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Weak-form market efficiency and calendar anomalies for Eastern Europe equity markets

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Abstract

In this paper we test the weak form of the efficient market hypothesis for Central and Eastern Europe (CEE) equity markets for the period 1999-2009. To test weak form efficiency in the markets this study uses, autocorrelation analysis, runs test, and variance ratio test. We find that stock markets of the Central and Eastern Europe do not follow a random walk process. This is an important finding for the CEE markets as an informed investor can identify mispriced assets in the markets by studying the past prices in these markets. We also test the presence of daily anomalies for the same group of stock markets using a basic model and a more advanced Generalized Autoregressive Conditional Heteroskedasticity in Mean (GARCH-M) model. Results indicate that day-of-the-week effect is not evident in most markets except for some. Overall results indicate that some of these markets are not weak form efficient and an informed investor can make abnormal profits by studying the past prices of the assets in these markets.

Keywords: Emerging stock markets, day-of-the-week effect , market efficiency, variance ratio test, GARCH-M.

JEL Classification: G12, G14, G22.

1. Introduction

The last decade has seen a rapid economic growth in the CEE countries and their equity markets. This growth has been driven by their integration in the European Union and Foreign Direct Investments inflows (Cartensen and Toubal, 2004; Wolff, 2006). This development of stock markets increase investment options for investors to diversify their portfolios with a view to include these asset classes in their portfolios. Market efficiency of the markets is of important consideration for asset allocations with global perspective.

Market efficiency has important implication for investors who seek to identify appropriate assets to invest in the equity markets. If the equity market is efficient, an attempt to find miss-priced assets to make abnormal profits do not provide any benefits. In efficient markets, prices of the assets will reflect the best estimate of agents in the market regarding the expected risk and the expected return of the assets taking into account the information known about the asset at the time. Therefore there will be no undervalued assets offering higher than expected returns or overvalued assets offering lower than expected return. All assets in the market will be appropriately priced offering optimal reward to risk. However, if the markets were not efficient investors can enhance their risk-adjusted returns by identifying mispriced assets; buying undervalued assets and shorting overvalued assets. Efficient market hypothesis (EMH hereafter) can be argued to provide dual function; first as a theoretical and predictive model of the operations of the financial markets. Second function it may serve is as an instrument for impression management campaign to convince more people to invest their savings in the equity markets (Will 2006).

Understanding of equity markets of the emerging countries is gaining importance with their integration with the developed markets and comparatively free movement of investments across national boundaries. Studies of efficiency in the equity markets among developed countries are numerous and these markets are believed to be at worst weak from efficient and at best semi-strong form efficient. On the contrary studies of market efficiency among emerging markets are few and the results are contradictory.[1] Contribution of equity markets in the process of economic development is much less and that could have resulted in weak markets with restrictions and controls (Gupta 2006).

[1] For a review of early studies of market efficiency see Gupta and Basu (2007).

Following section covers recent studies of market efficiency in emerging markets, especially eastern and central European markets[2]. Literature review is followed by the methodology used and data description. Section 5 documents the findings followed by conclusions.

2. Literature Review

Empirical studies on weak form efficiency in emerging Asian equity markets have found mixed results. Chakraborty (2006), using serial correlation test, runs tests, and variance ratio test, shows that the Pakistan stock market index KSE-100, do not follow the random walk hypothesis. Chang and Thing (2000) show that Lo and MacKinlay variance ratio test rejects random walk hypothesis for Taiwan's Stock market, on the other side that hypothesis cannot be rejected for lower frequency (i.e. monthly and quarterly) returns. Kim and Shamsuddin (2008) using a multiple variance ratio test evaluate the stock market efficiency of nine Asian stock markets grouped in developed, emerging and frontier stock markets. They found that the first and the second one group of stock markets show weak-form efficiency, while the last are found to be inefficient. Mobarek et al. (2008) using parametric and non-parametric tests find that Bangladesh's Stock Exchange (DSE) returns do not follow the random walk model, also the null hypothesis of weak-form efficiency is rejected. Al-Khazali et al (2008) try to find evidence of the weak-form efficient market hypothesis in several emerging markets in the Middle-East and North Africa. Using the new Wright (2000) variance-ratio as well as the classical VR test and the runs test, they found that all markets are weak-form efficiency when returns from the indices are corrected for the statistical biases residing within the published indices.

Study on weak form efficiency in Latin America stock markets (Urrutia (1995), using variance ratio test, showed that Argentinean, Brazilian, Chilean, and Mexican stock prices do not follow a random walk. Whereas Grieb and Reyes (1999), using variance ratio test, show that Brazilian stock market follow a random walk, while Mexican market does not. Ojah e Karemera (1999), among others using a multiple variance ratio test show that major Latin American emerging equity markets follow a random walk.

Using daily data for several Latin America stock market indices, Worthington and Higgs (2008) examined the weak form market efficiency of several Latin American equity markets. The tests they

[2] The review of studies testing market efficiency in the developed markets and early studies of market efficiency in the developing countries have been omitted here for space purposes.

employed include non-parametric and parametric tests, univariate unit-root tests as well as multiple variance ratio test. They conclude rejecting the random walks in any stock market investigated.

Only a few empirical studies have focused on testing the EMH for Central Eastern European equity markets. Nivet (1997) studying the Polish equity index WIG by using its daily returns for the period 1991-1994, shows that the stock market returns do not follow a random walk so the Polish stock market is not efficient in its weak-form. Chun (2000) find evidence that the Hungarian equity market is efficient: univariate test methodology (such as the ADF test as well as the variance ratio test) show that the Budapest Stock Exchange (BSE) follow a random walk. The behaviour of the BSE stock market is relatively closer to the western equity markets than other recently established Eastern European equity markets. The main reasons seem to be the high presence of foreign investors and of cross listed firms. And the variance ratio test is probably sensitive to the high trading volume. Contrary to that Gilmore and McManus (2003), using both univariate and multivariate tests find evidence that daily returns of Hungary, Poland, and the Czech Republic equity markets (for the periods July 1999, through September 2000) do not follow a random walk. This appear to be because of, market imperfections which interfere with the rapid processing of information, and infrequent trading day that could produce some predictability in market returns[3]. The main conclusion of these studies is that Hungarian and Polish equity markets are not yet semi-strong efficient. Rockinger and Urga (2000), evaluate the EMH for several Central Europe equity indexes over the period April 1994 through June 1999 using daily returns: they found that the Hungarian equity market satisfies the weak-form efficiency while the Czech and Polish equity markets are note efficient although moving towards efficiency. Worthington and Higgs (2004) test the random walk hypothesis for both developed and emerging countries (Czech Republic, Hungary, Poland, and Russia) using unit root tests, univariate and multiple variance ratio tests. Among emerging stock markets, only the Hungarian market show evidence of a random walk and hence is a weak-form efficient.

The day of the week effect has been widely studied in developed financial markets (French, 1980; Board and Sutcliffe, 1988; Athanassakos and Robinson, 1994; Agarwal and Tandon, 1994; Kenourgios and Samitas, 2008). Analysing emerging countries other than the developed countries may provide support for or against the proposition that these anomalies are a worldwide phenomenon. Only a few studies have been conducted on emerging markets. Choudhary (2000) finds presence of the day of the week in some Asian markets by using GARCH methodology: this

[3] As pointed out by Abraham et al. (2002), infrequent trading reduce the power of efficiency test particularly for thinly traded emerging markets.

confirm the proposition that these anomalies of the financial markets characterize not only developed markets but also emerging markets. The same methodology has been used by Al-Loughani and Chappell (2001) in order to evaluate the day of the week effect on the Kuwait Stock exchange index. they find evidence that the five trading days follow different processes so confirming the presence of the day of the week effect in the stock market of Kuwait.

Bhattacharya et al. (2003) focus on the Indian stock market by examining the day of the week effect in stock market returns and volatility by using a simple GARCH model: they find that returns have significant positive effect on both Thursday and Friday. At the same time the day of the week effect on volatility is observed in both Monday and Thursday[4].

As a possible explanation of the week effect Fortune (1991) suggest that firms and governments release good news during market trading, when it is readily absorbed, and store up bad news after the close on Friday when investors cannot react until Monday opening.

Because it is reasonable to expect market efficiency as well as day-of-the week effect to evolve over time due to factors such as institutional and regulatory changes, in this study the approach adopted is to partition the sample period into sub-periods on the basis of the accession of these countries to the European Union and observe the changes in test results. Examining the degree of efficiency as well as day-of-the week effect before and after the accession date, we can explore the issue whether the accession has caused stock markets of CEE countries to become more efficient.

3. Empirical methodology

According to Fama (1970), market efficiency under the random walk model implies that successive price changes of a stock are independently and identically distributed, so the past movements of a stock price or market cannot be used to predict its future movements. In order to test the weak-form of EMH many techniques have been applied in empirical studies. Following these studies, a set of complementary tests are used to detect the random walk in the returns of the CEE equity markets. First the parametric autocorrelation test is used to examine whether the consecutive returns are independent of each other. Second a non parametric runs test is also used. Third, the variance ratio tests, are conducted to examine whether uncorrelated increments exists in the series, under the

[4] These authors argue that two reasons may contribute to explain the day of the week in the Indian stock Market. The first one is due to interaction of the banking system with the capital market. The second one may be due to the stock exchange regulations which allow arbitrage opportunities across different stock exchanges in India.

assumptions of homoskedastic and heteroskedastic random walks. Finally, the day of the week effect is tested by using a GARCH (p,q) model.

3.1 Autocorrelation test

Autocorrelation is one of the statistical tools that is used for measuring the dependence of a variable on the past values of itself. Autocorrelation measures the relationship between the stock return at current period and its value in the previous period. It is given as follows:

$$\rho_k = \frac{\sum_{t=1-k}^{n} (r_t - \bar{r})(r_{t-k} - \bar{r})}{\sum_{t=1}^{n} (r_t - \bar{r})^2} \tag{1}$$

where ρ_k is the serial correlation coefficient of stock returns of lag *k*; *N* is the number of observations; r_t is the stock return over period *t*; r_{t-k} is the stock return over period *t-k*; $\bar{r}$ is the mean of stock returns; and *k* is the lag of the period. The test aims to determine whether the serial correlation coefficients are significantly different from zero. Statistically, the hypothesis of weak-form efficiency should be rejected if stock returns (price changes) are serially correlated (ρ_k is significantly different from zero). To test the joint hypothesis that all correlations are simultaneously equal to zero, the Ljung-Box Statistic (Q) is used. Under the null hypothesis of zero autocorrelation at the first *k* autocorrelations ($\rho_1 = \rho_2 = \rho_3 = ... = \rho_k$) the Q-statistic is distributed as a chi-squared with degrees of freedom equal to the number of autocorrelation (*k*). If Q-statistic is significantly different from 0, this means that autocorrelation is present in the sample. Such a result would allow us to reject the null hypothesis that price returns are independent.

3.2 Runs test

Runs test is a non-parametric test that is designed to examine whether successive price changes are independent. A run can be defined as a sequence of consecutive price changes with the same sign. The non-parametric run test is applicable as a test of randomness for the sequence of returns. Accordingly, it tests whether returns in emerging market indices are predictable. The null hypothesis for this test is for temporal independence in the series (or weak-form efficiency): in this perspective this hypothesis is tested by observing the number of runs or the sequence of successive price changes with the same sign, positive, zero or negative. (Campbell et al., 1997). Each change in return is classified according to its position with respect to the mean return. Hereby, it is a positive change when return is greater than the mean, a negative change when the return is less than the mean and zero when the return equals to the mean (Worthington and Higgs, 2004). To perform the runs test, the runs can be carried out by comparing the actual runs R to the expected number of runs (m) using the following equation:

$$m = \frac{N(N+1) - \sum_{i=1}^{3} n_i^2}{N} \tag{2}$$

where N denotes the number of observations (price changes or returns), i the sign of plus, minus, and no change, n_i is the total numbers of changes of each category of signs. For a larger number of observations (N>30), the expected number of runs m is approximately normally distributed with a standard deviation σ_m of runs as specified in the following formula:

$$\sigma_m = \left[\frac{\sum_{i=1}^{3} n_i^2 \left[\sum_{i=1}^{3} n_i^2 + N(N+1) \right] - 2N \sum_{i=1}^{3} n_i^3 - N^3}{N^2 (N-1)} \right]^{1/2} \tag{3}$$

then the standard normal Z-statistic used to conduct a run test is given by:

$$Z = \frac{R - m \pm 0.5}{\sigma_m} \sim N(0,1) \tag{4}$$

where R is the actual number of runs, and 0.5 is the continuity adjustment. As pointed out by Abraham et al. (2002), when actual number of runs exceed (fall below) the expected runs, a positive (negative) Z values is obtained. A negative Z value indicates a positive serial correlation, whereas a positive Z value indicates a negative serial correlation. The positive serial correlation implies that there is a positive dependence of stock prices, therefore indicating a violation of random walk. Since the distribution Z is N(0,1), the critical value of Z at the five percent significance level is ± 1.96.

3.3 Variance-Ratio (VR) tests

The VR procedure (Lo and MacKinlay, 1988) is motivated by the fact that the variance of a random walk term increases linearly with time. The VR approach has gained popularity and has become the standard tool in random-walk testing. The VR test is calculated as follows:

$$VR(q) = \frac{\sigma^2(q)}{\sigma^2(1)} \tag{5}$$

where $\sigma^2(q)$ is the unbiased estimator of 1/q of the variance of the *q-th* difference and $\sigma^2(1)$ is the variance of the first difference.

Under the hypothesis of homoskedasticity, the first test statistic z(q) is expressed as follows:

$$z(q) = \frac{VR(q) - 1}{\sqrt{v(q)}} \sim N(0,1) \quad (6)$$

where $v(q) = [2(2q-1)(q-1)]/3q(nq)$. The second test statistic z*(q) is developed under hypothesis of heteroskedasticity and expressed as follows:

$$z^*(q) = \frac{VR(q) - 1}{\sqrt{v^*(q)}} \sim N(0,1) \quad (7)$$

where

$$v^*(q) = \sum_{k=1}^{q-1} \left[\frac{2(q-k)}{q} \right]^2 \phi(k) \quad (8)$$

and

$$\phi(k) = \frac{\sum_{t=k+1}^{nq} (x_t - x_{t-1} - \hat{\mu})^2 (x_{t-k} - x_{t-k-1} - \hat{\mu})^2}{[\sum_{t=1}^{nq} (x_t - x_{t-1} - \hat{\mu})^2]^2} \quad (9)$$

both the z(q) and z*(q) statistics test the null hypothesis that VR(q)=1 or the chosen index follows a random walk. When the random walk hypothesis is rejected and VR(q)>1, returns are positively serially correlated. As pointed out by Urrita (1995), for emerging markets positive serial correlation in returns could simply describe market growth. When the random walk hypothesis is rejected and VR(q)<1, returns are negatively serially correlated. The situation is often described as a mean-reverting process and consistent. This has been interpreted as a signal of "bubble" in emerging financial markets (Summers, 1986).

3.4 Day of the week methodology

Following Al-Loughani and Chappell (2001), we initially use a standard methodology to test for daily seasonality in stock market returns by estimating the following regression model:

$$R_t = \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \mu_t \quad (10)$$

Where R_t is the rate of return on day *t*, while D_1, D_2, D_3, and D_4 are dummy variables for Monday, Tuesday, Thursday, and Friday respectively (i.e. 1, if *t* is Monday, 0 otherwise, and so on). We exclude Wednesday's dummy variable from the equation to avoid the dummy variable trap, while μ_t is an error term. β_i coefficients are the average returns for Monday through Friday. Under the null hypothesis of no day-of-the-week effect $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$ and the residuals should be independently and identically distributed (IID) random variables. To check the IID assumption, we will use Broch-Dechert-Lebaron-Scheinkman (BDS) test proposed by Brock et al. (1996). If the null hypothesis of IID is rejected then the residual should contain some hidden, possibly non linear, structure (Al-Loughani and Chappel, 2000) which can be due to the time varying volatility of stock returns data.

Possibility of non-linear relationship is tested by fitting a GARCH-M model (Bollerslev, 1987) to the returns series. Gilmore and McManus (2003) and Poshakwale and Murinde (2001) showed significant GARCH effect of Central European stock markets. The methodology followed by these studies is also adapted here, by applying a GARCH-M (1,1) model with the following specification:

$$R_t = \gamma_1 D_{1t} + \gamma_2 D_{2t} + \gamma_3 D_{3t} + \gamma_4 D_{4t} + \lambda\sqrt{h_t} + \varepsilon_t \tag{11}$$

$$\sigma_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \theta_1 \sigma_{t-1} + \sum_{i=1}^{4} \delta_i D_{it} \tag{12}$$

In the equation (11) R_t is the return at time t, D_{it} are dummy variables while significant values of $\gamma's$ imply significant shifts in mean return across days (thus confirming the existence of the day of the week effects), and λ is the market price of risk. The conditional variance equation is function of a constant term ω, news about volatility from the previous period, measured as the lag of the squared residual from the mean equation ε_{t-1}^2 (the ARCH term), the last period forecast variance h_{t-1}, and δ_i coefficients that measure the seasonality in volatility of the market.

4. Data

The data set consists of stock market indices for Poland, Hungary, the Czech Republic, Slovakia, Romania, Bulgaria, and Slovenia. The data used are daily price indices[5] and cover the period January 1, 1999 to January10, 2009. All data are obtained from *Thomson Financial Datastream* (see table 1 in Annexure A). In order to obtain a better understanding of the behaviour of stock prices, a preliminary analysis of the data is carried out in this section. Figure 1 (see Annexure B) shows the plot of the return data based on CEE indices covering the aforesaid period. It is clear from this plot that the data exhibit strong volatility.

[5] Daily data have been used following the suggestion of Fama (1991, p. 1607) which argue that "*The cleanest evidence on market efficiency comes from event studies, especially event studies on daily returns*".

Table 2 (see Annexure A) shows summary statistics for the log of the first differences of the stock price indices (continuously compounding returns[6]). For the period considered, the CEE stock markets experienced positive returns. The lowest mean return is observed in Slovenia, and the highest mean returns are for the Slovak index returns. The market risk measured using standard deviation is significantly higher in Bulgaria, and lowest in Slovenia. Mean return of the Slovak index is higher than the other indices considered in this study. The standard deviation of the Slovenian index is the lowest as compared with other indices suggesting a lower risk. All indices are negatively skewed and have positive kurtosis indicating a fatter-tailed distribution than normal. Deviation from normality for all indices are confirmed by the Jarque-Bera test statistic. The leptokurtic behaviour of the data is confirmed by the normal quintile and empirical density graph presented in Figure 2 and 3 (see Annexure B).

Table 3 (see Annexure A) reports descriptive statistics for continuously compounded daily returns of the CEE market indices. The lowest average returns are observed on Monday and Tuesday for Bulgaria and Slovenia, on Wednesday for the Czech Republic and Romania, on Thursday for Bulgaria and on Friday for Czech Republic and Hungary. The highest returns are observed on Monday for the Romania (0.0004), on Tuesday for Romania (0.0008), on Wednesday for Bulgaria (0.0019), on Thursday for the Czech Republic and Slovakia, and on Friday for Slovenia (0.0015) and Slovakia (0.0015). The highest standard deviation is found on Mondays for Bulgaria. The lowest standard deviation is found on Fridays for Slovenia.

5. Empirical findings

Although none of the countries here considered is a Euro area[7] member (except for Slovenia), we want to detect if their accession to the European Union as new member states[8] influenced our empirical results. In order to verify this hypothesis, we split our sample in two sub-samples: the first one covers the period before the accession to the European Union, while the other one covers the post accession period.

The first approach in testing for the random walk of the CEE equity market returns is the autocorrelation test with a maximum of 20 lags. Results are summarised in tables 4, 5, and 6 Considering the full sample (table 4), it is found that the null hypothesis of random walk is rejected

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[6] They were computed as $R_t = \ln P_t - \ln P_{t-1}$, where P_t is the daily price of stock market index at time *t*.

[7] Euro area refers to the countries that have adopted Euro as their official currency.

[8] On May 1, 2004 ten new member states joined the European Union (EU): among them Czech Republic, Hungary, Poland, Slovakia, and Slovenia. On January 1, 2007 Bulgaria and Romania also joined to EU.

for Bet, Bux, Px50, Sax16, Sbi, and Sofix stock markets: the autocorrelations at all lags are larger with *p-value* near to zero. This implies that the relationship between the stock returns at current period and its value in the previous period is significant. For the Pre-accession sample returns (table 5), we reject the null hypothesis of no autocorrelation for Bet, Sbi, and Sofix stock market returns. This means that the random walk hypothesis is rejected for these markets. The post Accession EU sample estimates (table 6) shows evidence against the random walk hypothesis for all stock returns. On the basis of the empirical results obtained from the autocorrelation tests for the observed returns, we argue that most CEE markets do not exhibit weak form efficiency, especially after these markets joined the European Union.

The Runs test is considered more appropriate than the autocorrelation test since all observed series do not follow the normal distribution (see the Jarque-Bera tests results in table 2). The results of the runs test for returns on indices for the CEE countries are reported in tables 7, 8, and 9. Considering the full sample (table 7), the runs test results show that the successive returns for all indices except the Hungarian index, are not independent at 5 per cent level (critical value of -1.96). Pre-accession sample results (table 8) indicate that Bux, Sofix and Wig stock market returns follow a random walk. The main conclusion is that during that time, an opportunity to make excess return using past prices existed in the others stock markets. The period after the accession of these countries to the EU, seem to have improved the overall results; 4 out of 7 stock indices satisfy the random walk hypothesis (table 9). All index returns are independent except the Bulgaria, Romania and Slovenia: we also note that the z-statistic of the Romania index gives a border line value (table 9). The implication for the efficient market hypothesis of the Bulgaria, Romania, and Slovenia stock markets is that these markets are not efficient since there is a chance that investors could use historical data to earn extraordinary gains by purchasing and selling stocks. Runs test results show that probably joining to the EU led some CEE to improve the efficiency of their equity markets.
The random walk hypothesis for each of the markets is tested using the Variance Ratio test described previously. The results of the variance ratio tests for CEE stock markets are reported in tables 10, 11, and 12. The variance ratio test is conducted using alternative daily intervals (q= 4, 8, 12, 16, and 20 days) for each index. For all series the differences between z(q) and z*(q) appear to reflect primarily variance clustering, since correcting for heteroskedasticity consistently reduces the size of the variance ratio statistics.

Considering the full sample period (table 10), all estimated value of z(q) and z*(q) indicate that the random walk hypothesis is strongly rejected for Bet stock market index for all five intervals examined. The rejection of the null hypothesis of the homoskedastic but not heteroskedastic random walk is found for Sbi, Sofix, and Wig market returns. These findings indicate the rejection of the null hypothesis of the random walk may be due to heteroskedasticity and therefore they meet at least some of the requirements of a strict random walk. These results indicate that Bet, Sbi, Sofix, and Wig equity markets are not efficient over the period 1999-2009.

Considering Pre-accession EU sample (table 11), we find that RWH is rejected for the Bet returns, and for the Px50 index returns the heteroskedatic random walk hypothesis is rejected but only at higher lags. We also note the rejection of the null hypothesis under homoskedasticity assumption for Sofix returns with lag equals to one. Given that the power of the VR test declines as q increases, so we say that the rejection of the null hypothesis is focused on 2 out 7 indices in the Pre-accession sample.

When the post-accession EU sample is considered (table 12), we find that the RWH is rejected for Sax16, Sbi, Sofix and Wig equity index returns: the rejection seem to be more pronounced for Sax16 and Sofix indices, but less pronounced for Sbi and Wig indices because of the null of a random walk under the assumption heteroskedasticity cannot be accepted at some cases of q. Moreover the evidence against the null hypothesis under the assumption of heteroskedasticity in the case of Bet and Bux indices is weak because only one rejection for each of them is reported (at q=4 and q=8 respectively).

Table 13 reports the day of the week effect in relation to the full sample. The results show that the day of the week effect is not typical for Central and Eastern Europe stock markets except for Polish, Slovakian, and Slovenian stock markets. Polish stock market has positive and significant Friday returns. On Monday Slovenian stock market returns are negative and significant at the 5 per cent and Friday returns are significant but positive. Slovakian stock market has significant and positive Friday returns.

Table 13a reports the results of the BDS test to the residuals of the basic model. The calculated z-statistics are quite high, indicating that the null hypothesis of IID is rejected at the 5 per cent level. Although, we have significant results for some stock markets they are not long-run efficient since we find significant ARCH effects in equation 10 for all stock markets. These findings suggest that variations in daily returns cannot be explained by the basic (linear) model.

Table 14 presents results from the GARCH-M(1,1) model that investigates the day of the week effect on stock returns and volatility. We find evidence of the day of the week effect in the Polish stock market, given that Monday, Thursday and Friday's returns in the Wig index are statistically significant. Monday, Tuesday and Friday effects are also statistically significant in the Slovenian stock market. Thursday effects are also significant in the Czech equity market. In the remaining indices we did not find evidence of the day of the week effect. Results in table 14 also show significant effect of Monday on conditional variance (volatility) equation for some stock markets. Significant positive Monday effect on volatility is found in Hungarian, Slovakian, Slovenian and Romanian stock markets. Significant positive effect implies that Monday increases stock returns volatility although the sizes of the coefficients are very small. Also in the case of Friday significant effects are found relative to the Slovenian and Bulgarian indices: effects are negative relative to the Bulgarian stock markets, this means that Friday reduces the volatility of the Sofix index. Volatilities from the Slovenian markets are affected by all days of the week considered here. Our results provide evidence of the day of the week effects on stock market volatility. To assess the general descriptive validity of the model, a battery of standard specification tests are employed. Specification adequacy of the first two conditional moments is verified through a serial correlation test of white noise. This test employs the Ljuang-Box Q statistics on the standardized residuals $\left(\varepsilon_t / h^{1/2}\right)$ and standardized squared residuals $\left(\varepsilon^2 / h\right)$. Results show that all equity markets models are free of serial correlation. Absence of serial correlation in the standardized squared residuals imply the lack of need to encompass a higher order ARCH process to all markets.

The estimation results for the GARCH-M specification for pre- and post-accession periods are reported in table 15 and 16. For the pre-accession period (table 15), the Polish stock market has the highest rate of return on Thursdays and Fridays. The day of the week effect is found on Thursdays in the Hungarian stock market. Monday volatility is significant in two indices out of seven. Results in table 15 show significant effect on all days of the week on conditional variance (volatility equation) of the Slovenian stock market. Post accession results (table 16) show that the day of the week effect is present only on the Slovenian Stock on Mondays. Results also show significant effect of Monday on conditional variance (volatility) of Bulgarian, Czech, Hungarian and Slovenian stock market returns. Tuesday effect is positive and significant for Czech, Slovak and Slovenian indices. Finally, the Ljung-Box Q statistics with 35 lags reject the presence of the auto-correlated residuals for the standardized residuals for almost all GARCH-M models estimated.

6. Conclusions

Our paper investigates the random walk hypothesis as well as the day of the week effect for CEE stock indices by using parametric and non-parametric tests, as well as OLS and conditional variance methodology.

From autocorrelation analyses and runs test we get mixed results: the autocorrelation analysis indicated that the returns of CEE indices are not random walk especially after CEE joined with the EU. Runs test indicates that after joining the EU, CEE stock markets improved their efficiency. Using the Variance ratio test, we find that after the accession to the EU the random walk hypothesis is rejected for two indices, that are the Sax16 and Sofix, out of seven.

The OLS results for day of the week effect, reveal different patterns of daily anomalies among the CEE equity markets. Friday effect feature predominantly among indices in the full sample.

When the GARCH-M model is employed in the full sample, the day of the week effect is present in both volatility and the returns: particularly Mondays and Tuesdays show significant effect in the volatility equation of four out seven indices. Splitting the sample in the pre-accession and post accession period, we see that in the volatility Monday effect tends to be presents in more indices in the post accession than in the pre accession EU period.

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Annexure A

Table 1 – Details of the stock price indices used

Country	Index name	Currency	Datastream Code
Bulgaria	Sofix	Bulgarian Lev	BSSOFIX(PI)
Hungary	Bux	Hungarian Fiorin	BUXINDX(PI)
Poland	Wig	Polish Zlooty	POLWG40(PI)
Romania	Bet	Romanian Leu	RMBETCI(PI)
Slovakia	Sax16	Euro	SXSAX16(PI)
Czech Republic	Px50	Czech krona	CZPX50(PI)
Slovenia	Sbi	Euro	SLOESBI(PI)

Table 2 – Summary statistics of CEE daily returns Full sample

	Sofix	Px50	Bux	Wig	Bet	Sbi	Sax16
Mean	0.000591	0.000306	0.000263	0.000295	0.000597	0.000228	0.000651
Median	5.37e-05	0.000328	0.000000	1.85e-05	0.000113	0.000000	0.000148
St.Dev.	0.018750	0.014986	0.016101	0.014003	0.015484	0.010181	0.012739
Min	-0.208995	-0.161855	-0.126489	-0.084678	-0.121184	-0.113440	-0.112322
Max	0.210733	0.123641	0.131777	0.068039	0.108906	0.110177	0.062300
Skewness	-0.677406	-0.565537	-0.156955	-0.249836	-0.671483	-0.474033	-0.566488
Kurtosis	30.63198	17.65633	10.65509	6.045306	12.30247	25.86454	10.06188
No Obs	2145	2615	2615	2615	2138	2615	2615
JB test	68404.22	23544.52	6395.745	1037.671	7869..57	57059.94	5573.633
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: Daily returns are computed as $R_t=\ln(P_t/P_{t-1})$, where P_t is the price of the index at instant *t*. The Jarque-Bera statistic tests the null hypothesis of a normal distribution and is distributes as a χ^2 with 2 degrees of freedom.

Table 3 – Summary statistics for daily CEE Equity markets returns Full sample

	Monday		Tuesday		Wednesday		Thursday		Friday	
	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St.Dev
Sofix	-0.00003	0.0196	-0.00014	0.0187	0.00193	0.021	-0.0005	0.0187	0.0019	0.0180
Px50	0.0004	0.0148	0.0003	0.014	-0.0004	0.0156	0.0011	0.0153	0.0001	0.0164
Bux	0.001	0.0167	0.0004	0.0153	-0.0014	0.018	0.0003	0.0165	0.001	0.0152
Wig	0.0002	0.0155	0.0001	0.0138	-0.001	0.0137	0.0008	0.0142	0.0013	0.014
Bet	0.0004	0.017	0.0008	0.0165	-0.0003	0.016	0.0009	0.0145	0.0013	0.0144
Sbi	-0.0002	0.0104	-0.0014	0.0114	0.0003	0.0106	0.00096	0.0099	0.0015	0.0092
Sax16	0.0002	0.0136	0.0002	0.0133	0.0004	0.0136	0.0011	0.0128	0.0015	0.0127

Table 4 - Autocorrelation Function results, Full Sample

	Bet		Bux		Px50		Sax16		Sbi		Wig		Sofix	
Lags	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat
1	0.156	52.10 (0.00)	0.08	16.77 (0.00)	0.062	10.08 (0.001)	0.013	0.466 (0.494)	0.164	70.606 (0.00)	0.050	6.539 (0.011)	-0.026	1.441 (0.230)
2	0.032	54.33 (0.00)	-0.062	26.92 (0.00)	-0.042	14.63 (0.001)	0.013	0.883 (0.643)	-0.029	72.785 (0.00)	-0.001	6.542 (0.038)	0.095	21.004 (0.00)
3	0.018	55.03 (0.00)	-0.035	30.20 (0.00)	-0.043	19.40 (0.00	-0.018	1.739 (0.628	-0.030	75.106 (0.00	0.017	7.327 (0.062	0.008	21.153 (0.00
4	-0.043	59.02 (0.00)	0.067	42.01 (0.00)	0.021	20.60 (0.00)	-0.041	6.105 (0.191)	-0.010	75.370 (0.00)	0.005	7.383 (0.117)	0.040	24.650 (0.00)
5	0.017	59.61 (0.00)	0.013	42.46 (0.00)	0.038	24.42 (0.00)	0.042	10.835 (0.055)	-0.003	75.393 (0.00)	0.031	9.878 (0.079)	0.009	24.813 (0.00)
6	-0.003	59.62 (0.00)	-0.042	46.98 (0.00)	-0.018	25.23 (0.00)	0.008	10.990 (0.089)	0.014	75.924 (0.00)	-0.008	10.048 (0.123)	0.065	33.926 (0.00)
7	0.054	65.08 (0.00)	0.001	46.98 (0.00)	0.021	26.43 (0.00)	0.019	11.959 (0.102)	0.017	76.639 (0.00)	-0.013	10.525 (0.161)	-0.064	42.685 (0.00)
8	0.041	69.35 (0.00)	0.037	50.56 (0.00)	0.010	26.71 (0.001)	0.051	18.857 (0.016)	0.066	88.081 (0.00)	-0.001	10.526 (0.230)	0.073	54.015 (0.00)
9	0.001	69.35 (0.00)	-0.015	51.19 (0.00)	-0.001	26.71 (0.002)	0.015	19.433 (0.022)	0.004	88.118 (0.00)	0.020	11.538 (0.241)	-0.051	59.681 (0.00)
10	-0.019	70.14 (0.00)	-0.067	62.97 (0.00)	-0.029	28.89 (0.001)	0.028	21.484 (0.018)	-0.003	88.150 (0.00)	0.019	12.439 (0.257)	0.064	68.459 (0.00)
11	0.059	77.60 (0.00)	-0.001	62.97 (0.00)	-0.023	30.25 (0.001)	-0.004	21.523 (0.028)	0.012	88.519 (0.00)	0.003	12.458 (0.33)	-0.026	69.878 (0.00)
12	0.034	80.13 (0.00)	0.008	63.15 (0.00)	0.054	37.85 (0.00)	-0.011	21.844 (0.039)	0.018	88.366 (0.00)	-0.007	12.595 (0.399)	0.074	81.818 (0.00)
13	0.075	92.10 (0.00)	-0.049	69.59 (0.00)	0.034	40.88 (0.00)	0.055	29.859 (0.005)	0.087	109.21 (0.00)	0.025	14.243 (0.357)	0.063	90.518 (0.00)
14	0.061	100.17 (0.00)	-0.037	73.13 (0.00)	0.014	41.43 (0.00)	0.031	32.375 (0.004)	0.091	130.86 (0.00)	0.002	14.254 (0.431)	0.015	90.973 (0.00)
15	0.055	106.57 (0.00)	0.01	73.37 (0.00)	0.005	41.49 (0.00)	-0.026	34.176 (0.003)	0.056	139.06 (0.00)	0.034	17.373 (0.297)	0.036	93.708 (0.00)
16	0.030	108.52 (0.00)	0.035	76.53 (0.00	0.046	46.98 (0.00	0.004	34.209 (0.005	0.086	158.72 (0.00	0.031	19.864 (0.226	0.101	115.57 (0.00)
17	0.031	110.54 (0.00)	0.059	85.57 (0.00)	-0.002	46.99 (0.00)	0.002	34.220 (0.008)	0.07	171.52 (0.00)	-0.022	21.124 (0.221)	-0.024	116.78 (0.00)
18	0.008	110.68 (0.00)	0.025	87.19 (0.00)	0.046	52.59 (0.00)	0.027	36.166 (0.007)	0.054	179.32 (0.00)	-0.008	21.280 (0.266)	0.044	120.90 (0.00)
19	0.054	116.96 (0.00)	0.035	90.37 (0.00)	0.073	66.64 (0.00)	-0.003	36.187 (0.01)	0.048	185.51 (0.00)	0.008	21.465 (0.312)	0.001	120.90 (0.00)
20	0.038	120.04 (0.00)	0.015	90.93 (0.00)	-0.064	77.34 (0.00)	-0.010	36.454 (0.014)	0.011	185.81 (0.00)	-0.021	22.615 (0.308)	0.037	123.83 (0.00)

Table 5 – Autocorrelation Function results Pre Accession EU sample

	Bet		Bux		Px50		Sax16		Sbi		Wig		Sofix	
Lags	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat
1	0.180	52.331 (0.00)	0.019	0.493 (0.482)	0.029	1.171 (0.279)	-0.001	0.009 (0.976)	0.035	1.742 (0.187)	0.028	1.125 (0.289)	-0.090	12.985 (0.00)
2	0.032	53.935 (0.00)	-0.018	0.942 (0.624)	0.014	1.427 (0.490)	-0.007	0.063 (0.969)	-0.044	4.990 (0.105)	-0.016	1.483 (0.476)	0.058	18.342 (0.00)
3	0.017	54.385 (0.00)	-0.057	5.429 (0.143)	-0.001	1.428 (0.699)	-0.043	2.640 (0.45)	-0.050	7.936 (0.047)	0.001	1.484 (0.686)	-0.053	22.842 (0.00)
4	-0.073	62.939 (0.00)	0.01	5.556 (0.234)	0.05	4.981 (0.289)	-0.056	6.948 (0.139)	0.009	8.048 (0.090)	-0.036	3.266 (0.514)	0.006	22.900 (0.00)
5	0.024	63.906 (0.00)	0.005	5.595 (0.348)	-0.032	6.394 (0.270)	0.018	7.384 (0.194)	0.034	9.642 (0.086)	0.009	3.389 (0.640)	0.003	22.911 (0.00)
6	0.030	65.351 (0.00)	-0.017	5.984 (0.425)	0.028	7.467 (0.280)	-0.009	7.505 (0.277)	0.014	9.911 (0.128)	0.006	3.443 (0.752)	0.048	26.713 (0.00)
7	0.062	71.594 (0.00)	-0.028	7.064 (0.422)	0.020	8.026 (0.330)	-0.00	7.505 (0.378)	0.036	11.757 (0.109)	0.010	3.589 (0.826)	-0.069	34.394 (0.00)
8	0.032	73.201 (0.00)	0.031	8.401 (0.395)	0.00	8.027 (0.431)	0.049	10.836 (0.210)	0.072	18.995 (0.015)	-0.012	3.782 (0.876)	0.056	39.514 (0.00)
9	0.020	73.848 (0.00)	0.044	11.111 (0.268)	0.021	8.650 (0.470)	-0.005	10.896 (0.283)	0.037	20.956 (0.013)	-0.009	3.903 (0.918)	-0.065	46.294 (0.00)
10	-0.028	75.079 (0.00)	-0.053	15.019 (0.131)	0.009	8.769 (0.554)	0.016	11.255 (0.338)	-0.059	25.787 (0.004)	0.044	6.655 (0.758)	0.036	48.356 (0.00)
11	0.010	75.226 (0.00)	-0.025	15.898 (0.145)	0.013	9.001 (0.622)	-0.026	12.180 (0.350)	-0.032	27.207 (0.004)	0.011	6.821 (0.813)	-0.066	55.524 (0.00)
12	0.028	76.456 (0.00)	0.002	15.902 (0.196)	0.026	9.968 (0.619)	-0.039	14.352 (0.279)	0.027	28.218 (0.005)	0.028	7.959 (0.788)	0.063	61.896 (0.00)
13	0.055	81.405 (0.00)	-0.024	16.711 (0.213)	0.039	12.086 (0.512)	0.038	16.372 (0.230)	0.041	30.615 (0.004)	0.033	9.465 (0.737)	0.046	65.319 (0.00)
14	0.051	85.612 (0.00)	0.019	17.212 (0.245)	-0.046	15.120 (0.370)	0.010	16.519 (0.283)	0.073	38.071 (0.001)	-0.001	9.466 (0.8)	-0.047	68.853 (0.00)
15	0.041	88.336 (0.00)	-0.013	17.455 (0.292)	0.071	22.153 (0.104)	-0.056	20.882 (0.141)	0.055	42.325 (0.00)	0.035	11.173 (0.740)	0.016	69.250 (0.00)
16	-0.015	88.709 (0.00)	0.013	17.681 (0.343)	0.053	26.109 (0.053)	-0.013	21.124 (0.174)	0.003	42.335 (0.00)	0.032	12.611 (0.701)	0.060	75.147 (0.00)
17	0.022	89.514 (0.00)	0.064	23.372 (0.138)	0.029	27.330 (0.053)	0.010	21.269 (0.214)	0.019	42.841 (0.001)	-0.026	13.541 (0.699)	-0.056	80.182 (0.00)
18	-0.025	90.569 (0.00)	0.057	27.984 (0.062)	0.016	27.682 (0.067)	0.015	21.595 (0.250)	0.049	46.222 (0.00)	-0.020	14.087 (0.723)	0.031	81.798 (0.00)
19	-0.003	90.583 (0.00)	0.035	29.733 (0.055)	0.028	28.805 (0.069)	0.004	21.615 (0.304)	-0.012	46.439 (0.00)	-0.021	14.687 (0.742)	-0.036	83.877 (0.00)
20	0.084	102.1 (0.00)	-0.008	29.820 (0.073)	-0.038	30.824 (0.058)	-0.026	22.564 (0.311)	-0.005	46.469 (0.001)	-0.005	14.723 (0.792)	0.049	87.784 (0.00)

Table 6 – Autocorrelation Function results Post Accession EU sample

	Bet		Bux		Px50		Sax16		Sbi		Wig		Sofix	
Lags	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat	ACF	Q-stat
1	0.111	6.589 (0.01)	0.135	22.232 (0.00)	0.083	8.518 (0.004)	0.047	2.690 (0.101)	0.244	73.075 (0.00)	0.078	7.463 (0.006)	0.127	8.629 (0.003)
2	0.016	6.725 (0.035)	-0.102	34.970 (0.00)	-0.080	16.434 (0.00)	0.064	7.721 (0.021)	-0.021	73.634 (0.00)	0.018	7.849 (0.02)	0.178	25.479 (0.00)
3	0.003	6.729 (0.081)	-0.016	35.300 (0.00)	-0.072	22.761 (0.00)	0.055	11.483 (0.009)	-0.020	74.109 (0.00)	0.040	9.807 (0.020)	0.155	38.2925 (0.00)
4	-0.026	7.099 (0.131)	0.118	52.328 (0.00)	0.002	22.765 (0.00)	-0.003	11.497 (0.022)	-0.024	74.829 (0.00)	0.056	13.712 (0.008)	0.110	44.798 (0.00)
5	-0.011	7.161 (0.209)	0.020	52.821 (0.00)	0.083	31.165 (0.00)	0.108	25.820 (0.00)	-0.028	75.816 (0.00)	0.058	17.892 (0.003)	-0.005	44.812 (0.00)
6	-0.059	9.053 (0.171)	-0.064	57.860 (0.00)	-0.052	34.448 (0.00)	0.053	29.239 (0.00)	0.012	75.992 (0.00)	-0.027	18.789 (0.005)	0.083	48.562 (0.00)
7	0.026	9.422 (0.224)	0.026	58.709 (0.00)	0.024	35.156 (0.00)	0.062	33.907 (0.00)	0.002	75.997 (0.00)	-0.047	21.568 (0.003)	-0.084	52.335 (0.00)
8	0.034	10.062 (0.261)	0.042	60.883 (0.00)	0.018	35.541 (0.00)	0.065	39.106 (0.00)	0.061	80.580 (0.00)	0.012	21.759 (0.005)	0.090	56.690 (0.00)
9	-0.040	10.945 (0.279)	-0.071	67.065 (0.00)	-0.018	35.922 (0.00)	0.062	43.874 (0.00)	-0.019	81.036 (0.00)	0.057	25.791 (0.002)	-0.047	57.886 (0.00)
10	-0.027	11.346 (0.331)	-0.082	75.397 (0.00)	-0.055	39.711 (0.00)	0.057	47.867 (0.00)	0.031	81.187 (0.00)	-0.018	26.212 (0.003)	0.115	65.074 (0.00)
11	0.096	16.388 (00.127)	0.021	75.992 (0.00)	-0.047	42.480 (0.00)	0.049	50.839 (0.00)	0.039	84.057 (0.00)	-0.008	26.291 (0.006)	0.058	66.922 (0.00)
12	0.026	16.752 (0.159)	0.015	76.214 (0.00)	0.070	48.618 (0.00)	0.054	54.415 (0.00)	0.011	84.220 (0.00)	-0.058	30.393 (0.002)	0.076	70.083 (0.00)
13	0.082	20.433 (0.085)	-0.071	82.489 (0.00)	0.035	50.095 (0.00)	0.106	68.228 (0.00)	0.116	100.82 (0.00)	0.013	30.588 (0.004)	0.081	73.638 (0.00)
14	0.056	22.144 (0.076)	-0.087	91.855 (0.00)	0.055	53.851 (0.00)	0.077	75.627 (0.00)	0.102	113.63 (0.00)	0.010	30.705 (0.006)	0.156	86.921 (0.00)
15	0.055	23.801 (0.069)	0.028	92.853 (0.00)	-0.042	56.044 (0.00)	0.047	78.351 (0.00)	0.055	117.34 (0.00)	0.03	31.847 (0.007)	0.059	88.845 (0.00)
16	0.071	26.553 (0.047)	0.055	96.548 (0.00)	0.039	57.921 (0.00)	0.046	80.933 (0.00)	0.138	141.19 (0.00)	0.03	32.944 (0.008)	0.185	107.67 0.00)
17	0.022	26.808 (0.061)	0.057	100.65 (0.00)	-0.024	58.617 (0.00)	-0.021	81.459 (0.00)	0.101	154.01 (0.00)	-0.015	33.227 (0.011)	0.033	108.28 (0.00)
18	0.031	27.322 (0.073)	-0.003	100.67 (0.00)	0.065	63.804 (0.00)	0.058	85.711 (0.00)	0.057	158.05 (0.00)	0.006	33.279 (0.015)	0.045	109.40 (0.00)
19	0.103	33.197 (0.023)	0.036	102.30 (0.00)	0.107	77.998 (0.00)	-0.018	86.125 (0.00)	0.087	167.49 (0.00)	0.051	36.518 (0.009)	0.07	112.13 (0.00)
20	-0.033	33.808 (0.027)	0.031	103.52 (0.00)	-0.081	86.149 (0.00)	-0.025	86.913 (0.00)	0.020	167.99 (0.00)	-0.039	38.451 (0.008)	-0.031	112.67 (0.00)

Table 7 – Results of the Non-parametric Runs Test Full sample

	No Obs	Returns< mean	Returns> mean	Number of Runs (R)	Expected Runs (m)	Z-statistic
Bet	2138	1107	1031	917	1068.64	-6.547**
Bux	2615	1350	1265	1343	1307.11	1.385
Px50	2615	1306	1309	1192	1307	-4.537**
Sax16	2615	1396	1219	1224	1302.50	-3.065**
Sbi	2615	1363	1252	960	1306.14	-13.54**
Sofix	2145	1117	1020	1021	1071.39	-2.510**
Wig	2615	1343	1273	1230	1308.06	-2.877**

Notes. if the Z-statistic is greater than or equal to ± 1.96, then we reject the null hypothesis at 5% level of significance. ** Indicates rejection of the null hypothesis that successive price changes are independent.

Table 8 – Results of the Non-parametric Runs Test Pre Accession EU sample

	No Obs	Returns< mean	Returns> mean	Number of Runs (R)	Expected Runs (m)	Z-statistic
Bet	1608	868	740	679	799.90	-6.045**
Bux	1390	742	648	723	692.82	1.599
Px50	1390	718	672	565	695.23	-6.969**
Sax16	1390	739	651	608	693.21	-4.564**
Sbi	1390	757	633	466	690.46	-12.115**
Sofix	1615	908	699	790	797.97	-0.226
Wig	1391	736	655	725	694.14	1.634

Notes. if the Z-statistic is greater than or equal to ± 1.96, then we reject the null hypothesis at 5% level of significance. ** Indicates rejection of the null hypothesis that successive price changes are independent.

Table 9 – Results of the Non-parametric Runs Test Post Accession EU sample

	No Obs	Returns< mean	Returns> mean	Number of Runs (R)	Expected Runs (m)	Z-statistic
Bet	530	2270	303	238	260.55	-1.957*
Bux	1225	612	613	620	613.49	0.343
Px50	1225	590	635	627	613.15	0.791
Sax16	1225	658	567	616	613.48	0.116
Sbi	1225	541	684	494	605.15	-6.413*
Sofix	530	212	318	231	255.4	-2.165*
Wig	1225	611	614	628	614.47	0.8

Notes. if the Z-statistic is greater than or equal to ± 1.96, then we reject the null hypothesis at 5% level of significance. ** Indicates rejection of the null hypothesis that successive price changes are independent.

Table 10 - Variance Ratios for Daily Returns Full sample

	Number of days, q, in holding period				
Index	**4**	**8**	**12**	**16**	**20**
Bet	1.268	1.3201	1.400	1.529	1.675
	(6.622)**	(5.004)**	(4.942)**	(5.565)**	(6.282)**
	[3.208]**	[2.568]**	[2.646]**	[3.056]**	[3.508]**
Bux	1.040	1.054	1.046	1.005	1.009
	(1.106)	(0.937)	(0.629)	(0.068)	(0.094)
	[0.576]	[0.515]	[0.354]	[0.039]	[0.054]
Px50	1.03	1.042	1.053	1.087	1.150
	(0.827)	(0.727)	(0.72)	(1.013)	(1.548)
	[0.326]	[0.289]	[0.295]	[0.418]	[0.647]
Sax16	1.026	1.024	1.096	1.16	1.212
	(0.709)	(0.423)	(1.311)	(1.868)	(2.185)**
	[0.562]	[0.330]	[1.028]	[1.483]	[1.754]
Sbi	1.203	1.204	1.268	1.370	1.545
	(5.562)**	(3.541)**	(3.667)**	(4.299)**	(5.611)**
	[1.759]	[1.301]	[1.480]	[1.847]	[2.517]**
Sofix	1.063	1.17	1.238	1.348	1.479
	(1.559)	(2.662)**	(2.939)**	(3.665)**	(4.471)**
	[0.607]	[1.241]	[1.485]	[1.915]	[2.378]**
Wig	1.079	1.115	1.148	1.182	1.223
	(2.179)**	(1.992)**	(2.021)**	(2.115)**	(2.297)**
	[1.677]**	[1.481]	[1.495]	[1.570]	[1.718]

Notes. Variance ratio test results for the sample period from 1 January 1999, to 9 January 2009. The variance ratios are reported in the main rows, with the homoskedasticity z(q) and heteroskedasticity-robust test statistics z*(q) given respectively in (.) and in [.]. Under the random walk null hypothesis, the value of the variance ratio test is 1 and the test statistic have a standard normal distribution (asymptotically). Test statistics marked with ** indicate that the corresponding variance ratios are statistically different from 1 at the 5 percent level of significance.

Table 11 - Variance Ratios for Daily Returns Pre Accession EU sample

	Number of days, q, in holding period				
Index	**4**	**8**	**12**	**16**	**20**
Bet	1.314	1.369	1.459	1.559	1.646
	(6.746)**	(5.001)**	(4.918)**	(5.10)**	(5.215)**
	[4.324]**	[3.417]**	[3.440]**	[3.645]**	[3.792]**
Bux	0.986	0.930	0.921	0.897	0.924
	(-0.279)	(-0.876)	(-0.783)	(-0.864)	(-0.570)
	[-0.217]	[-0.659]	[-0.598]	[-0.673]	[-0.454]
Px50	1.054	1.119	1.176	1.243	1.340
	(1.092)	(1.5)	(1.754)**	(2.064)**	(2.554)**
	[0.937]	[1.281]	[1.5]	[1.772]	[2.203]**
Sax16	0.971	0.886	0.892	0.882	0.869
	(-0.566)	(-1.435)	(-1.073)	(-0.992)	(-0.980)
	[-0.482]	[-1.197]	[-0.9]	[-0.842]	[-0.842]
Sbi	0.986	0.981	1.055	1.126	1.220
	(-0.263)	(-0.233)	(0.555)	(1.07)	(1.652)
	[-0.067]	[-0.079]	[0.22]	[0.477]	[0.797]
Sofix	0.899	0.875	0.855	0.867	0.887
	(-2.157)**	(-1.697)	(-1.549)	(-1.208)	(-0.913)
	[-0.796]	[-0.783]	[-0.785]	[-0.632]	[-0.483]
Wig	1.025	0.985	1.002	1.055	1.104
	(0.498)	(-0.186)	(0.023)	(0.472)	(0.782)
	[0.388]	[-0.145]	[0.018]	[0.375]	[0.629]

Notes. Variance ratio test results for the sub sample period from 1 January 1999, to 30 april 2004 for Czech Republic, Poland, Slovakia, Slovenia and Hungary, and from 1 January 1999 to 30 December 2006 for Bulgaria, and Romania.The variance ratios are reported in the main rows, with the homoskedasticity z(q) and heteroskedasticity-robust test statistics z*(q) given in parentheses immediately below each main row. Under the random walk null hypothesis, the value of the variance ratio test is 1 and the test statistic have a standard normal distribution (asymptotically). Test statistics marked with ** indicate that the corresponding variance ratios are statistically different from 1 at the 5 percent level of significance.

Table 12 - Variance Ratios for Daily Returns Post Accession EU sample

	Number of days, q, in holding period				
Index	**4**	**8**	**12**	**16**	**20**
Bet	1.167	1.151	1.159	1.265	1.43
	(2.059)**	(1.177)	(0.977)	(1.389)	(1.990)
	[1.046]	[0.635]	[0.553]	[0.808]	[1.178]
Bux	1.093	1.169	1.162	1.110	1.1
	(1.742)	(2.001)**	(1.512)	(0.878)	(0.703)
	[0.778]	[0.964]	[0.747]	[0.438]	[0.353]
Px50	1.009	0.979	0.956	0.971	1.016
	(0.185)	(-0.240)	(-0.404)	(-0.230)	(0.116)
	[0.066]	[-0.087]	[-0.150]	[-0.086]	[0.044]
Sax16	1.149	1.359	1.597	1.854	2.078
	(2.803)**	(4.252)**	(5.575)**	(6.795)**	(7.593)**
	[2.226]**	[3.358]**	[4.458]**	[5.50]**	[6.187]**
Sbi	1.338	1.340	1.394	1.514	1.747
	(6.338)**	(4.021)**	(3.678)**	(4.091)**	(5.261)**
	[2.383]**	[1.625]	[1.584]	[1.840]	[2.440]**
Sofix	1.458	1.818	2.024	2.305	2.661
	(5.636)**	(6.364)**	(6.282)**	(6.823)**	(7.691)**
	[2.697]**	[3.134]**	[3.231]**	[3.650]**	[4.246]**
Wig	1.155	1.288	1.339	1.352	1.392
	(2.915)**	(3.408)**	(3.169)**	(2.799)**	(2.760)**
	[2.221]**	[2.396]**	[2.183]	[1.918]	[1.893]

Notes. Variance ratio test results for the sub sample period from 1 May 2004, to 9 January 2009 for Czech Republic, Hungary, Poland, Slovakia, and Slovenia, and from 1 January 2007, to 9 January 2009 for Bulgaria, and Romania. The variance ratios are reported in the main rows, with the homoskedasticity z(q) and heteroskedasticity-robust test statistics z*(q) given respectively in (.) and in [.]immediately below each main row. Under the random walk null hypothesis, the value of the variance ratio test is 1 and the test statistic have a standard normal distribution (asymptotically). Test statistics marked with ** indicate that the corresponding variance ratios are statistically different from 1 at the 5 percent level of significance.

Table 13 – Parameter estimates of basic model full sample

	Bet	Bux	Px50	Sax16	Sbi	Sofix	Wig
β_1	0.0004	0.0004	0.0004	0.0002	-0.0002	-3.42E-05	0.0002
	(0.553)	(0.593)	(0.647)	(0.376)	(-0.5)	(-0.037)	(0.418)
β_2	0.0007	-0.001	0.0003	0.0002	-0.0014**	-0.0001	0.00014
	(0.974)	(-1.934)	(0.529)	(0.377)	(-3.195)	(-0.155)	(0.236)
β_3	0.0009	0.0003	0.001	0.001	0.0009	-0.0004	0.0007
	(1.202)	(0.539)	(1.689)	(1.920)	(2.113)	(-0.532)	(1.293)
β_4	0.001	0.0009	8.86E-05	0.001**	0.0015**	0.0017	0.0013**
	(1.686)	(1.354)	(0.135)	(2.489)	(3.407)	(1.942)	(2.150)
ARCH test							
F-statistic	210.59	264.13	323.61	6.483	652.61	162.50	41.488
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Obs*R^2	191.87	240.06	288.16	6.472	522.55	151.18	40.870
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Skewness	-0.664	-0.139	-0.564	-0.560	-0.439	-0.671	-0.249
Kurtosis	12.270	10.636	17.632	10.001	26.035	30.724	6.065
Jarque-Bera	7812.637	6362.124	23466.26	5476.01	57903.33	68858.51	1051.209
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes. Numbers in parentheses depict the t-statistics. ** significant at 5% level

Table 13a – BDS test statistic on the basic model residuals

Index	ε	m=2	m=3	m=4	m=5	m=6
Bux	0.02	0.015	0.030	0.039	0.049	0.045
		(9.243)	(11.356)	(12.476)	(13.486)	(14.263)
Px50	0.017	0.019	0.041	0.057	0.065	0.068
		(10.85)	(14.948)	(17.342)	(18.987)	(20.853)
Sax16	0.015	0.015	0.033	0.047	0.054	0.057
		(6.765)	(9.445)	(11.256)	(12.209)	(13.361)
SBI	0.01	0.0497	0.088	0.112	0.126	0.131
		(24.325)	(27.086)	(28.867)	(31.134)	(33.567)
Sofix	0.018	0.046	0.087	0.112	0.124	0.128
		(18.173)	(21.274)	(22.870)	(24.231)	(25.915)
Bet	0.018	0.036	0.065	0.083	0.0918	0.0957
		(16.913)	(19.162)	(20.309)	(21.503)	(23.168)
Wig	0.018	0.011	0.022	0.032	0.039	0.042
		(6.749)	(8.472)	(10.118)	(11.652)	(13.043)

Notes. z-statistics in parentheses.

Table 14 – GARCH-M estimates Full Sample

Mean Equation	Wig	Bux	Px50	Sax16	Sbi	Bet	Sofix
γ_1	0.0013**	0.0012	0.0007	-0.0001	-0.0011**	0.0005	0.0002
	(1.971)	(1.748)	(1.263)	(-0.214)	(-3.669)	(0.677)	(0.368)
γ_2	0.0003	0.0007	-3.61E-05	-0.0003	-0.001**	0.0001	-0.0004
	(0.456)	(1.018)	(-0.057)	(-0.500)	(-4.151)	(0.247)	(-0.846)
γ_3	0.0017**	0.0014	0.0013**	0.0006	0.0003	0.0002	2.06E-05
	(2.492)	(1.946)	(2.155)	(0.995)	(1.163)	(0.435)	(0.042)
γ_4	0.0017**	0.0013	0.0005	0.0005	0.0006**	0.001	0.0007
	(2.589)	(1.835)	(1.029)	(1.009)	(2.557)	(0.972)	(1.902)
λ	-0.033	-0.015	0.041	0.038	0.08**	0.062	0.067**
	(-0.865)	(-0.396)	(1.169)	(1.016)	(2.523)	(1.554)	(2.207)
Variance Equation							
ω	-1.74E-06	-2.09E-07	-2.19E-06	-2.49E-05**	-1.22E-05**	1.33E-05**	2.28E-05**
	(-0.182)	(1.637)	(-0.296)	(-5.441)	(-8.469)	(2.658)	(4.559)
α_1	0.065**	0.085**	0.127**	0.05**	0.253**	0.320**	0.164**
	(10.122)	(10.442)	(10.565)	(14.034)	(17.988)	(17.028)	(23.873)
θ_1	0.920**	0.887**	0.846**	0.937**	0.735**	0.609**	0.858**
	(118.94)	(81.853)	(57.730)	(252.71)	(60.653)	(31.358)	(202.29)
δ_1	1.79E-05	-3.20E-05**	9.80E-06	4.98E-05**	2.04E-05**	4.81E-05**	-7.79E-06
	(1.368)	(1.985)	(1.002)	(7.841)	(10.574)	(6.018)	(-1.379)
δ_2	1.79.E-05	-8.19E-06	2.78E-05**	3.92E-05**	3.63E-05**	9.14E-06	-2.39E-05**
	(0.01)	(-0.407)	(2.329)	(4.564)	(12.068)	(0.804)	(-2.824)
δ_3	1.32E-05	1.98E-05	1.77E-05	4.53E-05**	1.23E-05***	-1.33E-05	-3.79E-05**
	(0.864)	(-0.866)	(1.382)	(5.988)	(-4.922)	(-1.771)	(-4.72)
δ_4	-9.11E-06	-1.30E-05	-1.70E-05	-5.68E-07	1.10E-05**	3.15E-06	-3.40E-05**
	(-0.763)	(-0.815)	(-1.727)	(-0.093)	(4.996)	(0.489)	(-5.673)
standadized residual							
Q(35)	44.395	39.358	56.494	35.401	290.38	122.20	97.593
	(0.133)	(0.179)	(0.012)	(0.449)	(0.00)	(0.00)	(0.00)
Standardized residuals squared							
Q(35)	43.635	32.948	26.190	35.930	8.893	37.250	48.881
	(0.150)	(0.568)	(0.889)	(0.425)	(1.00)	(0.366)	(0.060)
ARCH Test							
F-statistic	1.955	0.002	1.843	0.291	1.598	0.128	8.516
	(0.162)	(0.963)	(0.174)	(0.588)	(0.206)	(0.720)	(0.003)
Obs*R^2	1.955	0.002	1.843	0.292	1.598	0.128	8.490
	(0.161)	(0.963)	(0.174)	(0.588)	(0.206)	(0.720)	(0.003)

Notes. ** significant at 5% level.

Table 15 – GARCH-M Estimates Pre-accession EU sample

Mean Equation	Wig	Bux	Px50	Sax16	Sbi	Bet	Sofix
γ_1	0.002	0.002	0.001	-0.0006	-0.0004	-0.0002	-0.0018
	(1.72)	(1.859)	(1.368)	(-0.154)	(-1.103)	(-0.312)	(-1.351)
γ_2	-1.42E-05	8.42E-05	0.0005	-0.0002	-0.001**	0.0003	-0.0008
	(-0.014)	(0.075)	(1.368)	(-0.188)	(-2.642)	(0.505)	(-1.737)
γ_3	0.003**	0.002**	0.0027**	0.0008	0.0005	0.0002	-0.0003
	(2.962)	(2.077)	(3.016)	(0.771)	(1.373)	(0.442)	(-0.762)
γ_4	0.0027**	0.001	0.0013	0.001	0.001**	0.0004	0.0004
	(2.579)	(1.663)	(1.564)	(1.223)	(2.914)	(0.658)	(1.108)
λ	-0.08	-0.046	-0.029	0.008	0.017	0.12**	0.145**
	(-1.433)	(-0.78)	(-0.563)	(0.154)	(0.386)	(2.807)	(4.568)
Variance equation							
ω	1.16E-05	3.19E-05	5.37E-06	-2.35E-05	-2.22E-05***	2.30E-05**	6.97E-06**
	(0.777)	(1.648)	(0.390)	(-1.681)	(-8.88)	(5.116)	(2.772)
α_1	0.053**	0.056**	0.08**	0.04**	0.306**	0.269**	0.159**
	(6.321)	(6.675)	(4.572)	(7.646)	(13.001)	(11.787)	(21.403)
θ_1	0.923**	0.914**	0.887**	0.935**	0.685**	0.669**	0.850
	(80.682)	(64.411)	(35.652)	(121.60)	(30.108)	(29.235)	(161.70)
δ_1	1.94E-05	-1.32E-05	8.95E-06	0.0001**	2.58E-05**	5.33E-06	-4.09E-05**
	(0.840)	(-0.534)	(0.512)	(6.243)	(7.29)	(0.960)	(8.527)
δ_2	-5.74E-05	-3.21E-05	1.84E-05	5.35E-05	6.58E-05**	-1.24E-05	-4.14E-06
	(-1.947)	(-1.057)	(0.890)	(0.239)	(12.37)	(-1.63)	(--0.658)
δ_3	3.10E-06	-3.75-05	-1.07E-05	4.29E-05	2.55E-05**	-3.58E-05**	-1.1E-05**
	(0.136)	(-1.045)	(-0.424)	(1.770)	(5.826)	(-4.169)	(-2.247)
δ_4	-1.57E-06	-4.48E-05	-1.63E-05	-2.28E-05	2.08E-05**	7.20E-06	-1.39E-05**
	(-0.080)	(-1.917)	(-0.891)	(-1.306)	(5.508)	(0.757)	(-3.212)
Standadized residuals							
Q(35)	30.716	21.277	41.285	28.141	105.27	101.23	49.631
	(0.675)	(0.967)	(0.215)	(0.788)	(0.00)	(0.00)	(0.00)
Standardized residuals squared							
Q(35)	32.382	40.229	23.309	32.482	8.383	43.172	41.803
	(0.641)	(0.250)	(0.935)	(0.590)	(1.00)	(0.162)	(0.199)
ARCH Test							
F-statistic	0.305	0.006	0.053	0.08	0.718	0.351	5.657
	(0.580)	(0.934)	(0.816)	(0.777)	(0.396)	(0.553)	(0.017)
Obs*R-squared	0.305	0.006	0.053	0.08	0.719	0.351	5.645
	(0.580)	(0.933)	(0.816)	(0.777)	(0.396)	(0.553)	(0.017)

Notes: Number in parentheses depict the z-statistics. ** significant at 5% level.

Table 16 – GARCH-M estimates, Post Accession EU sample

Mean Equation	Wig	Bux	Px50	Sax16	Sbi	Bet	Sofix
γ_1	0.001	0.0003	0.0004	-8.84E-05	-0.0017**	0.001	-0.0002
	(1.28)	(0.439)	(0.640)	(-0.127)	(-3.363)	(1.132)	(-0.165)
γ_2	0.0003	0.001	-0.0003	-0.0007	-0.001	-0.0003	-0.0012
	(0.375)	(1.4)	(-0.405)	(-0.818)	(-1.907)	(-0.185)	(-0.807)
γ_3	0.0006	0.0008	0.0003	0.0002	9.01E-05	0.0012	-0.0002
	(0.716)	(0.811)	(0.331)	(0.323)	(0.230)	(0.702)	(-0.205)
γ_4	0.001	0.0009	4.54E-06	-1.06E-05	0.0001	0.0028	0.0005
	(1.385)	(0.833)	(0.006)	(-0.014)	(0.273)	(0.702)	(0.474)
λ	0.005	0.016	0.101**	0.08	0.142**	-0.077	-0.015
	(0.106)	(0.31)	(2.027)	(0.147)	(2.949)	(-0.916)	(-0.184)
Variance equation							
ω	1.10E-05	1.30E-05	-8.33E-06	-1.55E-05	-5.65E-06***	3.19E-05***	-1.95E-05
	(-0.833)	(0.773)	(-1.07)	(-3.048)	(-2.48)	(3.20E-05)	(-1.089)
α_1	0.082**	0.115**	0.162**	0.06**	0.225**	0.373**	0.357
	(7.329)	(7.445)	(8.613)	(9.293)	(10.4)	(8.966)	(-1.089)
θ_1	0.906**	0.861**	0.817**	0.901**	0.758**	0.598**	0.595**
	(68.72)	(53.415)	(38.378)	(83.098)	(40.41)	(17.358)	(12.483)
δ_1	1.66E-05	-4.88E-05**	1.10E-05	1.60E-05**	1.76E-05**	9.18E-06	8.87E-05**
	(0.988)	(-2.198)	(0.950)	(2.452)	(6.35)	(0.239)	(3.666)
δ_2	3.99E-05	9.39E-06	3.48E-05**	3.93E-05**	1.68E-05**	2.39E-05	5.26E-05
	(-1.747)	(0.354)	(2.549)	(4.032)	(4.011)	(0.449)	(1.449)
δ_3	1.43E-05	2.95-07	4.23E-05	3.35E-05**	2.85E-06	-131E-05	3.60E-05
	(0.645)	(0.009)	(2.981)	(4.278)	(0.832)	(-0.269)	(1.428)
δ_4	-4.48E-06	-3.58E-06	-1.91E-05	5.39E-06	6.03E-06	3.26E-05	2.86E-05
	(-0.258)	(0.156)	(-1.647)	(0.805)	(1.952)	(-0.887)	(1.396)
Standadized residuals							
Q(35)	39.475	43.858	49.214	52.840	259.29	31.253	67.212
	(0.277)	(0.145)	(0.215)	(0.027)	(0.00)	(0.650)	(0.00)
Standardized residuals squared							
Q(35)	45.156	43.933	24.068	22.486	16.825	16.371	25.596
	(0.117)	(0.250)	(0.918)	(0.950)	(0.996)	(0.997)	(0.845)
ARCH Test							
F-statistic	6.693	0.001	2.344	0.02	0.718	0.037	0.00
	(0.01)	(0.972)	(0.126)	(0.879)	(0.396)	(0.845)	(0.97)
Obs*R-squared	6.668	0.001	2.343	0.02	0.719	0.038	0.00
	(0.01)	(0.972)	(0.125)	(0.879)	(0.396)	(0.845)	(0.97)

Notes: Number in parentheses depict the z-statistics. ** significant at 5% level.

Annexure B

Figure 1 – Daily return in CEE indices

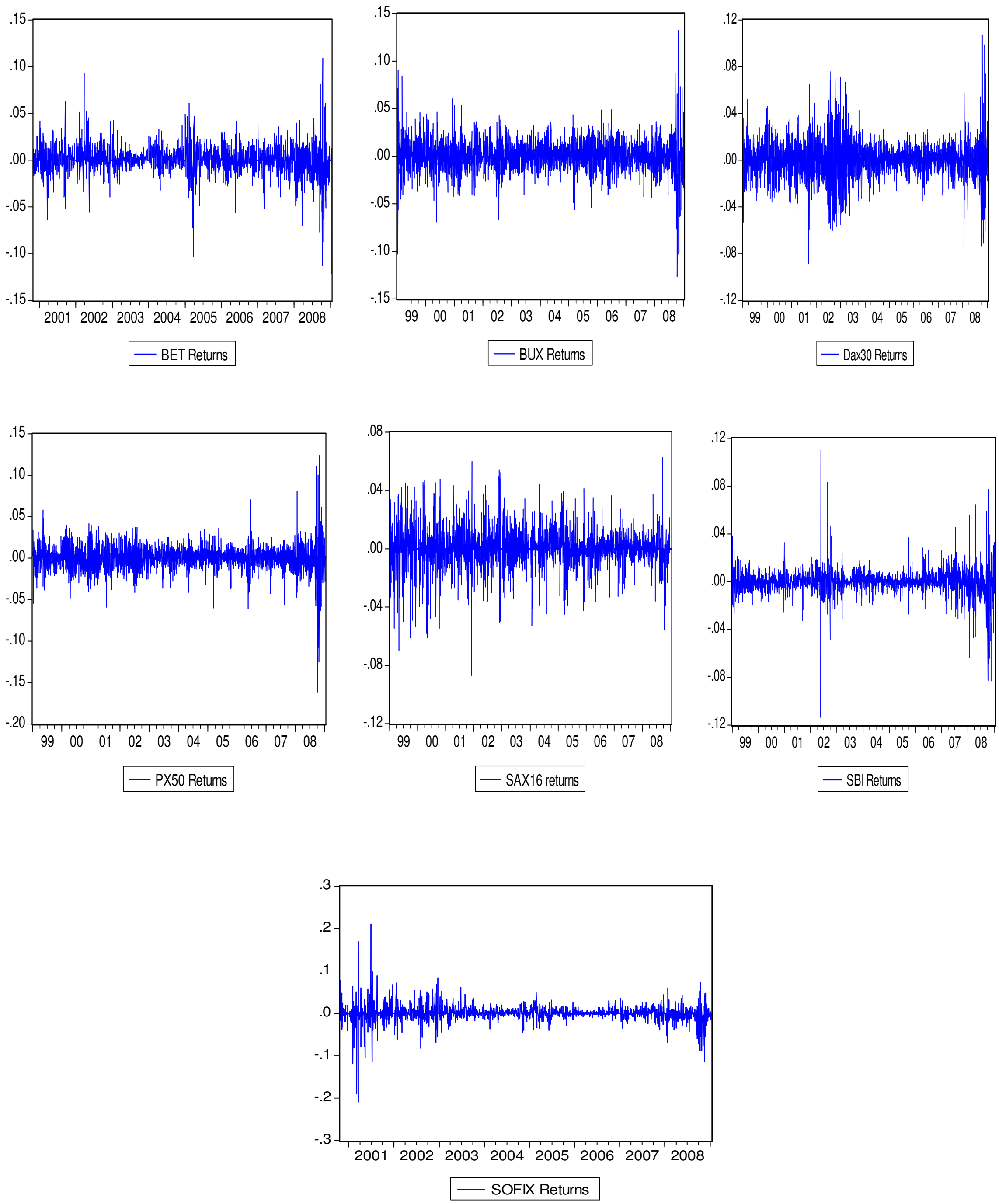

Figure 2 – Normal quantile-quantile (QQ)-plot quantile for CEE stock market returns

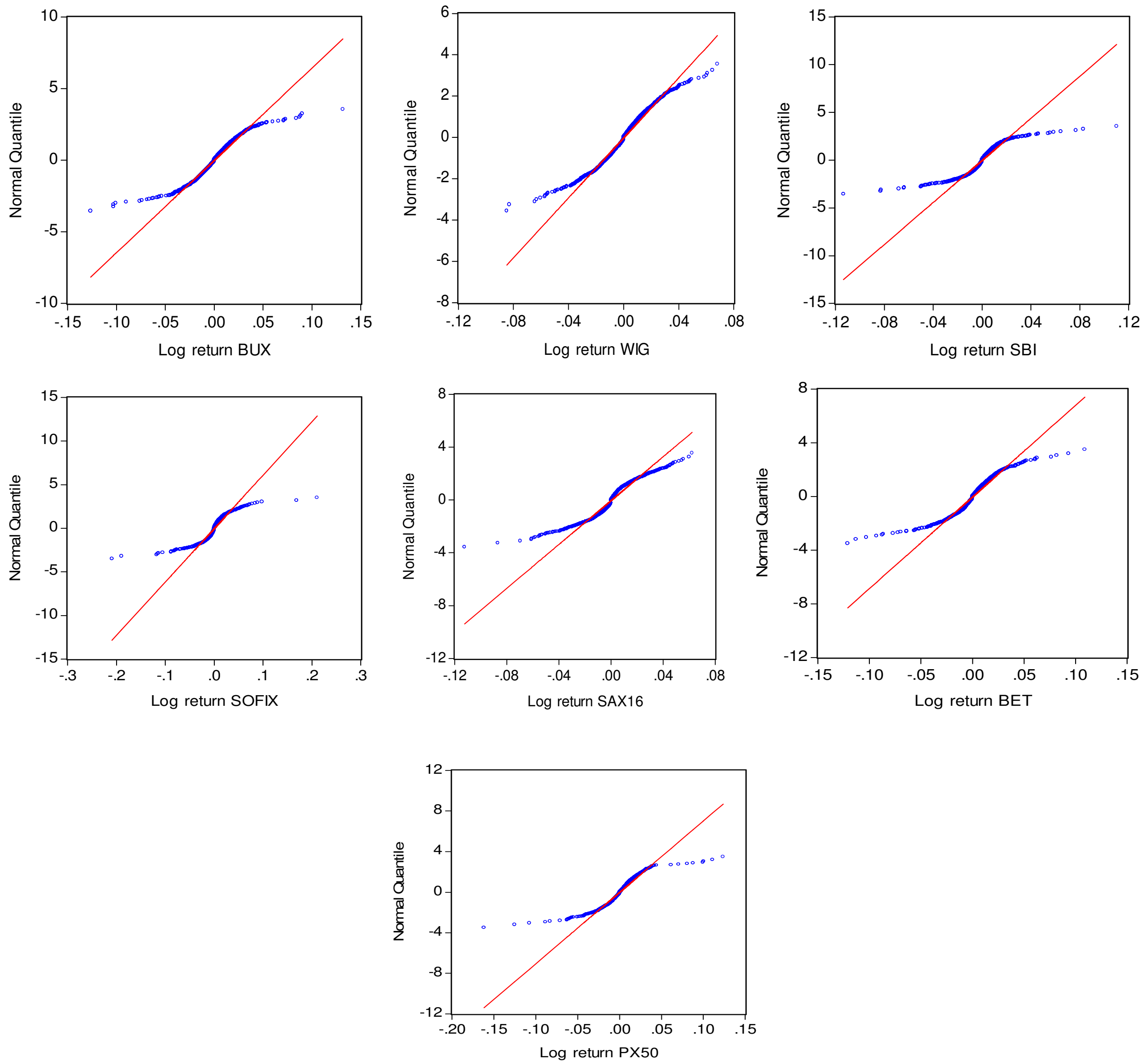

Figure 3 – Normal density graphs for CEE stock market returns