correlations as Lukács (1999) suggests:

$$z_i = 0{,}5 * \ln \frac{1+rho_i}{1-rho_i}, \qquad (8)$$

After the identification of market common movements, it is necessary to separate them on the ground of the hub return's extremity or normality.

How can we separate the "extreme" and "ordinary"? Jentsch et al. (2006) defined extreme events by their impact and probability – so we have to find a suitable threshold or milestone to form both groups. There are multiple solutions, see Campbell et al. (2002), but this study focus on the fatness of tails, therefore it is obvious to cut the empirical distribution with a fitted theoretical normal distribution on it.

This process was done in Matlab on the base logic of a QQ plot. QQ plots are common tools of visualizing the normal distribution of the time series with a straight line which represents the normal distribution and dots of the empirical distribution. Normal distribution of the empirical data is observable, if dots are fitting on the line, but most financial data has an "S" shape on the QQ plot – suggesting a power-law distribution and fat-tails (Clauset el al., 2007). Therefore it is reasonable to define the tails trough QQ plot, where the turning point of extremity is defined as the first empirical data in the lower quartile right from the normality line on the positive side and left from the normality line on the negative side.

This solution uses the markets as their developments would be the source of the shock or contagion. Therefore a rank of contagiousness could be defined between three CEE the US and Euro-zone markets were they could be scored according to the number of correlations divided into significantly different parts, as well as the extreme correlation should be higher. The results can be easily visualized on the following way: on the "x" axis lays the rate of significantly different and non different correlations, while on the "y" axis the number of correlations are observable, which extreme value is higher than the normal.

5. SUMMARY OF THE RESULTS

The theses of current dissertation are summarized in this chapter to evaluate my upper presented hypotheses. Their acceptance will support the idea of complexity of capital markets, with bounded actors and nested turbulences and imbalances.

Thesis 1.: *Dow Jones Industrial was a capable indicator the detect contagions on East-Central European capital markets for the entire sample (18):*

$$r_{n/x}^{m_{DJI}} \neq 0 \rightarrow \rho_n^{m_k m_j} < \rho_x^{m_k m_j}. \quad (18)$$

After rejection of market efficiency and proving the existence of contagions on the stock market, my opinion is to accept the concept of complex capital markets, based on Barabási-Albert's scale-free network, bounded rational agents. Market participants and central bankers have to focus much more on partner risks and they have to avoid the (opportunity of the) bankruptcy of the hub-actors, because it would cause the disintegration of market structure – which means a system-level crisis.

Thesis 2.: *Trade relations could be able to cause higher correlations between East-Central-European and German/Euro-zone markets, and this common movement increased until the crisis, but only the extreme days of DJI seemed to be capable to detect contagions* (19).

$$r_{n/x}^{m_{DJI}} \neq 0 \rightarrow \rho_n^{m_k m_j} < \rho_x^{m_k m_j}, while\ r_{n/x}^{m_{DAX}} \neq 0 \rightarrow \rho_n^{m_k m_j} \approx \rho_x^{m_k m_j}. \quad (19)$$

Networks of real economy and capital market are not parallel. Despite centrum-periphery relations structured on the same way, but common movement increased generally only under extreme jumps on the main US stock market (involving their time-lag too).

Thesis 3.: *Central bank autonomy increases on an unwanted way under extreme days (20), therefore daily turbulences of Euro-zone weakens the region's Euro-apotion's implicit guarantee:*

$$r_{n/x}^{m_i} \neq 0 \rightarrow \rho_n^{m_k m_j} > \rho_x^{m_k m_j}. \quad (20)$$

The divergence of 10 year yields and the sight contagion on the currency market supports this idea. The free floating currencies presented a strong correlation, which became much more tight under extreme fall of Euro against USD – causing more intensive fall in the case of East-Central European currencies. But the reduction of 10Y yields on the US and Euro-zone market are not followed by the region (due to the reduced correlation).

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