Dynamic correlation analysis of financial contagion:
Evidence from the Central and Eastern European markets

by

Manolis N. Syllignakis[1] and Georgios P. Kouretas[1*]

October 2009

Abstract

This paper applies the Dynamic Conditional Correlation (DCC) multivariate GARCH model of Engle (2002), in order to examine the time-varying conditional correlations, to the index returns of seven emerging stock markets of Central and Eastern Europe. We use weekly data for the period 1997-2009 in order to capture potential contagion effects among the US, German and Russian stock markets and the CEE stock markets. The main finding of the present analysis is that there is a statistically significant increase in conditional correlations between the US and the German stock returns and the CEE stock returns particularly during the 2007-2009 financial crisis, implying that these emerging markets are exposed to external shocks with a substantial regime shift in conditional correlation. Finally, we demonstrated that domestic and foreign monetary variables, as well as exchange rate movements have a significant impact on the corresponding conditional correlations.

Keywords: Central and Eastern European emerging stock markets, financial contagion, dynamic conditional correlations, financial crises.

JEL classification: C22, G15

*An earlier version of this paper was presented at the International Conference MAF 2008 on Mathematical and Statistical Methods for Actuarial Sciences and Finance, University Ca' Foscari of Venice, 26-28 March 2008 as well as at the 6th Summer School on Stochastic Finance, Athens 20-23 July 2009 and thanks are due to conference participants for many helpful comments and discussions. This paper has also benefited from comments by seminar participants at the Free University of Amsterdam and Athens University of Economics and Business. Syllignakis acknowledges generous financial support from PENED 2003 under research grant #03ED46 co-financed by E.U.-European Social Fund (75%) and the Greek Ministry of Development-GSRT (25%). Kouretas acknowledges financial support by a Marie Curie Transfer of Knowledge Fellowship of the European Community's Sixth Framework Programme under contract number MTKD-CT-014288, as well as by the Research Committee of the University of Crete under research grant #2257. We thank Panayiotis Diamandis, George Karathanassis, Dimitris Georgoutsos, Dimitris Moschos and Leonidas Zarangas for many helpful comments and discussions. The usual caveat applies.

[1]Department of Business Administration, Athens University of Economics and Business, 76 Patission Street, GR-10434, Athens, Greece.
*Corresponding author. Email: kouretas@aueb.gr

1. Introduction

It is well documented that stock return correlations vary over time. According to Ang and Bekaert (1999) and Longin and Solnik (1995, 2001), correlations among market returns tend to decline in bull markets and to rise in bear markets. Moreover, the fact that international stock market correlation is significantly higher during the periods of volatile markets (i.e. stock market crises periods) has become the accepted perception (Lin *et al*., 1994). The global scale of the October 1987 stock market crash, the Asian crisis in 1997 and the Russian default in 1998, have created a growing concern among researchers and policy makers to investigate the various aspects of international stock market relations, since the findings are significant both in application of passive and active international investment strategies and the identification of the channels of shock spreading from one market to the other. Low international correlation across markets is the starting place of global portfolio diversification strategy (Lessard, 1973 and Solnik, 1974). If correlations between stock returns are high, a loss in one stock is likely to be accompanied by a loss in other stocks as well. Therefore, diversification benefits are greater, when the correlation between the stock returns is low. On the other side, the identification of significantly increased correlation of stock market returns can be regarded as an evidence of existence of the contagion effect.[1]

The main body of the current literature explores the links among the developed stock markets (Hamao *et al*., 1990; Theodossiou and Lee, 1993; Longin and Solnik, 1995; Meric and Meric, 1997; Goetzmann *et al*. 2001; Cappiello *et al*., 2006; Kim *et al*., 2005), while some recent studies have extended this line of research

[1] Forbes and Rigobon (2002) define contagion as significant increases in cross market co-movement, while any continued high degree of market correlation suggests strong linkages between the two economies and is considered to be interdependence. Therefore, the existence of contagion must involve a dynamic increase in correlation in the aftermath of a crisis event.

to the linkages between the emerging and developed stock markets (Bekaert and Harvey, 2000; Chen *et al*., 2002; Yang, 2005; Chiang *et al*., 2007; Phylaktis and Ravazzolo, 2005). However, even though most of the aforementioned studies have focused on emerging markets in Asia and Latin America, evidence on stock market linkages of the emerging markets in Europe, remains relatively limited.

Gelos and Sahay (2000) investigate the impact of various external crises on Central and Eastern European (CEE) stock markets. They found increased financial market correlation since 1993, particularly around the time of the 1998 Russian crisis. The Hungarian market appeared to be highly affected by that crisis. This finding is consistent with Schotman and Zalewska (2006) who documented that the Hungarian market was the most and the Czech market was the least sensitive to the 1997 Southeast Asian and 1998 Russian crises, a finding that may be explained by the fact that among the three emerging markets discussed in that study the Hungarian market had the highest foreign share ownership level and the Czech market the lowest. Moreover, Wang and Moore (2008) documented a higher level of the stock market correlation between three emerging CEE markets and the aggregate eurozone market during the period after the Asian and Russian crises and also during the post-entry period to the European-union. Furthermore, Gilmore and McManus (2002) examined the short and long-term relationships between the US stock market and three CEE emerging markets (Hungary, Poland, Czech Republic) over the 1995-2001 period and he found that low short-term correlations between the CEE markets and the US existed, whereas the application of the Johansen cointegration procedure indicated that there is no long-term relationship among them. Additionally, Scheicher (2001) found evidence of limited interaction between some of the CEE markets and the major markets for daily stock market volatility.

Voronkova (2004) showed the existence of long-run links between the UK, the German, the French and three Central European stock markets (Hungary, Poland, Czech Republic) using daily data for the period 1993-2002, conditionally that structural changes are properly accounted for. In a similar vein, Syriopoulos (2004, 2007) documented the existence of a long-run relationship between the US, the German and four CEE stock markets (Hungary, Poland, Czech Republic and Slovakia), using Johansen's cointegration methodology over the period between 1997 and 2003, while he insists that CEE markets tend to display stronger linkages with their mature counterparts rather than their neighbors. Finally, Syllignakis and Kouretas (2010) provided evidence that the stock markets of the Central and Eastern European countries are partially integrated with the mature US and German stock markets, since they share a significant common permanent component, which drives the system of these stock exchanges in the long-run, with the Estonian market appeared to be segmented. Furthermore, they also argued that the 2007-2009 global financial turmoil had a negative effect on the convergence process.

The issue of contagion among stock markets has come to the surface once again as a result of the financial crisis of 2007-2009. The CEE countries have been hit dramatically by the events that originated in the mortgage subprime US market that was eventually turned to a credit and financial crisis. Thus, as a result of the 2007-2009 financial crisis investors in the over borrowed speculative hedge funds, private equity and other institutional investors have withdrawn almost all their investments from the emerging markets and certainly from the CEE stock markets. Facing bankruptcy, these institutional investors moved to liquidate most of their stocks, bonds and currencies from the CEE and other emerging markets and invested instead in safer assets like the US government bonds. As a result the stock markets of the

CEE countries lost over 50% of their value between June 2008 and November 2008 while their currencies have been devalued substantially.

Hungary was the country which has been hit hardest by the crisis and faced severe economic and financial problems. It had a huge current account deficit and was forced to raise its basic interest rate from 8.5% to 11.5% in an effort to prevent the depreciation of the Hungarian fiorin. However, this intervention policy did not work and its currency continued to depreciate against the euro and the dollar. This fall in value of the domestic currency resulted in a substantial increase in the value of its external debt, forcing Hungary to ask for a 16.5 billion dollar loan from the IMF and another 5 billion euro loan from ECB in an attempt to ease the severe consequences for its economy. Almost all other CEE economies faced significant problems. Estonia also faced an economic recession whereas the Romanian currency depreciated from May 2008 to November 2008 as a result of the substantial increase in its budget deficit, its current account deficit and its external debt which led to the reduction of its credit ratings by Standard and Poor's and Fitch. Even the currencies of Poland and the Czech Republic, which in the previous years had been quite stable, went under substantial pressure due to the capital flight which led to a reduction in their values against the euro.

Eichengreen and Steiner (2008) argued that part of the problem during this and past financial crises is the incurrence of liabilities that are denominated in foreign currency. Although some emerging economies have learned after the crises of 1994-2002 the negative effects that currency mismatches can create, several CEE countries borrowed in foreign currency during the subsequent cycle. This mistake was repeated by Hungary and to a lesser extent by Poland. Eichengreen and Steiner (2008) interpreted these transactions as a failed "convergence play" among CEE countries

considered to be on the path to joining the euro resulted in this way to another episode of the carry trade observed in foreign exchange and money markets during the last five years.

In this paper we provide further analysis to the issue of contagion by examining the correlations among seven stock markets of the CEE economies which have been recently become members of the European Union. We coupled our analysis by linking the volatility of returns of these stocks markets with those of the US, German and Russian stock markets. We chose the US and German stock markets since they have an influential role in emerging European stock markets due to their significant investment flows in these markets. In addition, Russian has been historically an important trade partner of the CEE economies and trade flows is considered to be an important channel for the spread of currency crises particularly in the case of geographic proximity. We conducted our analysis with the application of the Dynamic Conditional Correlation (DCC) multivariate GARCH models developed by Engle (2002). We then looked into the impact that the 1997-1998 Asian and Russian financial crises, the 2000-2002 dot-com bubble and the 2007-2009 financial crisis had on the stock markets of the CEE economies. Finally, we investigated potential explanatory factors that may drive the stock market conditional correlations.

Several important findings stem from our analysis. First, the examination of the estimated correlation coefficients between the stock returns of the US and German and the corresponding returns of the CEE stock markets are statistically significant providing evidence in favor of the influential role of these two mature markets on the CEE emerging stock markets. By contrast the Russian stock market has limited influence on the stock returns of the CEE markets. Second, based on the plots of pairwise conditional correlation coefficients it is revealed that these were increased in

magnitude substantially during the 1997-1998 Asian and Russian crisis, whereas during the 2007-2009 financial crisis the conditional correlation coefficients rose dramatically and they reached their highest value in December 2008. These results may also suggest that during the periods of the crises and in particular in the second half of 2008, the increase in equity market correlations could be attributed to herding behaviour that is the observed contagion effects are investor induced through portfolio rebalancing. Third, we provided evidence that these financial crises had a statistically highly significant effect on the conditional correlations suggesting that these emerging markets are exposed to external shocks with a substantial regime shift in conditional correlation. Finally, we demonstrated that domestic and foreign monetary variables, as well as exchange rate movements have a significant impact on the corresponding conditional correlations.

The rest of the paper is organized as follows. In section 2 we discuss the financial liberalization process and market characteristics of the CEE economies. Section 3 presents the econometric methodology. In section 4 we discuss the data and the empirical results and section 5 provides our conclusions.

2. Central and Eastern European emerging stock markets

2.1 Market characteristics

Following the change in political regime in the early 1990s a key element of the transition process towards adopting the mechanisms of a market economy was the re-establishment of the capital markets in the Central and Eastern European countries. One of the main objectives of the reformers in the post-communist countries was the creation of private ownership via privatization of state-owned enterprises. Moreover, legal structures for ownership rights, corporations and contracts, order execution,

transparency in transaction of shares and the abolishment of restrictions in capital flows have been established. The first stock exchange that reopened in the area was the Ljubljana Stock Exchange (LJSE), on March 29, 1990, followed by the Budapest Stock Exchange (BSE), on June 21, 1990, and the Warsaw Stock Exchange (WSE) on April 16, 1991.

The accession of these countries to the European Union on May 1, 2004, gave new perspectives on these markets and attracted the interest of many investors worldwide, who previously refrained from investing in CEE markets because of real or perceived political, liquidity and corporate governance risks.[2] However, the first fifteen years of operation of the emerging European stock markets have been characterized by several events, such as the Asian crisis in 1997, the Russian default in 1998 and most recently by the credit and financial crisis of 2007-2009, which led to financial instability for the entire region and affect the confidence of investors that have started investing in those markets.

In Table 1 we provide an overview of important characteristics of the examined stock markets in Central and Eastern Europe, including the market capitalization, the number of listed companies and the market (index) annual returns. Therefore, it is shown that the larger stock markets in the CEE region, in terms of market capitalization at the end of 2008, are those of Poland, the Czech Republic and Hungary, with market capitalization of 90.81, 41.16 and 18.46 billion dollars respectively.[3] Moreover, the smaller market in the region is this of Estonia with market capitalization of only 1.31 billion dollars. As a result of the different

[2] During the period from January to December of 2004, the CEE stock exchanges recorded significantly high returns. The Slovakian stock exchange recorded a return of 83.9%, the Hungarian 57.2%, the Estonian 57.1%, the Czech 50.9%, the Polish 27.9% and the Slovenian recorded a return of 24.7%.

[3] Compared to world-developed markets (NYSE, LSE, Euronext and Deutsche Börse) the CEE equity markets remain thin in terms of market capitalization. However, the Warsaw stock exchange is bigger in terms of market capitalization than several eurozone equity markets like the Wiener Börse, the Irish SE and the Athens SE.

approaches to privatization pursued by the CEE countries, the examined stock markets had substantially different patterns of growth, in terms of the listed firms. For instance, the number of firms listed on the Czech and Slovakian stock exchanges was initially large, following the first of several mass waves of privatization. Since then, the majority of those firms have been delisted, because of the lack of liquidity and the overly stricter listing requirements.[4] However, in other exchanges, like the Polish one, the number of listed firms has grown slowly, as a result of a steady approach to the implementation of the privatization scheme. The number of listed firms in the Warsaw stock exchange at the end of 2008 was 458.

2.2 Financial liberalization

The international financial integration which increased dramatically in the last three decades resulted to the gradual removal of controls on capital account transactions and the deregulation of the domestic financial sector. This international financial liberalization move was initiated in the developed countries after the collapse of the Bretton Woods system. It was followed by a first wave of financial liberalization by several Latin American and Southeast Asian countries in the late 1970s. Financial liberalization programs were further implemented in these two regions in the late 1980s and early 1990s. During that period several Western European countries also removed all capital controls as a prerequisite of the formation of the European Monetary Union. The countries of CEE have been the most recent group of economies which gradually adopted policies for the abolishment of capital controls which was coupled with the re-opening of the stock exchanges in the region.

[4] At most CEE exchanges only a minority of the companies are listed at the official and regulated markets, where the listing requirements are much higher than other developed exchanges. On the contrary, there is large concentration of listings in the free market (unregulated) segments, since these listings impose no costs on the companies.

Although financial liberalization may have several positive effects on the operation of financial, investment and growth there are also arguments against complete financial liberalization. As Kaminsky (2008) argued the severity of the current crisis has raised the question of whether modern liberalized financial markets lead to more problems than they solve. Kaminsky and Schmukler (2008) further demonstrated that the empirical evidence on the effects of financial liberalization is rather mixed. One the one hand it is argued that the deregulation of financial markets was the main cause of the current crisis as well as of all previous crises since the 1970s. On the other hand it is claimed that financial liberalization leads to more efficient allocation of capital, increasing productivity and growth and helps the financial markets to function much better. Although these two lines of thought seem to be conflicting Kaminsky and Schmukler (2008) provide a framework that leads to a reconciliation of these two arguments. Therefore, they argue that if we consider a time-varying nature of the financial liberalization then the removal of capital controls may trigger, in the short-run, financial booms and busts and subsequent output collapses in those economies in which financial markets exhibit substantial distortions. However, in the long-run, financial liberalization may lead to improvements in institutions and accountability of investors eventually promoting financial and economic stability.

This time-varying nature of financial liberalization may explain the capital flow reversals which has been observed during the financial crisis of 2007-2009, since foreign investors liquidate their portfolio investments in the CEE countries in order to invest in the mature stock markets in a typical ‘flight to quality’ movement. These capital reversals followed the investment boom of the 1990s and early 2000s in the capital markets of the CEE countries. Such capital flow reversals have also occurred

in the 1980s and in the late 1970s and as Kaminsky (2008) demonstrated sudden stops as being an important source of financial crises and contagion among the international financial markets.

In Table 2, information is provided regarding the date when the CEE capital markets opened to foreign investors, following the methodology proposed by Bekaert and Harvey (1995) and Bekaert (1995).[5] According to that information, most restrictions were lifted from the markets examined between 1996 and 1999. The Czech market was the first that took certain measures towards official capital market liberalization, while the Slovenian market was the last. However, it is important to point out that the legal restrictions on foreign participation were lifted gradually. The first country that issued an ADR was Hungary in 1992 and the last was Estonia in 1998. Moreover, the fifth and the sixth rows of Table 1 report the number of mutual funds (UCITS) or ETFs that operates in each country. The investment funds or trusts are considered as a mean for institutional investors to invest in the local markets. Therefore, the most active funds the most open are the markets to foreign investors. Specifically, Hungary is the country with the most active funds (129), while Romania is the one with the least (6).

3. The DCC model

In this paper we apply the multivariate GARCH model proposed by Engle (2002), to estimate dynamic conditional correlations (DCC) between the Central and Eastern European stock market returns and those of the US, Germany and Russia respectively. For a number of reasons the multivariate DCC-GARCH model is

[5] Bekaert and Harvey (1995) proposed an indicator for characterizing the situation in which the emerging markets were opened to foreign investors considering a multitude of elements including: the official date of the capital market liberalization, the date of the ADR (American Depository Receipts) introduction on the market and the date of the first country fund (FCF).

simpler in its estimation over the computationally intensive multivariate VEC model and its variants described in Engle and Kroner (1995). First, the number of the estimated parameters grows linearly with the number of stock returns and therefore the model is relatively parsimonious. Secondly, another advantage of the DCC-GARCH model is that requires a two-step estimation procedure, so that the number of parameters to be estimated simultaneously is too small. In the first step univariate GARCH models are estimated for each stock return, while in the second one the standardized residuals obtained from the first step are used in order to estimate correlation coefficients and thus accounts directly for heteroskedasticity. The resulting estimates of time-varying correlation coefficients enable us to study the correlation behavior between the national stock-index returns during a period with multiple regime shifts in response to shocks and crises events. The stock market returns are assumed as the following process:

$$r_t = \mu + \gamma_1 r_{t-1} + \gamma_2 r_{t-1}^{dev} \varepsilon_{i,t} \ , \qquad (1)$$
$$r_t = (r_{1,t}, r_{2,t}, ..., r_{n,t})', \ \varepsilon_t = (\varepsilon_{1,t}, \varepsilon_{2,t}, ..., \varepsilon_{n,t})' \text{ and } \varepsilon_t \left| I_{t-1} \sim N(0, H_t). \right.$$

where r_t is a $n \times 1$ vector of stock return index and ε_t is a $n \times 1$ vector of residuals conditional on the information at time period $t-1$, I_{t-1} with N multivariate normal distribution. The first order autoregressive term is used to account for the autocorrelation of stock returns. The lagged U.S., German and Russian stock return is included in the mean equation, respectively, in order to account for a global or local factor (Chiang *et al.*, 2007). The inclusion of this factor is also based on the empirical finding that U.S., German and Russian stock returns play an important role in determining stock returns in CEE countries, while CEE stock returns have no

significant dynamic effect on them. The multivariate conditional variance is specified as:

$$H_t = D_t R_t D_t \tag{2}$$

where D_t is a $(n \text{ x } n)$ diagonal matrix of time-varying standard deviations obtained from univariate GARCH(1,1) specifications with $\sqrt{h_{ii,t}}$ on the ith diagonal, $i = 1,2,.....n$.[6] R_t is the $(n \text{ x } n)$ time-varying correlation matrix.[7] The DCC specification is given as:

$$\begin{aligned} q_{ij,t} &= \bar{\rho}_{ij}(1-a-b) + bq_{ij,t-1} + a\eta_{i,t-1}\eta_{j,t-1} \\ \rho_{ij,t} &= \frac{q_{ij,t}}{\sqrt{q_{ii,t}}\sqrt{q_{jj,t}}} \\ i, j &= 1,2,...,n, \text{ and } i \neq j. \end{aligned} \tag{3}$$

where $q_{ij,t}$ is the i, j element of Q_i $(n \text{ x } n)$ time-varying covariance matrix of the standardized residuals $\eta_{i,t} = \varepsilon_{i,t} / \sqrt{h_{ii,t}}$, $\bar{\rho}_{ij}$ is the unconditional correlations of $\eta_{i,t}\eta_{j,t}$ and a, b are nonnegative scalar parameters satisfying $a+b<1$. Finally, $\rho_{ij,t}$ is a typical element of the time-varying correlation matrix (R_t).

As proposed by Engle (2002), the log-likelihood of the estimators can be written as:

$$L(\vartheta) = -\frac{1}{2}\sum_{t=1}^{T}[(n\log(2\pi) + \log|D_t|^2 + \varepsilon_t' D_t^{-1} D_t^{-1} \varepsilon_t) + (\log|R_t| + \eta_t' R_t^{-1} \eta_t - \eta_t' \eta_t)] \tag{4}$$

---

[6] The univariate GARCH(1,1) specification is specified as: $h_{ii,t} = \omega_i + \alpha_{i,1}\varepsilon_{i,t-1}^2 + \beta_{i,1}h_{ii,t-1}$, for $i = 1,2,....,n$.

[7] The correlation matrix R_t is obtained from the scale of the covariance matrix Q_t that does not generally have ones on the diagonal: $R_t = (diag(Q_t))^{-1/2} Q_t (diag(Q_t))^{-1/2}$, $(diag(Q_t))^{-1/2} = diag(1/\sqrt{q_{11,t}}, ..., 1/\sqrt{q_{nn,t}})$.

where n is the number of equations, T is the number of observations and ϑ is the vector of parameters to be estimated. The first part of the likelihood function is the sum of the individual GARCH likelihoods and can be maximized in the first step over the parameters in D_t. In the second step the correlation coefficients can be estimated given the parameters estimated in the first step from the maximization of the second part of the likelihood function.

4. Data and preliminary empirical results

The data used in this paper are weekly stock-price indices from October 3, 1997, through February 13, 2009, for the equity markets of seven new European Union member states.[8] The data set consists of the local stock indices of Czech Republic (PX), Estonia (TALSE), Hungary (BUX), Poland (WIG), Romania (BET), Slovakia (SAX12) and Slovenia (SBI). Moreover, the S&P500 index is used to represent the U.S. equity market, the DAX index the German market and the RTS index the Russian market. The inclusion of the German and the U.S. markets in the sample is due to the fact that both markets serve as a regional and global factor in the region, respectively.[9] Moreover, the Russian market is the biggest stock market in Eastern Europe and has an influential role in emerging European stock market movements, due to its significant trade flows with these markets. All national stock-price indices are used in local currency terms and are based on weekly closing prices

[8] The starting date of our sample reflects the earliest data available for Romanian stock index. Weekly data are used due to the presence of more noise with higher frequencies, such as daily data.

[9] We select Germany and the U.S. as the key developed markets because these markets are the biggest, in terms of market capitalization, in North America and the Eurozone, respectively, and they can serve as proxies for the rest mature markets in both regions, in depicting possible linkages with the emerging European stock markets examined. Furthermore, the German and the U.S. markets have an influential role in emerging European stock market movements due to their significant investment flows in these markets (see Table 1).

for each market.[10,11] These stock market indices are transformed into weekly rates of returns taking the first difference of the natural log of each stock-price index. The source of the data is the Datastream International.

The summary statistics of stock-index returns in the seven Central and Eastern European markets, the US, German and Russian markets are presented in Table 3. Specifically, we report information on the mean, standard deviation, skewness coefficient, kurtosis coefficient, the Jarque-Bera normality test, and the Ljung-Box test (LB). As expected with emerging equity markets, the index returns series are negatively skewed (with the exception of Slovakia) and leptokurtic. Moreover, the Jarque-Bera test statistic reveals the typical non-normality of high frequency financial time series. This finding suggests that for these markets, big shocks of either sign are more likely to be present and that the stock returns series may not be normally distributed. Furthermore, the results also reveal that the emerging markets of CEE have higher Sharpe ratios than those reported for the developed equity markets. Slovakia is the market with the highest Sharpe ratio (0.306) while Estonia is the one with the lowest (-0.221). In addition most of the stock return series are found to exhibit significant autocorrelation as it is suggested by the Ljung-Box test statistic.

Figure 1 provides plots of the weekly stock returns for each market and it is shown that a clustering of larger returns volatility around and after 1997-1998 when the Asian and Russian financial crisis took place. Moreover, a significantly higher variation of the weekly stock returns was observed during the period of the 2007-2009 financial turmoil.

[10] When data were unavailable, because of national holidays, bank holidays, or any other reasons, stock prices were assumed to stay the same as those of the previous day.

[11] Expressing the stock price indices in their national currencies restricts their changes to the movements in the stock prices only, avoiding distortions induced by numerous devaluations of the exchange rates that have taken place in the CEE region [see Voronkova (2004), Chiang et al. (2007), Syriopoulos (2007)].

The unconditional correlation between the stock returns for the markets under examination is presented in Table 4 and it is shown that the unconditional correlation of the emerging markets of Central and Eastern Europe with the mature markets of Germany and the U.S. is relatively low and ranges between 0.063 and 0.539. Furthermore, the unconditional correlation of the CEE markets with the Russian market ranging from 0.08 to 0.53, with the Hungarian market to be the most and the Slovakian market the least correlated with the Russian market.

4.2 The DCC model and estimation results

Table 5 (Panel A, B and C) presents the results of the multivariate DCC-GARCH model that is estimated using the quasi-maximum likelihood method described in Section 3. The constant term in the mean equation (eq. 1) is statistically significant for all markets except for Slovakia. The AR(1) term in the mean equation, γ_1, is statistically significant and negative for Czech Republic and Hungary, while it is statistically significant and positive for Estonia and Slovenia. However, the AR(1) coefficient is not statistically significant for Poland, Romania and Slovakia. The effect (γ_2) of the US and German stock returns on CEE stock returns is highly significant and consistently of large magnitude, confirming the influential role of the US and German stock markets on the CEE stock markets. By contrast, the Russian stock returns do not have any significant effect on CEE stock returns, with the exception of Slovakia. The last two rows of Panels (A, B and C) report the estimates of the DCC(1,1) parameters a and b in eq. 3. Both parameters are statistically highly significant, revealing a significant time-varying co-movement. Moreover, the conditional correlations also exhibit high persistence, with the average sum of the two coefficients to be over 0.90 during the sample period. The remaining rows are

parameter estimates of the mean and conditional variance equations for the stock market returns examined. Furthermore, it is revealed that the coefficients for the lagged conditional volatility and ε^2 terms in the variance equation (given in footnote 6) are highly significant, justifying the appropriateness of the GARCH(1,1) specification. The results indicate that the volatility persistence measure $(a+b)$ is close to one for all the markets examined. These results lead to the conclusion that the volatility in the GARCH models displays high persistence.

An advantage of the multivariate DCC-GARCH model is based on the fact that we can obtain all possible pair-wise correlation coefficients for the index returns in the sample and study their behavior during periods of particular interest, such as periods of financial turmoil. Therefore, we are able to examine for possible contagion effects between the markets which have been affected by a specific crisis. According to Boyer *et al.* (2006), contagion can either be investor induced through portfolio rebalancing or fundamental based. The latter can be associated to what have been described by Forbes and Rigobon (2002) as interdependence, while the former case is described in behavioral finance literature as herding. The herding behavior can occur because investors are following other investors, which has been characterized by Hirshleifer and Teoh (2003) as "Convergence of behaviors". The result of such a herding behavior is that a group of investors trading in the same direction over a period of time. Some recent empirical studies (see Corsetti *et al.*, 2005; Boyer *et al.*, 2006 and Chiang *et al.*, 2007) used the dynamic conditional correlations measure to investigate possible herding behavior in emerging financial markets during crises periods.

We now move to the discussion of the estimated conditional correlation coefficients. We estimated a regression equation for the conditional return

correlations on a constant and a trend in order to examine whether the conditional correlations changed over time. Table 6 reports the regression results and it was revealed that the average conditional correlations between the stock returns of US, Germany and Russia and those of Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia and Slovenia were of the same magnitude as the unconditional correlations. Moreover, the volatility of the conditional correlations ranged from 2.33% to 6.81%. These findings show that a statistically significant rise over time in conditional correlations was detected for all the pairs examined (except for the pair Czech Republic – Russia) at the 5% level of significance. This rise in correlations is measured by the term, $\Delta\rho$, which is equal to the difference between the last and first fitted values. The increase in correlation is particularly evident for Romania ($\Delta\rho$ = 128.4%) and Estonia ($\Delta\rho$ = 58.97%), suggesting that these markets and the S&P 500 index have become more interrelated over the period analyzed. However, these markets together with the Slovakian market are still the least correlated with the developed markets (Germany and US) ranging on average from 0.06 to 0.29. These results further suggest that the diversification benefits from a portfolio which includes equities from mature markets alongside with equities from the CEE markets may have decreased during the last decade due to the EU accession process of the CEE states and the increased participation of foreign investors in the local markets. Therefore, based on these findings we may argue that the stock markets of the CEE economies are mainly influenced by the markets of the US and Germany due to the inclusion of stocks from these emerging markets in international portfolios and the accession of these economies in the European Union. These results also revealed that the coefficients with respect to Russia are not statistically significant and this maybe an

indication against the argument that geographic proximity is a potential source of contagion.

Figures 2-4 show pair-wise conditional correlation coefficients between the stock returns of US, Germany and Russia and those of Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia and Slovenia during the period 1997-2009. These time series patterns show that the pair-wise conditional correlations incremented dramatically during the current financial crisis and reached their highest level on December, 2008. Particularly, the conditional correlation between the S&P 500 index and the CEE markets increased by 120% on average during the period September-December 2008. This dramatic increase in equity market correlations in the second half of 2008 can be attributed to what have been previously described as "Herding behavior". According to this notion, in times of severe stress like that experienced in 2008, disparate markets will all tumble together as investors scramble to sell whatever they can and move into cash. The outcome of that behavior was more intense during the current crisis since the advent of exchange-traded funds, or ETFs, allowed investors to buy and sell equity portfolios in Central and Eastern Europe (e.g. Lyxor ETF Eastern Europe, iShares DJ STOXX EU Enlarged 15, iShares MSCI Eastern Europe 10/40) with the click of a mouse.

The correlation coefficients between the stock returns of US, Germany and Russia and those of Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia and Slovenia increased but to a lesser extent throughout the 1997-1998 crisis period. In general the pattern of the conditional correlation coefficients is quite similar around the 1997-1998 crises period, where the correlation temporary peaks, particularly among the developed markets of Germany and US and those of Czech Republic, Hungary and Poland. It is interesting to note that during the 1997-1998 period despite

the significant effect of the two crisis events on the CEE markets, the conditional correlations reached their highest level on October 1998, after the surprise cut of the interest rate by the FED.[12] The sudden increase in correlations during this period can be associated with what was named by Alan Greenspan as *flight to quality*, the phenomenon where investors substitute the risky stock assets with the most safe bond assets. This spillover effect seems to be indicative of contagion effects across emerging markets of Eastern Europe and underlines the significant role of the US market in the region. Moreover, it is also fascinating to note that the pattern of conditional correlation seems to coincide for Czech Republic, Hungary and Poland throughout the rest of the period examined. It is quite evident also a common upward trend since the entry to the EU in May 2004. In contrast, the pattern of conditional correlation for the smallest CEE markets (Estonia, Romania and Slovakia) seems to diverge from that of the rest CEE markets and follow mainly country-specific movements.[13]

4.3 Statistical analysis of conditional correlation coefficients

We further study the time series behavior of conditional correlations and provide additional insight on the impact that crises events and stock market volatility have on their movements. Specifically, we estimate the following model:

$$\rho_{ij,t} = \omega + \beta_i h_{t,i} + \beta_j h_{t,j} + \sum_{k=1}^{3} \alpha_k DM_{k,t} + \varepsilon_{ij,t} \qquad (5)$$

where $\rho_{ij,t}$ is the estimated pair-wise conditional correlation coefficients between the stock returns of US, Germany, Russia and those of Czech Republic, Estonia,

[12] In October 1998 there was a surprise cut of the interest rate by the FED to relieve the pressure in the tight credit market, since lenders where very reluctant to provide new loans, after several crises in Asia, Argentina and Russia.
[13] The results for the dot-com bubble were found to be statistically insignificant.

Hungary, Poland, Romania, Slovakia and Slovenia, such that i = US, Germany, Russia, j = Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia and Slovenia, h_t is the conditional volatility, $DM_{k,i}$ is the dummy variable which is used to take into account the effects of three major financial crises: the crisis in Asia and Russia (21/11/1997-30/10/1998), the dot-com bubble (10/03/2000-27/09/2002) and the US Credit bust (Lehman collapse) (26/09/2008-End of sample period). A positive β_i suggests that conditional correlations between the developed market indices and the CEE market indices rise with the volatility of the developed market indices. On the other hand, a negative β_i indicates that the correlations between the developed market return series and the CEE market return series fall in periods of high volatility in developed markets. This result implies that the usefulness of emerging European stock markets as a diversification tool increases in periods of above average developed market volatility.

In table 7, we report the estimates of the parameters of eq. (5). The results in Panel A, regarding the β_i coefficients, reveal that the relation between conditional correlation and S&P 500 volatility is not consistent throughout the cross section. The evidence suggests that the slope coefficient β_i of equation (5) is positive for 4 CEE markets and negative for 3 at the 5% level. Particularly, a 1% rise in market (S&P 500 index) risk leads to a 13.40% rise in correlation between the equity markets in US and Hungary. In contrast, *ceteris paribus*, a 1% rise in market (S&P 500 index) risk leads to a 25.69% fall in correlation between the equity markets in US and Czech Republic. The different impact that market volatility has on conditional correlation confirms the argument that the CEE markets behave in a different manner from one another and cannot be treated as a unique market with the same characteristics. The estimated

slope coefficients β_i in Panel B and Panel C are relatively lower comparing to those in Panel A, revealing that the impact of the German and the Russian markets volatility changes on conditional correlations is less significant.

We now turn to the discussion of the estimated dummy variable coefficients which are reported in Table 7. The effect of the crisis events on the conditional correlation coefficients between the developed market indices (S&P 500, DAX, RTS) and the CEE market indices (BET, BUX, PX, SAX, SBI, TALSE, WIG) is of particular interest; since in periods of market turbulence is higher the need and the benefit that arise from the application of portfolio diversification techniques. The results show that $DM_{1,t}$ is statistically significant and slightly negative, for the majority of the pairs examined, indicating that the correlation during the period of the 1997 Asian and the 1998 Russian crises has to some extent declined.[14]Regarding the $DM_{2,t}$ coefficients the findings reveal that most of these coefficients are negative and statistical significant at the 5%. This finding demonstrates that during the period 2000-2002 when the developed stock markets indices declined significantly the correlation coefficients with the CEE markets were significantly lower than the post-crisis period. Finally, during the crisis of 2007-2009, the correlation coefficients given by the estimates of $DM_{3,t}$, were positive and increased significantly in almost all the cases. This finding is consistent with the co-movement paths shown in Figures 2-4 and supports the evidence of herding behavior during the recent stock market crash that we mentioned above.

[14] Based on the visual examination of increased correlations peaked on October 1998 we would expect a positive coefficient for $DM_{1,t}$. This apparent contraction may be due to the fact that the 1997-1998 period coincides with the beginning of the sample period which may affect the regression estimates. However, data availability restricted us to have to have our sample started earlier for most CEE stock markets.

4.4 Factor analysis of the conditional correlation coefficients

In the final stage of the present analysis we examined the time varying conditional correlation coefficients between the stock returns of US, Germany and Russia and those of Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia and Slovenia, in this section, we investigate the potential explanatory factors that drive the stock market conditional correlations. Specifically, we estimate the following linear equation for the CEE markets with respect to the US market[15]:

$$\rho_{ij,t} = \omega + \alpha_1 IP_{t,cee} + \alpha_2 IR_{t,cee} + \alpha_3 M2_{t,cee} + \alpha_4 CR_{t,cee} + \alpha_5 IP_{t,us} + \alpha_6 IR_{t,us} + \alpha_7 M2_{t,us} + \alpha_8 ER_{t,cee/us} + \varepsilon_{ij,t} \quad (6)$$

where IP, IR, M2 and ER stand for the monthly change of the seasonally adjusted industrial production, the nominal one-month interbank rate, the money supply (M2), and the exchange rate respectively. The CR factor is used in order to capture the effect of sovereign credit rating changes reported by Standard and Poor's in CEE markets during the period analyzed. The CR indicator is set equal to zero if there is no change in the sovereign credit ratings, otherwise for an upgrade of one notch, we set CR=1; for a downgrade of 2, we set CR= -2 whereas $\rho_{ij,t}$ is the end of month dynamic conditional correlation between the CEE and the US stock market. We applied a rolling regression methodology using a time window of 36 months, thus we have 5544 estimated coefficients in total.[16] The rolling regression technique is applied in order to identify a possible time variation of the regression coefficients. A summary of the estimated coefficients is presented in Table 8. In each cell we report the number of times the t-statistic of each explanatory variable is significant at 5% level of significance. Overall we found empirical evidence of the time variation of the

[15]We have also estimated equation (7) with respect to the German and Russian relevant macroeconomic variables. The overall evidence is similar to that for the US case. To save space the results are available upon request.

[16] We estimated the model for 99 rolling time periods, 8 factors and 7 CEE markets.

explanatory power and the regression coefficients. The mean R^2 statistic ranges between 0.44 and 0.68. The coefficient on the interest rates of the CEE markets and the US are significant at the 5% level for the majority of the rolling periods, implying that the interest rates seem to affect the stock market return correlations. This finding confirms our earlier argument that the October 1998 surprise interest rate cut by the FED coincides with the temporal peak of the estimated conditional correlations. The US money supply had also shown to be highly statistically significant with a positive sign particularly during the last rolling periods in our sample. It implies that the higher the US money supply, the higher the correlation between the US and the CEE stock returns. Therefore, we may argue that to some extent changes in the US and domestic monetary variables affect the corresponding conditional correlations. A similar result is evident for the exchange rate coefficients. They are highly significant with a positive sign particularly during the last rolling periods. This finding confirms the empirical evidence that the CEE currencies have been greatly devaluated against the US dollar during the period of the recent stock markets crash. The rest of the estimated coefficients are not statistically significant for the majority of the rolling periods in our sample.

5. Summary and concluding remarks

In this paper, we used the multivariate DCC-GARCH model to investigate the relationship between the stock returns of various Central and Eastern European stock markets during the 1997-1998 Asian and Russian financial crises, the 2000-2002 dot-com bubble and the 2007-2009 credit and financial crisis. Our analysis was focused on the examination of the pair-wise conditional correlation coefficients between the stock returns of the U.S, Germany and Russia and those of the Czech Republic,

Estonia, Hungary, Poland, Romania, Slovakia and Slovenia by employing weekly stock price data for the period October 1997 to February 2009. Following the recent studies by Corsetti *et al*. (2005), Boyer *et al*. (2006) and Chiang *et al*. (2007), we employed the Dynamic Conditional Correlations technique as the appropriate framework to investigate the existence of increased correlation between the stock returns of the mature stock market and those of the emerging markets as well as the presence of contagion effects due to herding behavior during the periods of financial turmoil.

The main findings that emerge from our analysis are summarized as follows. First, based on the pair-wise correlation coefficients for the index returns resulted from the estimated multivariate DCC-GARCH specification it was shown that the conditional correlations increased significantly during the 1997-1998 crisis period and reached their highest level on October, 1998, the week after the surprise cut of the interest rate by the FED. Similarly, the pair-wise conditional correlation coefficients increased enormously during the credit and financial turmoil of 2007-2009 and reached their highest level in December 2008. This analysis of the pattern of the conditional correlation coefficients during the period 1997-2009 provides substantial evidence in favor of contagion effects due to herding behavior in the financial markets of the Central and Eastern European emerging markets particularly around the 2007-2009 financial turmoil.

Second, with the use of dummy variables we demonstrated that for the case of the 2007-2009 financial turmoil the estimated dummy variable coefficients were statistically significant and positive, confirming the evidence in favor of contagion effects in the financial markets of the Central and Eastern Europe. In contrast, for the cases of the Asian and Russian crises (1997-1998) and for the dot-com bubble the

contagion effect hypothesis is not consistent throughout the panel of the CEE countries. These results further suggested that the episodes of financial turbulence and in particular that of 2007-2009 had a statistically high significant effect on the conditional correlations leading to the argument that these emerging markets are exposed to external shocks with a substantial regime shift in conditional correlation. Finally, the estimation of a stepwise linear regression of the conditional correlations on a set of real and monetary variables showed that domestic and foreign monetary variables as well as exchange rate movements have a significant impact on the corresponding conditional correlations.

References

Ang, A. and G. Bekaert, 1999, International asset allocation with time-varying correlations, NBER Working Paper, 7056.

Bekaert, G., 1995, Market integration and investment barriers in emerging equity Markets, World Bank Economic Review, 9, 75-107.

Bekaert, G. and C. R. Harvey, 1995, Time-varying world market integration, Journal of Finance, 50, 403-444.

Bekaert, G. and C.R. Harvey, 2005, Chronology of important financial, economic and political events in emerging markets", http://www.duke.edu/_charvey/chronology.htm

Boyer, B., T. Kumagai, and K. Yuan, 2006, How do crises spread? Evidence from accessible and inaccessible stock indices, Journal of Finance, 61, 957-1003.

Cappiello, L., R. Engle and K. Sheppard, 2006, Asymmetric dynamics in the correlations of global equity and bond returns, Journal of Financial Econometrics, 4, 537-572.

Chen, G.M., M. Firth and O.M. Rui, 2002, Stock market linkages: Evidence from Latin America, Journal of Banking and Finance, 26, 1113-1141.

Chiang, T. C., B.N., Jeon, and H. Li, 2007, Dynamic correlation analysis of financial contagion: Evidence from Asian markets, Journal of International Money and Finance, 26, 1206-1228.

Corsetti, G., M. Pericoli and M. Sbracia, 2005, Some contagion, some interdependence: more pitfalls in tests of financial contagion. Journal of International Money and Finance 24, 1177-1199.

Dvorak, T. and R. Podpiera, 2006, European Union enlargement and equity markets in accession countries, Emerging Markets Review, 7, 129-146.

Eichengreen, B. and K. Steiner, 2008, Is Poland at risk of a boom-and bust cycle in the run-up to euro adoption?, NBER Working Paper No. 14438.

Engle, R.E., 2002, Dynamic conditional correlation: a simple class of multivariate generalized autoregressive conditional heteroskedasticity models, Journal of Business and Economic Statistics 20, 339-350.

Engle, R. and K. Kroner, 1995, Multivariate simultaneous generalized ARCH, Econometric Theory, 11, 122–150.

Forbes K. and R. Rigobon, 2002, No contagion, only interdependence: Measuring stock market comovements, Journal of Finance, 57, 2223-2262.

Gelos, G. and R. Sahay, 2000, Financial market spillovers in transition economies, Economics of Transition, 9, 53-86.

Gilmore, C.G. and G.M. McManus, 2002, International portfolio diversification: US and Central European equity markets, Emerging Markets Review, 3, 69-83.

Goetzmann W.N., L. Li and K.G. Rouwenhorst, 2001, Long-term global market correlations, Journal of Business, 2005, 78, 1-38.

Hamao, Y., R. Masulis, and V. Ng, 1990, Correlations in price changes and volatility across international stock markets, Review of Financial Studies, 3, 281-308.

Hirshleifer, D. and S.H. Teoh, 2003, Herd behaviour and cascading in capital markets: a review and synthesis, European Financial Management, 9 , 25-66.

Kaminsky, G. L., 2008, Crises and sudden stops: Evidence from international bond and syndicated-loan markets, NBER Working Paper No. 14249.

Kaminsky, G.L. and S.L. Schmukler, 2008, Short-run pain, Long-run gains: Financial liberalization and stock market cycles, Review of Finance, 12, 253-292.

Kim, S.J., F. Moshirian, and E. Wu, 2005, Dynamic stock market integration driven by the European Monetary Union: An empirical analysis, Journal of banking and finance, 29, 2475-2502.

Lessard, D. R., 1973, International portfolio diversification: Multivariate analysis for a group of Latin American Countries, Journal of Finance, 28, 619-633.

Lin, W.L., R.F. Engle and T. Ito, 1994, Do bulls and bears move across borders? International transmission stock returns and volatility, Review of Financial Studies 7, 507-538.

Longin, F. and B. Solnik, 1995, Is the correlation in international equity returns constant: 1960–1990?, Journal of International Money and Finance, 14, 3–26.

Longin, F. and B. Solnik, 2001, Extreme correlation in international equity markets, Journal of Finance, 56, 649-676.

Meric, I. and G. Meric, 1997, Co-movements of European equity markets before and after the 1987 crash, Multinational Finance Journal, 2, 137-52.

Phylaktis, K. and F. Ravazzolo, 2005, Stock market linkages in emerging markets: implications for international portfolio diversification, Journal of International Financial Markets, Institutions and Money, 15, 91-106.

Scheicher M. 2001, The comovements of stock markets in Hungary, Poland and the Czech Republic, International Journal of Finance and Economics, 6, 27-39.

Schotman, P.C. and A. Zalewska, 2006, Non-synchronous trading and testing for market integration in Central European emerging markets, Journal of Empirical Finance, 13, 462–494.

Solnik, B., 1974, Why not diversify internationally rather than domestically?, Financial Analysts Journal, 30, 48–54.

Syllignakis, M. and G.P. Kouretas, 2010, German, US and Central and Eastern European stock market integration, Open Economies Review, forthcoming.

Syriopoulos, T., 2004, International portfolio diversification to Central European stock markets, Applied Financial Economics, 14, 1253-68.

Syriopoulos, T., 2007, Dynamic linkages between emerging European and developed stock markets: Has the EMU any impact?, International Review of Financial Analysis, 16, 41–60.

Theodossiou, P. and U. Lee, 1993, Mean and volatility spillovers across major national stock markets: Further empirical evidence, Journal of Financial Research, 16, 337-350.

Voronkova, S., 2004, Equity market integration in Central European emerging markets: A cointegration analysis with shifting regimes, International Review of Financial Analysis, 13, 633-647.

Yang, S.-Y., 2005, A DCC analysis of international stock market correlations: the role of Japan on the Asian four tigers, Applied Financial Economics Letters, 12, 89-93.

Wang, P. and T. Moore, 2008, Stock market integration for the transition economies: Time-varying conditional correlation approach, The Manchester School, 76, S116-S133.

Table 1: Market Characteristics for CEE stock exchange markets

	Number of listed firms													
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Czech	1716	1670	320	304	195	151	102	79	65	55	39	21	21	29
Estonia	---	11	25	22	23	20	17	14	14	13	19	17	18	19
Hungary	42	45	48	54	66	59	58	49	50	47	44	41	41	43
Poland	65	83	143	198	221	225	230	216	203	230	241	265	375	458
Romania	9	17	76	126	122	109	60	60	57	55	59	53	54	64
Slovakia	850	970	918	833	830	866	888	510	452	389	306	187	160	193
Slovenia	17	45	78	90	130	149	151	135	134	140	116	100	87	84
	Market Capitalization (billions of US dollar)													
Czech	24,5	19,3	14,4	13,9	13,3	11,7	9,4	15,8	24,8	43,67	54,12	44.37	68.91	41.16
Estonia	---	0,694	1.11	0,519	1.18	1.81	1.73	2.43	3.79	6.20	3.53	3.42	2.81	1.31
Hungary	2.40	5.19	14,70	13,79	16,10	11,90	10,36	13,01	18,86	28,63	32,57	41.93	46.19	18.46
Poland	4.56	8.41	12,13	20,46	29,57	31,42	26,15	28,84	37,40	71,54	93,60	151.81	211.62	90.81
Romania	0,100	0,060	0,626	0,356	0,313	0,415	1.23	2.72	3.71	11,93	18,18	25.23	30.64	8.99
Slovakia	5.35	5.77	5.29	4.12	3.63	3.27	3.47	2.65	3.37	4.93	4.74	5.83	6.91	5.43
Slovenia	0,311	0,890	1.88	2.98	2.85	3.10	3.46	5.58	7.13	9.68	7.90	15.18	28.79	11.79
	Stock Index Return (%)													
		96/95	97/96	98/97	99/98	00/99	01/00	02/01	03/02	04/03	05/04	06/05	07/06	08/07
Czech	PX	26.7	-8,2	-29,4	24,2	-2,3	-13,6	17,0	41,6	50,9	46,9	9.7	14.1	-52.7
Estonia	TALSE	---	61,90	54,86	39,3	19,1	4,7	46,8	34,4	57,1	50,7	28.9	-13.3	-62.98
Hungary	BUX	176.4	93,5	-21,1	39,8	-11,0	-9,2	9,4	20,3	57,2	41,0	19.5	5.9	-53.3
Poland	WIG	89.1	2,3	-12,8	41,3	5,0	-26,7	3,2	44,9	27,9	33,7	41.6	10.4	-48.2
Romania	BET	---	-24,2	-50,9	-2,6	9,1	-4,8	126,9	26,0	103,5	38,2	28.5	32.6	-70.3
Slovakia	SAX	15.8	2,5	-49,5	-19,0	19,2	31,4	15,9	26,9	83,9	26.5	0.6	7.2	-19.4
Slovenia	SBI	-18.3	18,7	21,4	5,9	0,1	19,0	55,2	17,7	24,7	-5,6	37.9	78.1	-66.1

Sources: WFOE (World Federation Of Exchanges), FESE (Federation of European Securities Exchanges), National stock exchanges.

Table 2: Indicators of financial liberalization for the CEE stock exchanges

Country	Stock market established	Restrictions lifted	1st ADR	N° of ETFs	N° of UCITS
Czech	June 1992	September 1994[1]	June 1995	--	32
Estonia	May 1996	1996[5]	December 1997	--	46
Hungary	July 1990	1996[2]	July 1992	1	128
Poland	January 1991	February 1997	February 1997	--	47
Romania	April 1995	March 1998[6]	April 1998	--	6
Slovakia	January 1994	April 1998[4]	April 1996	--	43
Slovenia	December 1989	1999[3]	June 1997	3	8

Sources: Bekaert and Harvey, (2005), Dvorak και Podpiera (2006), WFOE (World Federation of Exchanges), FESE (Federation of European Securities Exchanges) and National stock exchanges. ETFs are the exchange traded funds and UCITS are the Undertakings for Collective Investment in Transferable Securities.

1) More restrictions lifted in 1999
2) More restrictions lifted in 1998
3) Until 1999 foreign sales within 7 years taxed 12%. 25% foreign ownership limit.
4) More restrictions lifted in 2000
5) More liberalization in 2000. Restrictions on certain industries.
6) Some restrictions have been lifted since 1991, when the new FDI law (No. 35/1991) came into effect, while more restrictions lifted on 2001.

Table 3: Descriptive statistics of weekly index return series

	Czech Republic	Estonia	Germany	Hungary	Poland	Romania	Russia	Slovakia	Slovenia	U.S.
Ann. Return	2.67%	-3.64%	0.69%	3.87%	2.61%	7.30%	2.10%	5.82%	8.43%	-1.17%
Ann. Std. Dev.	24.69%	30.01%	26.10%	30.96%	25.79%	33.61%	49.83%	20.93%	17.72%	19.34%
Sharpe ratio (RF=3%)	-0.013	-0.221	-0.089	0.028	-0.015	0.128	-0.018	0.135	0.306	-0.216
m_3	-1.30	-1.18	-0.62	-1.26	-0.58	-0.66	-0.32	0.61	-1.69	-0.93
m_4	14.95	11.31	7.78	12.52	5.92	9.76	7.22	7.53	14.55	10.02
J.B.	3704.21*	1847.20*	602.15*	2400.03*	244.28*	1173.91*	450.70*	545.28*	3587.05*	1304.18*
LB(12)	20.01*	47.30*	26.11*	22.35*	8.97	24.01*	35.28*	22.61*	92.86*	33.98*

Notes: m_3 and m_4 are the coefficients of skewness and kurtosis of the weekly index returns respectively; JB is the statistic for the null of normality; LB(12) denotes the Ljung-Box test statistic for serial correlation with 12 lags respectively. (*) denotes statistical significance at the 5 percent critical level.

Table 4: Correlation coefficients of weekly stock return series

	Czech Republic	Estonia	Germany	Hungary	Poland	Romania	Russia	Slovakia	Slovenia	U.S.
Czech Republic	1	0.300	**0.523**	**0.635**	**0.594**	0.385	**0.460**	0.096	0.367	**0.480**
Estonia	0.300	1	0.296	0.255	0.295	0.216	0.304	0.094	0.272	0.206
Germany	**0.523**	0.296	1	**0.539**	**0.493**	0.194	0.438	0.063	0.296	**0.772**
Hungary	**0.635**	0.255	**0.539**	1	**0.626**	0.252	**0.536**	0.140	0.358	**0.474**
Poland	**0.594**	0.295	**0.493**	**0.626**	1	0.270	0.444	0.087	0.307	**0.480**
Romania	0.385	0.216	0.194	0.252	0.270	1	0.215	0.055	0.357	0.193
Russia	**0.460**	0.304	0.438	**0.536**	0.444	0.215	1	0.080	0.216	0.366
Slovakia	0.096	0.094	0.063	0.140	0.087	0.055	0.080	1	0.077	0.076
Slovenia	0.367	0.272	0.296	0.358	0.307	0.357	0.216	0.077	1	0.277
U.S.	**0.480**	0.206	**0.772**	**0.474**	**0.480**	0.193	0.366	0.076	0.277	1

Table 5: Estimation results from the DCC-GARCH models

Mean equations:

$r_t = \mu + \gamma_1 r_{t-1} + \gamma_2 r_{t-1}^{us,ge,rus} \varepsilon_t$, where $r_t = (r_{1,t}, r_{2,t}, ..., r_{7,t})'$, $\varepsilon_t = (\varepsilon_{1,t}, \varepsilon_{2,t}, ..., \varepsilon_{7,t})'$ and $\varepsilon_t \left| I_{t-1} \sim N(0, H_t). \right.$

Variance equations: $h_{ii,t} = \omega_i + \alpha_{i,1} \varepsilon_{i,t-1}^2 + \beta_{i,1} h_{ii,t-1}$, for i = 1,2,....,7.

$$q_{ij,t} = \bar{\rho}_{ij}(1-a-b) + b q_{ij,t-1} + a \eta_{i,t-1} \eta_{j,t-1}$$

DCC equation: $\rho_{ij,t} = \dfrac{q_{ij,t}}{\sqrt{q_{ii,t}}\sqrt{q_{jj,t}}}$, where $i, j = 1, 2, ..., 7,$ and $i \neq j$.

Panel A. CEE - US

	Czech Republic	Estonia	Hungary	Poland	Romania	Slovakia	Slovenia	U.S.
				Panel A: Mean equations				
	0.003*	0.003*	0.003*	0.002*	0.004*	0.000	0.002*	0.001
M	(2.722)	(2.490)	(2.546)	(2.398)	(2.596)	(0.175)	(3.232)	(1.473)
	-0.105*	0.142*	-0.139*	-0.054	0.044	-0.016	0.129*	-0.112*
	(-3.425)	(3.996)	(-3.957)	(-1.651)	(1.200)	(-0.396)	(3.619)	(-2.963)
	0.179*	0.149*	0.229*	0.184*	-0.007	-0.001	0.058*	---
	(3.772)	(3.345)	(4.069)	(4.038)	(-0.114)	(-0.012)	(1.967)	
				Panel B: Variance equations				
	0.000*	0.000*	0.000*	0.000	0.000	0.000*	0.000*	0.000
Q	(1.989)	(3.761)	(1.858)	(1.767)	(1.353)	(2.526)	(2.865)	(0.874)
γ_1	0.097*	0.206*	0.104*	0.091*	0.074*	0.252*	0.138*	0.066*
A	(3.693)	(5.350)	(2.967)	(4.372)	(2.531)	(4.368)	(4.107)	(4.486)
	0.869*	0.761*	0.872*	0.895*	0.916*	0.749*	0.828*	0.937*
B	(21.83)	(21.08)	(19.09)	(36.44)	(25.12)	(15.67)	(21.83)	(61.35)
Pers.	0.966	0.967	0.976	0.986	0.99	1.00	0.966	1.00
				Panel C: Multivariate DCC equation				
A				0.009* (2.571)				
B				0.970* (47.169)				

Panel B. CEE - GE

	Czech Republic	Estonia	Germany	Hungary	Poland	Romania	Slovakia	Slovenia
				Panel A: Mean equations				
	0.003*	0.003*	0.003*	0.004*	0.003*	0.004*	0.000	0.003*
μ	(3.032)	(2.844)	(3.276)	(3.219)	(2.703)	(2.426)	(0.193)	(3.152)
	-0.094*	0.146*	-0.050	-0.176*	-0.048	0.029	-0.018	0.119*
	(-2.887)	(3.453)	(-1.373)	(-4.966)	(-1.486)	(0.766)	(-0.376)	(3.072)
γ_1	0.086*	0.077*	---	0.172*	0.097*	0.053	0.009	0.042*
γ_2	(2.829)	(2.695)		(4.327)	(3.255)	(1.171)	(0.280)	(1.833)
				Panel B: Variance equations				
	0.000*	0.000*	0.000*	0.000*	0.000*	0.000	0.000*	0.000*
ω	(2.452)	(3.461)	(2.628)	(2.561)	(2.030)	(1.588)	(2.628)	(2.858)
	0.108*	0.192*	0.151*	0.230*	0.095*	0.090*	0.252*	0.145*
a	(4.175)	(4.972)	(4.239)	(3.799)	(4.628)	(3.134)	(4.281)	(5.235)
	0.837*	0.777*	0.826*	0.670*	0.888*	0.894*	0.747*	0.820*
β	(19.17)	(21.01)	(19.88)	(7.618)	(34.91)	(23.78)	(15.15)	(24.67)
Pers.	0.945	0.969	0.977	0.900	0.983	0.984	0.999	0.965
				Panel C: Multivariate DCC equation				
a				0.014* (3.325)				
b				0.912* (20.861)				

Panel C. CEE - RUS

	Czech Republic	Estonia	Hungary	Poland	Romania	Russia	Slovakia	Slovenia
				Panel A: Mean equations				
M	0.003* (2.653)	0.003* (2.613)	0.003* (2.473)	0.002* (2.163)	0.004* (2.369)	0.005* (2.292)	0.000 (-0.015)	0.002* (3.233)
γ_1	-0.088* (-2.608)	0.131* (3.270)	-0.114* (-3.498)	-0.044 (-1.289)	-0.001 (-0.001)	0.090* (2.351)	-0.020 (-0.524)	0.123* (2.792)
γ_2	-0.003 (-0.149)	-0.004 (-0.233)	-0.023 (-0.785)	-0.003 (-0.155)	0.041 (1.490)	---	0.028* (1.847)	-0.008 (-0.709)
				Panel B: Variance equations				
Ω	0.000* (2.095)	0.000* (3.585)	0.000 (1.487)	0.000* (1.901)	0.000 (1.424)	0.000* (2.777)	0.000* (2.686)	0.000* (3.835)
A	0.104* (3.680)	0.190* (4.999)	0.108* (2.612)	0.085* (4.238)	0.084* (2.432)	0.149* (5.725)	0.237* (3.877)	0.139* (5.477)
B	0.850* (18.51)	0.783* (22.85)	0.865* (14.72)	0.900* (37.45)	0.901* (20.50)	0.838* (31.46)	0.753* (14.71)	0.824* (31.54)
Pers.	0.954	0.973	0.973	0.985	0.985	0.987	0.990	0.963
				Panel C: Multivariate DCC equation				
A				0.007* (2.272)				
B				0.958* (34.441)				

Notes: (*) denotes statistical significance at the 5%, and 1% levels, respectively. Numbers in parentheses are Z-statistics.

Table 6: Dynamic Conditional Correlations statistics

	Average	Standard Deviation	Trend (*1000)	t-statistic	Δρ
Panel A: US - CEE Dynamic Conditional Correlations					
Czech Republic	0.460505	0.060639	0.18	14.40052	26.23%
Estonia	0.20528	0.054049	0.158	14.05662	58.97%
Hungary	0.468691	0.035162	0.0675	8.471359	8.91%
Poland	0.476008	0.035184	0.0883	11.57342	11.62%
Romania	0.1712	0.068145	0.226	16.80191	128.40%
Slovakia	0.071311	0.028967	0.0356	5.238905	34.70%
Slovenia	0.251996	0.058242	0.12	9.160044	32.77%
Panel B: GERMANY - CEE Dynamic Conditional Correlations					
Czech Republic	0.516741	0.048698	0.114	10.66337	14.00%
Estonia	0.298586	0.047738	0.0958	8.900177	20.99%
Hungary	0.537865	0.031413	0.0393	5.329694	4.42%
Poland	0.491964	0.036085	0.0836	10.51237	10.59%
Romania	0.18896	0.060117	0.171	13.53175	72.97%
Slovakia	0.060219	0.027692	0.014	2.118791	14.82%
Slovenia	0.28802	0.053598	0.0918	7.460731	20.83%
Panel C: RUSSIA - CEE Dynamic Conditional Correlations					
Czech Republic	0.153217	0.031135	0.00137	0.182778	0.53%
Estonia	0.233142	0.036567	0.0399	4.631142	10.68%
Hungary	0.13084	0.038236	0.0514	5.758192	26.34%
Poland	0.157858	0.028897	0.0176	2.545682	6.81%
Romania	0.225238	0.033213	0.0397	5.085543	11.01%
Slovakia	0.012306	0.029671	0.0806	12.79217	412.80%
Slovenia	0.147058	0.02338	0.0254	4.604425	10.77%

Note: "Trend" is the slope coefficient of a regression of conditional correlations $\rho_{ij,t}$ on a constant and a time trend. t-ratio is the associated t-statistic. Δρ is the difference between the last and first fitted values of a regression of conditional correlations on a constant and a zero-mean time trend.

Table 7: Dynamic correlation, volatility and the crises periods

The results are derived by estimating the regression $\rho_{ij,t} = \omega + \beta_j h_{t,j} + \beta_i h_{t,i} + \sum_{k=1}^{3} \alpha_k DM_{k,t} + \varepsilon_{ij,t}$, where i = US, Germany, Russia and j = Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia and Slovenia. $\rho_{ij,t}$ is the dynamic conditional correlation between the CEE and the developed stock markets, h_t is the conditional volatility, $DM_{k,t}$ are dummy variables for three crises periods: crisis in Asia and Russia (21/11/1997-30/10/1998), the dot-com bubble (10/03/2000-27/09/2002) and the 2008 stock market crash (Lehman Brothers collapse) (26/09/2008-End of sample period).

	Constant	$h_{t,j}$	$h_{t,i}$	$DM_{1,t}$	$DM_{2,t}$	$DM_{3,t}$	R^2
Panel A: US - CEE Dynamic Correlation							
Czech Republic	0.4518	26.8830	-25.6921	-0.0114	-0.0409	0.1570	0.7064
	(167.5967)	(10.8383)	(-5.5861)	(-2.2529)	(-10.4878)	(10.7022)	
Estonia	0.1941	-0.1436	21.6331	-0.0908	-0.0002	0.0968	0.5771
	(71.7178)	(-0.1842)	(5.2074)	(-12.2794)	(-0.0478)	(6.6663)	
Hungary	0.4546	4.8028	13.4071	-0.0295	-0.0226	0.0768	0.6948
	(294.3139)	(8.4810)	(5.5789)	(-8.8708)	(-9.8775)	(9.5756)	
Poland	0.4680	3.3021	7.7047	0.0133	-0.0289	0.0998	0.6337
	(262.5993)	(2.8130)	(2.8696)	(3.7649)	(-11.6006)	(11.2708)	
Romania	0.1670	3.7243	11.9017	-0.0547	-0.0679	0.1988	0.7240
	(52.7495)	(2.7418)	(2.6289)	(-9.4868)	(-16.2659)	(13.3178)	
Slovakia	0.0707	-1.7145	-11.4994	0.0083	0.0274	0.1079	0.3034
	(35.2715)	(-1.5971)	(-4.0790)	(2.2422)	(9.7919)	(10.7496)	
Slovenia	0.2438	22.4688	-10.9162	-0.0005	-0.0187	0.1917	0.6986
	(99.3207)	(6.7154)	(-2.4331)	(-0.0919)	(-4.7225)	(13.5312)	
Panel B: GERMANY - CEE Dynamic Correlation							
Czech Republic	0.4944	23.5125	-3.4710	-0.0300	-0.0040	0.0664	0.5788
	(208.7033)	(10.6965)	(-2.2669)	(-6.1874)	(-1.2317)	(5.4230)	
Estonia	0.2785	0.4135	15.8548	-0.0855	0.0131	0.0535	0.6965
	(159.9406)	(0.6504)	(14.2081)	(-14.9072)	(4.8564)	(6.7004)	
Hungary	0.5254	1.0716	8.0738	-0.0256	-0.0042	0.0656	0.5818
	(381.2156)	(2.3823)	(9.1679)	(-7.6625)	(-1.9801)	(10.5771)	
Poland	0.4866	-4.0275	4.4531	0.0107	-0.0025	0.1200	0.4866
	(240.8992)	(-2.6781)	(3.8292)	(2.4613)	(-0.9463)	(15.1881)	
Romania	0.1744	6.0506	3.7108	-0.0334	-0.0351	0.1788	0.6515
	(60.0254)	(4.9717)	(2.4481)	(-5.8759)	(-9.6253)	(15.1256)	
Slovakia	0.0561	-1.1353	3.5298	0.0019	-0.0036	0.0297	0.1210
	(28.4103)	(-0.9935)	(3.4086)	(0.4769)	(-1.3630)	(3.7485)	
Slovenia	0.2759	30.9126	-7.9724	-0.0118	-0.0005	0.1505	0.7132
	(141.9495)	(11.0302)	(-5.9314)	(-2.6420)	(-0.1582)	(13.0992)	
Panel C: RUSSIA - CEE Dynamic Correlation							
Czech Republic	0.1340	9.5416	2.4685	-0.0182	-0.0100	-0.0082	0.5245
	(85.2129)	(6.4342)	(9.6144)	(-4.5401)	(-4.6201)	(-0.9760)	
Estonia	0.2351	1.9092	-4.0280	0.0759	0.0130	0.1353	0.4407
	(141.8093)	(2.7639)	(-13.2295)	(12.8536)	(4.7127)	(18.2365)	
Hungary	0.1128	16.2212	-0.5411	-0.0875	-0.0173	-0.0019	0.6569
	(77.6707)	(18.7722)	(-1.6532)	(-21.4401)	(-7.6568)	(-0.3164)	
Poland	0.1450	6.5345	2.3057	-0.0608	-0.0090	0.0099	0.4584
	(88.9390)	(4.5700)	(8.5367)	(-15.6929)	(-4.2341)	(1.7109)	
Romania	0.2188	-2.4174	2.4476	0.0055	-0.0132	0.0767	0.4767
	(110.6488)	(-2.4091)	(8.4429)	(1.2514)	(-5.4557)	(10.4886)	
Slovakia	0.0166	-1.2931	-2.1502	0.0022	0.0128	0.1185	0.4484
	(10.6488)	(-1.2250)	(-9.6934)	(0.5437)	(5.7635)	(19.7720)	
Slovenia	0.1357	7.7716	2.2160	-0.0418	0.0000	-0.0115	0.4508
	(119.1195)	(4.7123)	(11.8238)	(-13.1928)	(0.0063)	(-1.6677)	

Table 8: Dynamic correlation and Macroeconomic variables

	CEE				US			Exchange rate	Mean R^2
	Industrial Production	Interest Rate	Money Supply	Credit Rating	Industrial Production	Interest Rate	Money Supply		
Czech Republic	14	69	9	10	7	59	7	8	54,70%
Estonia	3	78	7	0	9	84	12	6	68,98%
Hungary	1	57	0	8	4	86	5	5	54,73%
Poland	7	52	3	35	9	64	23	22	47,82%
Romania	1	76	7	5	13	74	33	27	49,74%
Slovakia	3	47	5	4	34	52	28	13	43,93%
Slovenia	5	58	15	0	1	82	21	19	59,53%

Notes: The results are derived by estimating the regression

$$\rho_{ij,t} = \omega + \alpha_1 IP_{t,cee} + \alpha_2 IR_{t,cee} + \alpha_3 M2_{t,cee} + \alpha_4 CR_{t,cee} + \alpha_5 IP_{t,us} + \alpha_6 IR_{t,us} + \alpha_7 M2_{t,us} + \alpha_8 ER_{t,cee/us} + \varepsilon_{ij,t} \ ,$$

where IP, IR, M2, CR and ER stand for the industrial production, interest rate, money supply, credit rating and exchange rate respectively. $\rho_{ij,t}$ is the dynamic conditional correlation between the CEE and the developed stock markets. We applied a rolling regression methodology using a time window of 36 months. Thus we have 5544 (99 rolling periods * 8 factors * 7 CEE markets) estimated coefficients in total. The values in the cells stand for the number of times the t-statistic of each explanatory variable is significant at 5% level of significance. R^2 is the mean adjusted coefficient of determination statistic.

Figure 1: Weekly Returns

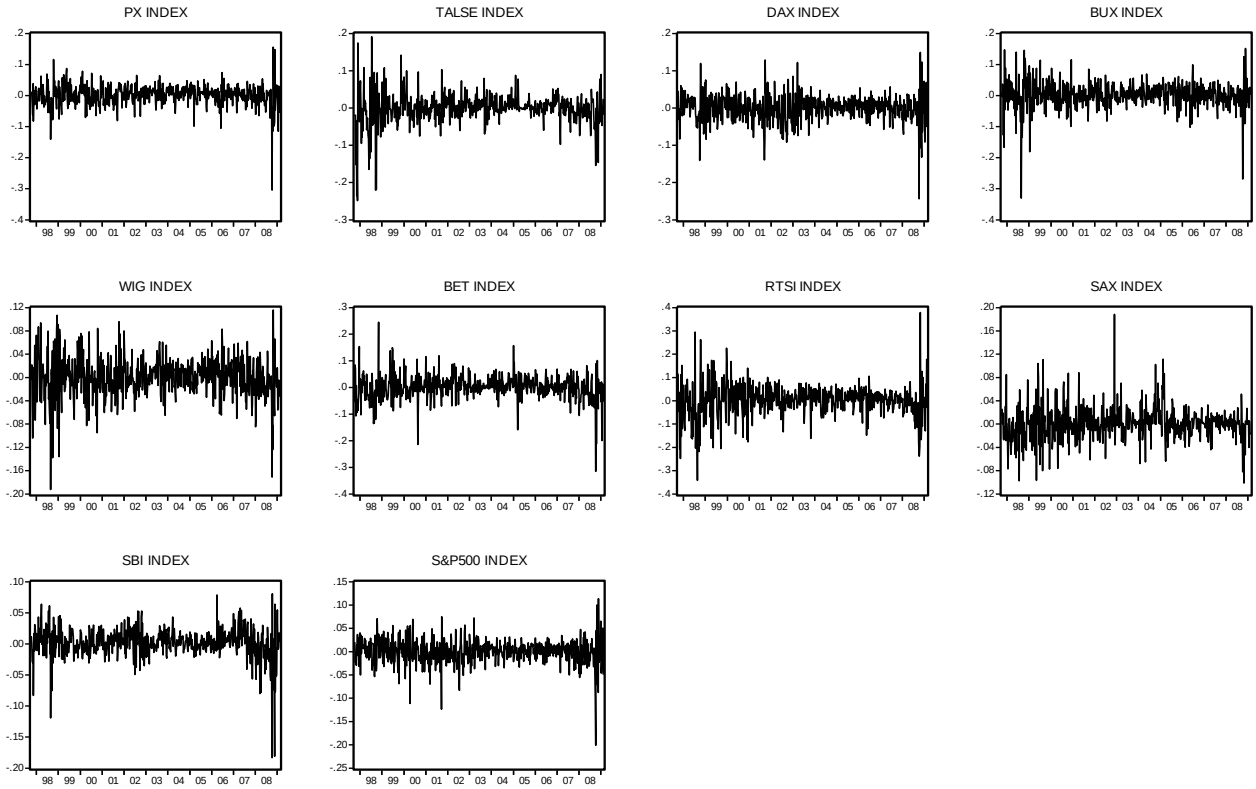

Figure 2: Dynamic Conditional Correlations CEE – US

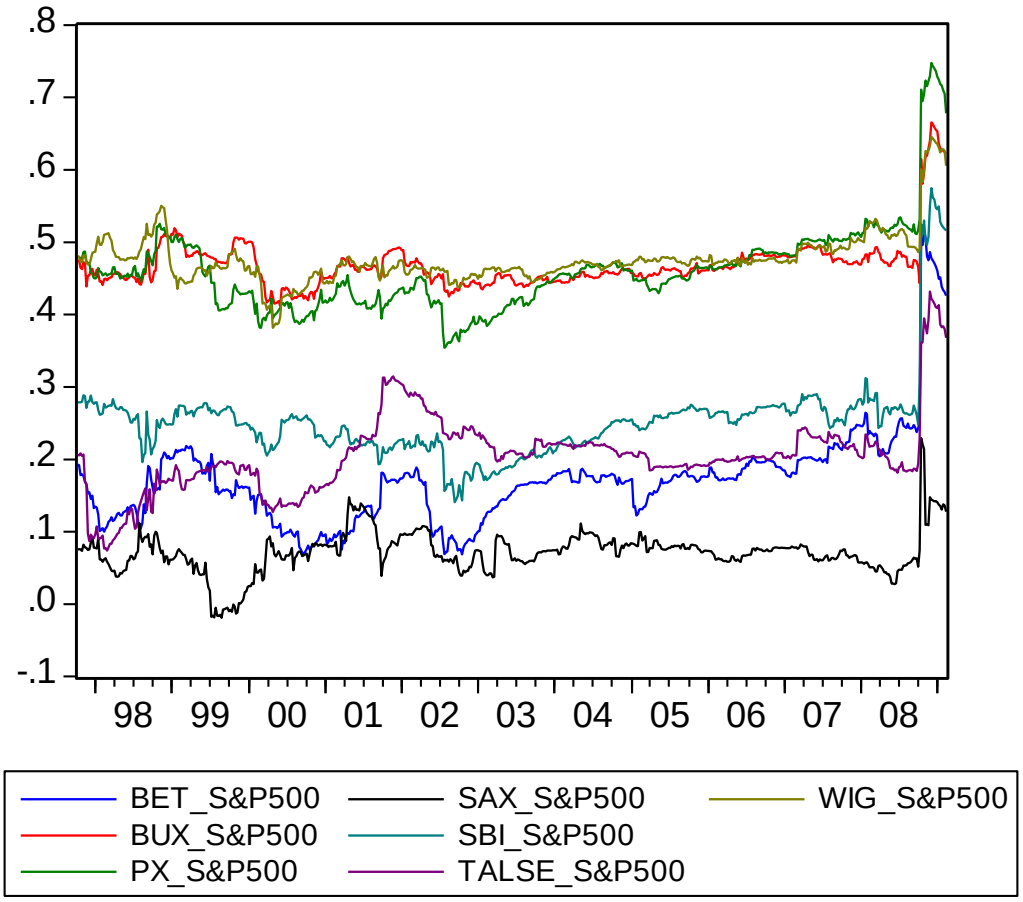

Figure 3: Dynamic Conditional Correlations CEE – GERMANY

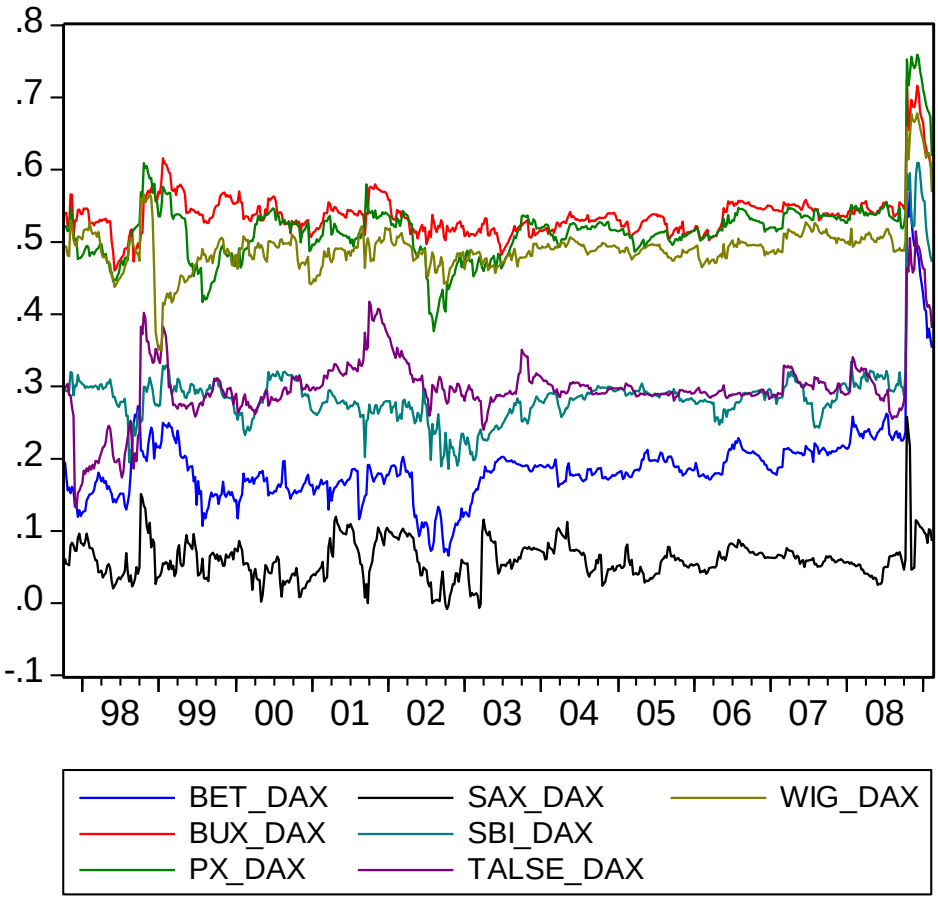

Figure 4: Dynamic Conditional Correlations CEE – RUSSIA