Interdependence between Eastern and Western European Stock Markets: Evidence from Intraday Data

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Abstract

We analyze comovements among three stock markets in Central and Eastern Europe and, in addition, interdependence which may exist between Western European (DAX, CAC, UKX) and Central and Eastern European (BUX, PX-50, WIG-20) stock markets. The novelty of our paper rests mainly on the use of five-minute tick intraday price data from mid-2003 to early 2005 for stock indices and on the wide range of econometric techniques employed. We find no robust cointegration relationship for any of the stock index pairs or for any of the extended specifications. There are signs of short-term spillover effects both in terms of stock returns and stock price volatility. Granger causality tests show the presence of bidirectional causality for returns as well as volatility series. The results based on a VAR framework indicate a more limited number of short-term relationships among the stock markets.

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1. Introduction

Stock markets in Central and Eastern Europe (CEE), especially those in Budapest, Prague and Warsaw, underwent some remarkable developments both in terms of market capitalisation and daily trade volumes from the very beginning of the economic transformation. Although the financial system of these countries largely remains bank-dominated, the stock exchanges appear to be well integrated with world financial markets following the lifting of restrictions on portfolio capital movements. However, given that these markets are small compared to the stock exchanges of the largest OECD countries, they may be sensitive to shifts in regional and worldwide portfolio adjustments of large investment funds and other market participants, even though the amount of capital involved in such moves are not necessarily very large by global standards. Consequently, these markets may be more volatile than well-established stock markets.

The literature distinguishes cross-market comovements during calm periods as opposed to periods before and after a crisis. Interdependence defines how strong the interlinkage between two markets is during normal times. By contrast, there is contagion if the interlinkage becomes stronger in the aftermath of a crisis than prior to a crisis (Forbes and Rigobon, 2002).

An increasing number of papers investigate the short- and long-term linkages among the CEE stock exchanges both in terms of stock returns and stock market volatility. Regarding long-run relationships, Gilmore and McManus (2002, 2003) cannot establish any long-term relationship among the three CEE markets (Budapest, Prague and Warsaw; the “CEE-3”) and the US and German stock markets, whereas Voronkova (2004) shows the presence of long-run links among the Central European markets and between CEE and their mature counterparts once structural changes in the long-run links are properly accounted for. In a similar vein, Syriopoulos (2004) finds that CEE markets tend to display stronger linkages with their mature counterparts than with their neighbours.

Regarding short-term linkages, Bohl and Henke (2003) show for daily stock market volatility for 20 Polish stocks that volatility persistence tends to disappear when trading volume is included in the conditional variance equation, a result that is in agreement with the findings of studies on developed stock markets. Scheicher (2001) finds evidence of limited interaction between the CEE-3 and major markets: in returns, both regional and global shocks are identified, but innovations to volatility chiefly exhibit a regional character. Tse, Wu, and Young (2003) show that there is no volatility spillover between the US and the Polish markets and that short-term spillover goes from the US to the Polish stock market but not the other way around. Serwa and Bohl (2005) is the only study which analyzes changes in interdependence, i.e. whether there is contagion, for the CEE countries and finds that CEE stock markets are not more prone to contagion than more developed stock markets.

The evidence in the literature is mostly based on data with daily or even lower frequencies, since historical intraday series from the CEE stock markets are usually unavailable. Yet, developments in volatility and contagion effects that materialize during the trading day represent a finer picture that often cannot be extracted from daily observations. Another big advantage of using intraday data is that the estimates are more robust to structural breaks (Terzi, 2003) given the relatively short time horizon (2 years) as compared to studies employing daily data (up to 10 years).

To our knowledge, the only paper that uses intraday stock market data for CEE stock markets is Černý and Koblas (2005). The authors use intraday data for an 8-month period from June 2003 to February 2004 at different frequencies and show the absence of any long-run (Engle or Granger type) relationship between Warsaw and Prague on the one hand and the DAX index on the other hand. The Granger causality tests reveal only a one-directional link running from the DAX to the two CEE stock markets

Against the general lack of empirical evidence for intraday stock market interlinkages between Eastern and Western European stock markets, our paper indeed aims to fill this gap in the literature by investigating the links and possible spillover effects for stock returns and stock volatilities among markets in Budapest, Prague and Warsaw from June 2003 to February 2005. We also study their interactions with selected major markets in the EU (Frankfurt, London and Paris) on the basis of intraday data recorded in five-minute intervals. Given that this period does not cover any major crisis, we focus on interdependence rather than on contagion. We do not find any robust cointegration relationship for any of the stock index pairs but we identify short-term spillover effects both in terms of stock returns and stock price volatility.

The outline of the paper is as follows: Section 2 deals with data issues. Section 3 focuses on the testing procedure. Section 4 presents the estimation results. Finally, section 5 provides some concluding remarks.

2. Markets and Data

2.1 Market characteristics

CEE stock markets are small when compared with mature stock markets in Europe or the USA despite the considerable development that can be observed over the last 10 years or so due to the overall economic transformation, restructuring and EU integration process of the CEE countries. Table A1 in the Appendix shows the evolution of the market capitalization to GDP ratio as well as proportion of the domestic and foreign issues on stock markets.

In Hungary, market capitalization started to rise sharply during the 1994 to 1996 period and literally jumped to 36.6% as a share of GDP in 1997 as newly privatized firms entered the market. The ratio of market capitalization to GDP peaked in 1999 at 38.7% but it is currently the lowest of the three Central European markets at 31.9% in 2005. The market is dominated by domestic issues.

Market capitalization increased markedly during the 1994 to 1996 period in the Czech Republic after several thousand firms privatized during the large-scale privatization campaign were put on the stock market. The majority of these stocks were illiquid, though. Substantial delisting in 1997 and later reduced the number of quoted shares dramatically. Following some fluctuations, market capitalization increased substantially in 2003 to 2004 and reached 44.8% in 2005, the highest among the three markets in question. Almost a third of the issues currently on the market are foreign.

In Poland, market capitalization rose sharply to around 20% by 2000 (a more than six-fold increase since 1994). It declined temporarily in 2001, only to almost triple in 2004. The early increase of market capitalization resulted from the introduction of privatized firms on the stock market. The recent increase should to some extent be credited to the fact that foreign companies started to be traded on the market in 2003. In 2005 the market capitalization to GDP ratio reached 43.9% and currently more than a fourth of the issues are foreign.

2.2 Intraday data

Our dataset is composed of intraday data for the stock markets of three CEE and three industrialized countries as quoted by Bloomberg. Stock exchange index quotes are available in five-minute intervals (ticks) for stock indices at the stock markets in Budapest (BUX), Prague (PX-50), Warsaw (WIG-20), London (FTSE-10, UKX), Frankfurt (DAX-30) and Paris (CAC-40).

The time period of our data starts on 2 June 2003, at 13:30 and ends on 9 February 2005 at 13:00 Central European Daylight Time (CEDT). The time difference between the markets is accounted for by setting the CEDT time for all indices, which eliminates the time difference between London and continental Europe. Table 1 gives an overview of the trading hours of the six stock indices.

[**Table 1.** Overview of Trading Hours]

Two problems arise in this context. First, trading hours are longer in Western Europe than in the CEE markets. In order to make our analysis fully comparable and executable, it would be useful to use a common denominator: we could for instance take the shortest window, i.e. the one for WIG-20 running from 10:00 to 15:55.

Another potential problem is the well-observed fact that absolute returns and volatility, measured for instance in terms of squared returns, exhibit a U-shape during the trading day both in mature and in emerging markets. In other words, absolute returns and volatility tend to be higher following market opening and before trading ends than during the mid-day trading (see e.g. McMillan and Speight, 2002 for the UK and Fan and Lai, 2006 for the case of Taiwan). Such a pattern could be explained by the arrival and incorporation of news during the first hours of the trading day or by intraday trading activity, implying the opening and closing of positions at the beginning and at the end of the trading session.

Against this backdrop, we computed average squared returns for the trading day for the six stock market indices. The results are plotted in Figure 1 and indicate that there is a strong asymmetric U-shape for all stock indices. The clearest U-shape can be observed for the WIG-20, while there is probably only a one-sided U-shape pattern for the PX-50. Apart from the tick at 9:05 of the DAX, volatility in the CEE stock markets appears to be larger during the early hours of trading than in their Western counterparts. Western European stock markets are clearly influenced by US macroeconomic announcements at 14:30 CET and by the opening of the US stock markets at 15:30 CET. Yet none of these effects seem to have an impact on the CEE markets.

Figure 1. Average Squared Returns and the Intraday U-Shaped Pattern

Because this observed intraday behaviour may have an influence on the results of our econometric estimations, we analyze two windows. First, we take the shortest common window given by the WIG-20, i.e. from 10:00 to 15:55. Second, we account for the U-shaped pattern and the impact of the US event within this window, which leads us to downsize the WIG-20 window to the period running from 11:00 to 14:40.

In order to prevent our results from being distorted by overnight returns, we compute the returns as log first differences where each trading day is a separate sub-sample. This means that the first return observation on each day is not based on the closing price of the previous day. For the volatility estimations we employ a dummy variable that captures the beginning of each new day. It should be noted that there are some missing observations for some of the series. These missing observations, replaced with zero for the volatility estimations (and left as they are for the cointegration and causality tests), are controlled for with the use of dummies that take the value of one if a given observation is zero.

Table 2 shows some descriptive statistics for the window corrected for the U-shaped pattern according to which the log stock returns are highly non-normal, which justifies the use of GARCH models to investigate volatility spillovers between the stock markets under study.

Table 2. Descriptive Statistics

3. Econometric Methods

3.1 Unit Root and Stationarity Tests

In our econometric investigation we follow a multi-stage approach. We first perform some standard unit root and stationarity tests: the augmented Dickey-Fuller (ADF) and Philips-Perron (PP) unit root tests and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) stationarity test.

3.2 Cointegration Tests

Further, we are interested in possible long-term relationships between the individual stock indices. For this purpose, we perform pairwise cointegration tests between the CEE stock indices and between the individual stock indices and their three Western European counterparts. In addition, a cointegration relationship including all three CEE stock indices and one Western European stock index is analysed.

We implement four alternative cointegration techniques, namely a) the Engle-Granger residual-based cointegration method; b) the dynamic ordinary least squares (DOLS) introduced by Stock and Watson (1993), which accounts for the endogeneity of the regressors and serial correlation in the residuals; c) the bounds testing approach proposed by Pesaran et al. (2001), which is based on the error correction formulation of an ADL; and d) the Johansen cointegration technique, which is an efficient tool of testing for the number of cointegrating vectors in a VAR (vector autoregressive) framework.

3.3 Granger Causality Tests for Stock Prices and for Stock Market Volatility

In the second stage, we investigate short-term interactions among the stock markets under study. The first step of this stage is to conduct pairwise Granger causality tests. If the stock index series are stationary in levels, the level variables can be used for this exercise. However, causality tests applied to level variables make sense only if the two variables included in the VAR system are stationary.[1] If the series are nonstationary in levels but stationary in first differences, the Granger and Sims causality tests should be carried out within a VAR in first differences. An additional problem that arises in this context is that ignoring long-term cointegration relationships among the variables may lead to spurious causality. If the two I(1) variables are not connected via a cointegrating vector, a simple VAR in first differences can be used.

The Granger causality tests will also be applied to stock volatility. In this context, one may use either volatility measures based on the implied volatility of option prices or volatility derived using econometric techniques, such as the GARCH framework.

We follow the second avenue mainly because of the general lack of data on stock options in the countries under study, especially data at an intraday frequency. In our endeavour, we

[1] Toda and Yamamoto (1995) proposed a procedure that allows causal inference to be conducted in level VARs that may contain integrated processes but does not involve rigorous attention and strict reliance upon integration and cointegration properties of any or all variables in the system. Therefore, we prefer to retain a conservative approach in our analysis.

estimate the recent component GARCH (CGARCH) model of Engle and Lee (1999), where equation (1) is the mean equation and equation (2) is the conditional variance equation:

$$\Delta s_t = \phi_1 + \sum_{i=1}^{m} \phi_{5,i} \Delta s_{t-i} + \varepsilon_t \tag{1}$$

$$\sigma_t^2 - q_t = \overline{\omega} + \alpha \cdot (\varepsilon_{t-1}^2 - \overline{\omega}) + \beta \cdot (\sigma_{t-1}^2 - \overline{\omega}) . \tag{2}$$

The CGARCH model distinguishes between short-term (transitory) and long-term (permanent) conditional volatility. Contrary to constant conditional volatility in a standard GARCH model, long-term volatility (q_t) is allowed to vary over time, to which the short-term volatility or the transitory component of long-term volatility ($\sigma_t^2 - q_t$) mean-reverts as shown in (3):

$$q_t = \omega + \rho \cdot (q_{t-1} - \omega) + \delta \cdot (\varepsilon_{t-1}^2 - \sigma_{t-1}^2) . \tag{3}$$

CGARCH makes it possible to model separately the effect of spillovers on exchange rate volatility in the short and long-run, for example. Note that we select the optimal lag length of the mean equation using the Schwarz information criterion.

3.4 VAR Estimations for Stock Returns and Volatility

The final step of our analysis is to investigate possible spillover effects between three Western European stock markets and three stock markets in Central and Eastern Europe on the one hand, and among the three CEE stock markets themselves. With this in mind, we estimate a VAR model that includes stock returns and stock market volatility obtained using the above CGARCH model. Each VAR model includes data for the three CEE markets and one Western European stock market, which yields a total of three estimated VAR models:

$$Y_{k,t} = A_{k,0} + \sum_{i=1}^{p-1} A_{k,i} Y_{k,t-i} + \varepsilon_{k,t} , \tag{4}$$

with $Y_{1,t} = \begin{bmatrix} \Delta s_t^{BUX} \\ \Delta s_t^{PX50} \\ \Delta s_t^{WIG20} \\ \Delta s_t^{DAX} \\ \Delta g_t^{BUX} \\ \Delta g_t^{PX50} \\ \Delta g_t^{WIG20} \\ \Delta g_t^{DAX} \end{bmatrix}$, $Y_{2,t} = \begin{bmatrix} \Delta s_t^{BUX} \\ \Delta s_t^{PX50} \\ \Delta s_t^{WIG20} \\ \Delta s_t^{CAC} \\ \Delta g_t^{BUX} \\ \Delta g_t^{PX50} \\ \Delta g_t^{WIG20} \\ \Delta g_t^{CAC} \end{bmatrix}$, $Y_{3,t} = \begin{bmatrix} \Delta s_t^{BUX} \\ \Delta s_t^{PX50} \\ \Delta s_t^{WIG20} \\ \Delta s_t^{UKX} \\ \Delta g_t^{BUX} \\ \Delta g_t^{PX50} \\ \Delta g_t^{WIG20} \\ \Delta g_t^{UKX} \end{bmatrix}$,

where Δs_t and Δg_t denote stock returns and the estimated stock market volatility. The optimal lag length is selected using the Schwarz information criterion.

4. Empirical Findings

4.1 Cointegration

As we are interested first in possible long-run relationships between the stock market indices included in this study, it appears necessary to check whether the individual stock index series are stationary in levels or are difference stationary. For this reason, a battery of unit root and stationarity tests is implemented. The results of this exercise, which are reported in the Appendix (Table A2), strongly confirm at the standard 5% significance level that the stock index series are not stationary in levels, but are stationary in first differences. The unit root tests were also applied to data in second differences in order to detect any I(2) features of the data. These results are very much in line with those obtained for first-differenced data, which makes us think that the series are difference-stationary processes.

With this as a background, we set out to perform a variety of cointegration methods. As shown in Table 3, the single equation approaches (E-G, DOLS and bounds testing approach) usually cannot establish any robust pairwise or extended cointegrating vectors. Generally, the cointegration statistics indicate that the residuals are not stationary. The only exception is when both the Engle-Granger and DOLS (but not the bounds testing approach) find evidence for cointegration at the 5% significance level for the relationship WIG-20 – CAC. For the Engle-Granger and DOLS estimates, the error correction terms sometimes appear to be significantly negative but the formal cointegration tests do not validate these results.

Finally, the Johansen trace statistics show that the null of no cointegration cannot be rejected only in some cases, for instance for the relationships WIG-20 – DAX, WIG-20 – UKX and CEE-3 – UKX. Two observations deserve mention in this respect. First, these findings do not overlap with the cointegration findings from the single-equation approach, except perhaps in the case of WIG-20 – CACPX-50 – WIG-20 and BUX – PX-50 – WIG-20. Second, the cointegration finding is strongly mitigated by the fact that the Schwarz information criterion systematically chooses the model with no cointegration and that for some of the relationships, the roots of the VAR model are located outside the unit circle, indicating the instability of the VAR model. Finally, for some of the pairwise relationships, the tests indicate the presence of two cointegration relationships.

Thus far, these results are related to the U-shaped pattern-corrected common window. The results obtained for the window given by WIG-20 are fairly similar in that they provide fairly little evidence in favour of cointegration. The two perhaps noteworthy differences are that for the latter, the bounds testing approach find more cointegrating relationships and that the Johansen approach yields less evidence for cointegration. Overall, it is not an exaggeration to conclude that the findings do not provide any firm evidence for long-term cointegration relationships among the stock indices studied here.

Table 3. Cointegration Tests

4.2 Granger Causality for the Returns Series

We now turn to the question of whether there is a causal relationship among the stock markets under study. Since the data series turned out to be difference stationary and because we were unable to establish any robust cointegration between them, according to the testing strategy sketched out earlier, Granger causality tests performed for data in first differences, e.g. for stock index returns, seem to be the appropriate tool.

Coming now to the results of the Granger causality tests, results for a window corresponding to 50 ticks are reported in Table 4. Here, all 15 possible pairs are tested. It appears that most of the series Granger-cause each other at horizons of up to one day. Put differently, not only stock returns in Frankfurt, London and Paris Granger-cause stock returns in the three CEE markets, but the CEE-3 also influence each other and stock returns in Frankfurt, London and Paris. While this holds true fully for the sample adjusted for the U-shape, for the unadjusted sample a notable exception are the returns on the Polish WIG-20, which Granger-cause the

BUX and PX-50 only at very short horizons, and no causality is running from the WIG-20 to the DAX, CAC and UKX stock market indices.[2] In sum, there is causality across the board up to 50 ticks, the sole exception being WIG-20 on the three Western indices.

Table 4. Granger Causality for Returns

4.3 Granger Causality for the Volatility Series

The first necessary step to make when investigating volatility spillovers across countries is to estimate a univariate GARCH model, from which we can extract the estimated volatility of the individual stock markets. Research examining high-frequency financial data has suggested that volatility dynamics may be confounded by the existence of both a periodic pattern and long-memory volatility. Thus, we derived volatility from the component GARCH model (CGARCH) as our volatility series for the Granger causality analysis.[3] Indeed, we derive not only total volatility but also the permanent component of volatility.

Having done this, we need to find out the degree of integration of the estimated volatility series in order to adhere to our testing strategy and to remain consistent with earlier parts of the paper. The ADF and PP unit root test can reject the null of a unit root both for data in levels and in first differences, while the KPSS tests reject in most cases the null of stationarity for the same setting (see Table A3 in the Appendix). At the same time, all tests show that the series are stationary in first differences. Although the evidence is not unambiguous whether the series are I(0) or I(1), we employ Granger causality to the GARCH series in levels.

For Granger causality, all 15 possible bilateral relationships are tested. If we consider the sample which is unadjusted for the U-shape, the test results provide convincing evidence in favour of bidirectional Granger causality existing among the volatility of the stock markets under consideration (not reported here). In other words, changes in the volatility in BUX, for instance, tend to induce changes in the volatility of PX-50 and WIG-20, and vice versa. All the same, volatility changes in Western European stock markets seem to affect volatility in Eastern Europe, which also holds true the other way around.

Nevertheless, once we eliminate the U-shape from the data, some of the above bilateral causal relationships become weaker or break down completely (Table 5). Exceptions are the reverse causal relationship between CAC, DAX and UKX, and between DAX – BUX and DAX – WIG-20. While bidirectional causality still can be detected for the pairs BUX – PX50, CAC – PX50 and CAC – WIG-20, they are now limited to very short horizons of up to 10 ticks. Furthermore, Table 7 also indicates one-way causal links (up to 50 ticks) running from BUX to CAC, WIG-20, and UKX as well as from WIG-20 to UKX. A similar one-way but shorter-term causal relation characterizes the pairs CAC – BUX and WIG-20 – PX50. Note that the use of the permanent component of the CGARCH induces only very few changes to the overall picture.

Table 5. Granger Causality for GARCH series – CGARCH

4.4 VAR Estimations

[2] This feature was earlier documented by Gilmore and McManus (2003) for an earlier period and for daily data; they also found some short-term effects running from the German to the Polish market but no reverse causality. It should be noted that our results show more evidence for bidirectional causality than those reported in Černý and Koblas (2005).

[3] McMillan and Speight (2002) estimate a component-GARCH model and are able to confirm the presence of both long-run and short-run volatility dynamics. Their results suggest that taking both components into account improves the accuracy of volatility forecasts.

The VAR framework described in Section 4 allows us to analyze the following four features: 1) spillovers from stock returns to stock returns, 2) spillovers from volatility to stock returns, 3) spillovers from volatility to volatility and 4) spillovers from stock returns to volatility. In this section, we focus on the two most interesting relations, namely the link running from returns to returns and the link running from volatility to volatility. The estimations are carried out for the two samples (unadjusted and adjusted for the U-shaped pattern). For the adjusted sample, we consider both overall volatility and the permanent component of volatility. Given that the results do not differ markedly, we only discuss short-run relationships among overall volatilities.

The results for the adjusted sample, reported in Tables 6a to 6d, indicate that past values of the return series of the CEE-3 indices have a positive and significant influence on the other CEE countries. PX-50 intraday returns can be considered as an exception since they affect only those of BUX but not WIG-20. These results hold true whatever the VAR specification is. The only caveat is that these results apply to selected lagged returns.

The returns of DAX and CAC have a very robust positive impact on intraday CEE stock returns and UKX also has a bearing on the CEE-3, mostly on WIG-20 for the VAR systems which only include one of the Western stock markets. However, once all three indices are incorporated into the system, only DAX seems to have a positive very short-term influence on the CEE-3.

At the same time, no links emerge from the CEE-3 toward Western European stock returns. Looking now at the block of CAC, DAX and UKX, DAX influences stock returns in the two other markets only with a lag of one tick, while the two others have an effect on the two other markets with lags up to three ticks. It is worthwhile noting that these results do not change qualitatively for the unadjusted sample (not reported here).

Turning now to the influence of developments on other markets on stock market volatility, the estimation results indicate that changes in volatility in the three CEE countries positively affect volatility in the two others. More specifically, the volatility of BUX is also found to have a positive influence on WIG-20 and PX-50 volatility, and PX-50 and WIG-20 affect BUX. Similarly to the results reported for stock returns, these results apply only at specific lag lengths. Furthermore, not only positive but also negative effects can be established for some cases.

In addition to this, higher volatility in the three Western European stock indices leads in a number of instances to higher volatility in the CEE markets. In particular, in the smaller VAR models which include only one Western European market, only the relationship running from CAC to BUX and from DAX to WIG-20 appear to be nonfunctional. Some of the relationships break down, however, if all Western stock markets are considered simultaneously (Table 8d). In this case, volatility in DAX and CAC impact the volatility of BUX and WIG-20, respectively, while UKX has a significant positive effect on the volatility of the Budapest and Prague stock exchanges.

Unlike for returns, there exist some volatility spillover effects from CEE to Western Europe. However, more research would be needed to see whether this is a general phenomenon or whether this is a feature of our specific sample. This finding is not unimportant since a general conclusion of earlier research is that volatility spillover effects were significant only from the dominant markets to smaller markets (Janakiramanan and Lamba, 1998; Hamao, Masulis and Ng, 1990). Our results are in line with those of Bala and Premarante (2004), who provide evidence that it is plausible for volatility to spill over from the smaller market to the dominant market. They indeed find small but significant volatility spillover from Singapore into Hong Kong, Japan and US markets even though these three are dominant markets.

Finally, there seems to be a lot of action between the three Western markets in terms of volatility spillovers as volatility in each market is found to have a positive (or in some cases negative) effect on volatility in the two other markets.

Generally speaking, comparing the results for volatility to those obtained for the unadjusted sample reveals that significant volatility spillovers for the unadjusted sample are found more frequently than for the adjusted sample. In other words, volatility spillovers are probably more frequent at the beginning and end of trading.

Table 6a. VAR mean – variance, CGARCH, CEE-3 and DAX

Table 6b. VAR mean – variance, CGARCH, CEE-3 and CAC

Table 6c. VAR mean – variance, CGARCH, CEE-3 and UKX

Table 6d. VAR mean – variance, CGARCH, CEE-3, DAX, CAC and UKX

5. Conclusions

In this paper, we analyzed possible interdependences among three stock markets in Central and Eastern Europe and, in addition, interconnections which may exist between Western European stock markets on the one hand (DAX, CAC, UKX) and CEE stock markets (BUX, PX-50, WIG-20) on the other. The analysis was performed on a sample over which no major crisis occurred. The novelty of our paper rests mainly on the use of the five-minute tick intraday data for stock indices and on the wide range of econometric techniques employed.

Our estimation results indicate that for a common daily window adjusted for the observed U-shaped pattern running from mid-2003 to early 2005, no robust cointegration relationship could be established for any of the stock index pairs or for any of the extended specifications. Apart from the lack of any stable long-term relation between the stock market indices under study, there are signs of short-term spillover effects both in terms of stock returns and stock price volatility. Granger causality tests show the presence of bidirectional causality for the returns as well as volatility series. However, the overwhelming evidence for bidirectional causality is partly mitigated by the results based on a VAR framework which includes both stock returns and stock market volatility. The results from the VAR shed light on a more limited number of short-term relationships between the stock markets. In general, we find spillover effects from returns to returns among the CEE markets, among the Western markets and from Western Europe to CEE. However, no spillover seems to occur from the East to the West. Surprisingly, we are able to identify volatility spillover effects among the CEE markets, among the Western markets and from Western markets to CEE markets, but also from BUX and WIG-20 to DAX and UKX, respectively. This casts some doubt on the well-established position that only dominant markets can influence volatility on other markets. Our findings also indicate a peculiar pattern in CEE: the Prague and Warsaw stock exchanges seem to interact both in terms of returns and volatility with the Budapest stock exchange, but not with each other. As a result, short-term spillovers from Prague to Warsaw and vice versa are mostly likely to transit via Budapest.

To conclude, our research bears two implications. First, the finding that smaller markets may impact dominant markets shows that the CEE markets may be considered by hedge funds and institutional investors as a separate “asset class” as compared to stocks in Western Europe. Second, the finding of only short-term but no robust long-term relationships between CEE and Western European stock markets—already shown in earlier research—may have positive importance for international portfolio diversification into CEE.

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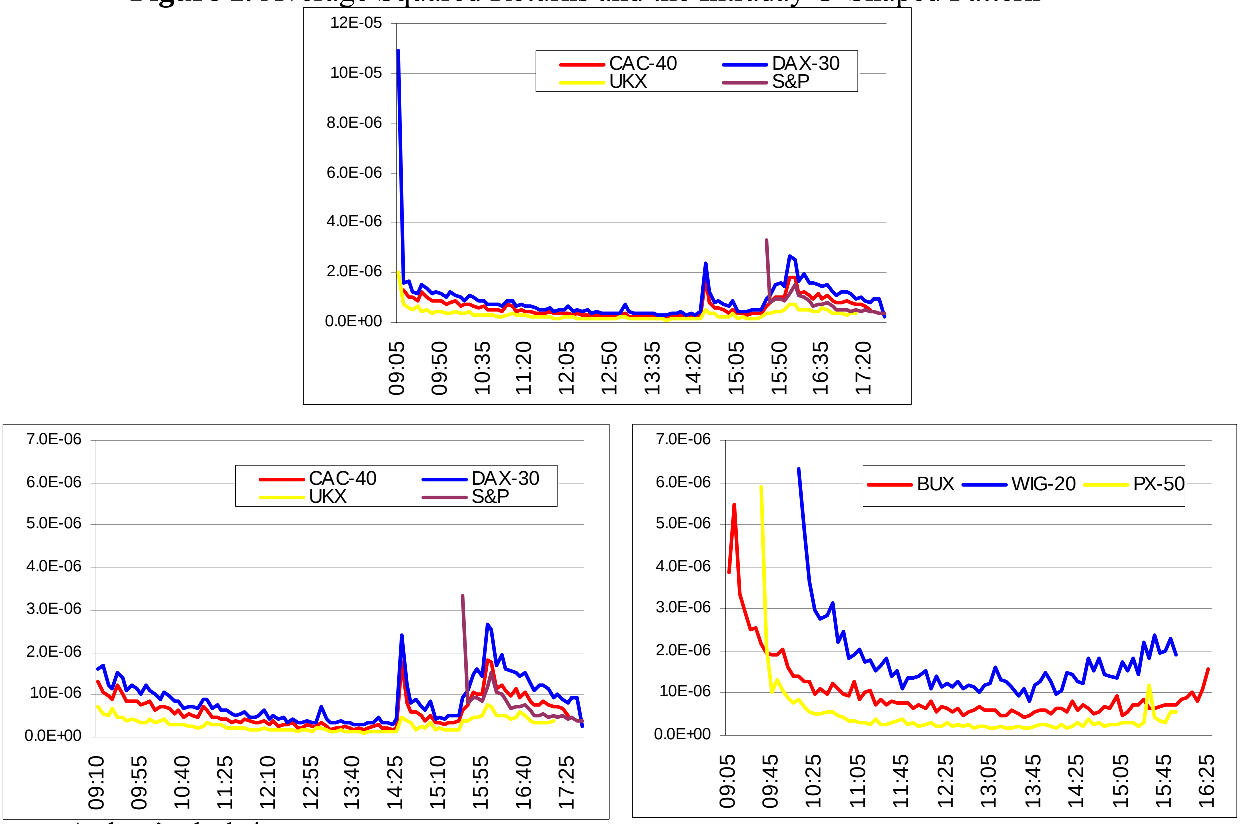
Figure 1. Average Squared Returns and the Intraday U-Shaped Pattern



Source: Authors' calculations

Table 1. Overview of Trading Hours

	Start	End	Ticks
BUX	9:00	16:25	90
PX-50	9:30	16:00	79
WIG-20	10:00	15:55	72
DAX	9:00	20:10/17:40*	135/105
CAC	9:05	17:25	101
UKX	9:00	17:35	104

* From November 2003, trading ends at 17:40.

Table 2. Descriptive Statistics

	Log levels						Log differences					
	BUX	**PX-50**	**WIG-20**	**CAC**	**DAX**	**UKX**	**BUX**	**PX-50**	**WIG-20**	**CAC**	**DAX**	**UKX**
Mean	9.3	6.6	7.4	8.2	8.2	8.4	2.E-05	2.E-05	9.E-06	3.E-06	6.E-06	-1.E-06
Median	9.3	6.7	7.4	8.2	8.3	8.4	0.E+00	0.E+00	-6.E-06	3.E-06	0.E+00	0.E+00
Maximum	9.7	7.0	7.6	8.3	8.4	8.5	9.E-03	5.E-03	9.E-03	5.E-03	6.E-03	3.E-03
Minimum	9.0	6.3	7.1	8.0	8.0	8.3	-8.E-03	-5.E-03	-9.E-03	-5.E-03	-7.E-03	-3.E-03
Std. Dev.	0.2	0.2	0.1	0.1	0.1	0.0	8.E-04	5.E-04	1.E-03	6.E-04	7.E-04	4.E-04
Skewness	0.2	0.1	-1.0	-0.7	-0.7	0.1	0.058	-0.189	0.129	-0.038	-0.090	-0.123
Kurtosis	2.1	2.1	3.5	2.4	2.7	2.5	8.1	13.3	6.5	10.0	8.9	6.6
Jarque-Bera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Obs	17206	17186	17289	17547	17601	17263	17204	17184	17287	17545	17599	17261

Note: P-values are reported for the Jarque-Bera normality test.

Table 3. Cointegration Tests

		EG	DOLS	ARDL	R	JOHANSEN TRACE	SIC	ROOTS
BUX – PX-50					0	26.674***	-20.452*	NO
	COINT	-2.652 (0)	-2.652 (0)	-11.347	1	7.486	-20.451	
	ECT	-0.001**	-0.001**	-0.001**	2		-20.449	
BUX – WIG-20					0	25.97***	-19.708*	OK
	COINT	-2.254 (2)	-2.256 (2)	-9.871	1	8.979	-19.707	
	ECT	0.000*	0.000*	0000*	2		-19.704	
PX-50 – WIG-20					0	35.499***	-20.127*	OK
	COINT	-2.566 (0)	-2.567 (0)	-32.598	1	12.346**	-20.126	
	ECT	0.000**	0.000**	0.000**	2		-20.124	
BUX – DAX					0	20.108**	-19.991*	NO
	COINT	-1.766 (0)	-1.767 (0)	-13.206	1	7.561	-19.989	
	ECT	0.000	0.000	0.000	2		-19.987	
BUX – CAC					0	21.506**	-20.359*	NO
	COINT	-2.385 (0)	-2.385 (0)	-12.770	1	8.826	-20.358	
	ECT	0.000	0.000	0.000	2		-20.355	
BUX – UKX					0	21.618**	-21.010*	NO
	COINT	-3.257* (0)	-3.258* (0)	-12.436	1	8.884	-21.009	
	ECT	0.000	0.000	0.000	2		-21.006	
PX-50 – DAX					0	33.415***	-20.377*	OK
	COINT	-2.131 (0)	-2.132 (0)	-21.675	1	14.471***	-20.376	
	ECT	0.000	0.000	0.000	2		-20.374	
PX-50 – CAC					0	36.201***	-20.752*	OK
	COINT	-3.133* (0)	-3.136* (0)	-72.745	1	14.490***	-20.751	
	ECT	0.000**	0.000**	0.000**	2		-20.749	
PX-50 – UKX					0	26.631***	-21.418*	OK
	COINT	-3.258* (0)	-3.258* (0)	-65.418	1	12.001**	-21.416	
	ECT	0.000*	0.000*	0.000**	2		-21.414	
WIG-20 – DAX					0	18.943	-19.637*	OK
	COINT	-2.685 (2)	-2.684 (2)	-1.413	1	6.936	-19.635	
	ECT	-0.001**	-0.001**	-0.001**	2		-19.633	
WIG-20 – CAC					0	21.721**	-20.047*	OK
	COINT	-3.45** (0)	-3.45** (0)	0.178	1	8.721	-20.046	
	ECT	-0.001**	-0.001**	-0.001**	2		-20.043	
WIG-20 – UKX					0	16.176	-20.709*	OK
	COINT	-3.075* (0)	-3.075* (0)	0.032	1	6.105	-20.707	
	ECT	-0.001**	-0.001**	-0.001**	2		-20.705	
CEEC3 – DAX					0	68.422***	-40.497*	OK
	COINT	-3.152 (0)	-3.154 (0)	-9.346	1	40.287**	-40.494	
	ECT	-0.001***	-0.001***	-0.001***	2	18.580	-40.490	
					3	5.845	-40.485	
					4		-40.480	
CEEC3 – CAC					0	72.371***	-40.871*	OK
	COINT	-3.407 (0)	-3.41 (0)	-9.797	1	42.446***	-40.868	
	ECT	-0.001***	-0.001***	-0.001***	2	17.542	-40.864	
					3	6.844	-40.859	
					4		-40.854	
CEEC3 – UKX					0	57.813	-41.491*	OK
	COINT	-2.836 (0)	-2.838 (0)	-10.628	1	32.126	-41.488	
	ECT	-0.001**	-0.001**	-0.001**	2	14.830	-41.484	
					3	5.446	-41.479	
					4		-41.474	
CEE3 – W3					0	107.04**	-64.960*	OK
	COINT	-3.894 (0)	-3.896 (0)	-6.313	1	76.598	-64.954	
	ECT	-0.001***	-0.001***	-0.001***	2	51.051	-64.948	
					3	30.279	-64.942	
					4	13.599	-64.935	
					5	5.792	-64.927	
					6		-64.920	

Notes: EG, DOLS and ARDL denote the Engle-Granger, Dynamic OLS and bounds testing approaches. COINT indicates the result of the residual-based cointegration tests for EG and DOLS (in parentheses are the lag lengths selected using the Schwarz information criterion; maxlag = 10) and the F-tests for ARDL. ECT is the error-correction term. *, ** and *** indicate the rejection of the null of no cointegration at the 10%, 5% and 1% levels, respectively, and indicate the statistical significance of the ECT at the 10%, 5% and 1% levels, respectively. For the Johansen cointegration test, R stands for "rank", and the numbers below indicate the actual rank considered. The trace statistics are displayed below Johansen. *, ** and *** show the rejection of the (R) number of cointegrating vectors at the 10%, 5% and 1% levels, respectively. SIC is the Schwarz information criterion for the model including a constant and no trend. "ROOTS" indicates whether the roots of the VAR system are in the unit circle. If they are (OK), the VAR is stable.

Table 4. Granger Causality for Returns

	1	5	10	20	30	40	50
PX50=> BUX	409.723***	144.629***	109.545***	79.894***	64.115***	54.551***	49.881***
BUX=> PX50	177.893***	48.545***	27.632***	14.979***	9.769***	8.059***	6.626***
WIG20=> BUX	394.319***	114.889***	63.794***	36.19***	27.369***	22.784***	21.177***
BUX=> WIG20	350.26***	79.462***	44.128***	23.66***	18.212***	16.041***	15.537***
PX50=> WIG20	935.51***	310.725***	223.704***	149.199***	117.503***	97.796***	83.241***
WIG20=> PX50	231.843***	65.614***	42.514***	25.181***	19.283***	16.358***	13.938***
DAX=> BUX	10.808***	7.009***	5.331***	4.403***	6.27***	5.904***	6.088***
BUX=> DAX	531.695***	128.97***	80.295***	46.659***	35.657***	28.611***	26.047***
CAC=> BUX	108.695***	27.543***	20.03***	12.093***	9.438***	8.07***	7.286***
BUX=> CAC	468.222***	124.449***	73.944***	43.866***	33.401***	26.508***	24.227***
UKX=> BUX	358.169***	76.847***	42.555***	22.389***	16.418***	14.634***	13.188***
BUX=> UKX	424.249***	103.709***	58.768***	35.168***	25.727***	21.481***	19.587***
DAX=> PX50	41.113***	14.387***	9.209***	5.382***	5.245***	4.389***	4.267***
PX50=> DAX	927.65***	335.821***	221.273***	150.735***	119.545***	106.125***	95.289***
CAC=> PX50	104.716***	26.981***	15.145***	11.013***	9.397***	10.158***	9.521***
PX50=> CAC	889.982***	322.914***	215.865***	144.017***	112.453***	101.463***	91.639***
UKX=> PX50	291.714***	59.914***	35.367***	19.545***	16.955***	14.127***	11.995***
PX50=> UKX	675.334***	253.472***	179.941***	130.26***	100.26***	86.974***	79.024***
DAX=> WIG20	60.922***	19.864***	13.835***	9.123***	7.539***	6.844***	6.689***
WIG20=> DAX	293.072***	71.379***	43.902***	25.836***	21.052***	18.168***	17.781***
CAC=> WIG20	79.619***	24.612***	13.646***	8.273***	7.373***	6.689***	6.227***
WIG20=> CAC	262.966***	65.872***	39.212***	24.509***	19.108***	16.007***	15.136***
UKX=> WIG20	361.051***	81.995***	45.545***	26.838***	19.818***	16.577***	15.454***
WIG20=> UKX	251.386***	62.594***	37.123***	21.363***	16.632***	14.605***	13.636***
CAC=> DAX	107.351***	30.123***	17.079***	11.287***	8.482***	7.826***	7.069***
DAX=> CAC	169.589***	35.677***	19.26***	10.798***	7.959***	6.443***	5.58***
UKX=> DAX	226.719***	64.31***	35.708***	20.349***	18.155***	15.447***	13.736***
DAX=> UKX	501.45***	103.171***	53.3***	28.136***	19.804***	15.187***	12.514***
UKX=> CAC	184.555***	53.17***	29.963***	17.174***	15.666***	12.976***	11.318***
CAC=> UKX	382.507***	84.607***	43.101***	22.558***	16.002***	12.821***	10.784***

Note: pairwise Granger causality (=>) tests for the common window adjusted for the U-shape. The numbers across the top of the table refer to ticks 1 through 50.

Table 5. Granger Causality for GARCH series – CGARCH

	1	5	10	20	30	40	50
PX50 => BUX	7.758***	2.337**	1.316	0.935	0.76	1.236*	1.182
BUX => PX50	16.531***	6.473***	3.056**	1.937*	1.374	1.104	1.401***
WIG20=> BUX	2.198*	0.776	2.04*	1.369	1.471	1.248*	1.274**
BUX=> WIG20	4.787***	5.869***	3.92***	2.904**	1.96**	1.817***	1.648***
PX50=> WIG20	2.844**	1.19	0.792	0.798	1.119	1.211*	1.251**
WIG20=> PX50	0.367	0.803	0.801	0.904	0.822	0.78	0.941
DAX=> BUX	12.566***	3.116***	2.818**	2.457**	2.103**	2.275***	3.595***
BUX=> DAX	24.708***	10.514***	7.03***	3.711***	2.826***	2.381***	2.95***
CAC=> BUX	0.673	0.571	1.23	1.696	1.319	1.149	1.014
BUX=> CAC	5.317***	1.508	2.098*	1.37	1.044	1.269**	1.459***
UKX=> BUX	5.57***	0.77	0.876	1.299	1.124	1.12	1.054
BUX=> UKX	7.648***	2.941***	3.529***	1.832*	1.569*	1.306**	1.716***
DAX=> PX50	2.285*	1.361	1.065	1.05	0.962	0.88	1.214*
PX50=> DAX	1.645	1.866*	1.791	1.079	0.944	1.145	1.076
CAC=> PX50	4.203***	2.065**	1.503	0.981	0.755	0.855	1.131
PX50=> CAC	4.108***	2.47**	1.679	1.141	1.207	1.303**	1.134
UKX=> PX50	13.412***	5.348***	3.108**	2.82**	2.115**	1.734***	1.587***
PX50=> UKX	5.708***	2.162**	1.575	1.314	1.079	1.138	1.116
DAX=> WIG20	9.692***	2.889***	2.777**	1.616	1.367	3.016***	4.685***
WIG20=> DAX	88.411***	28.151***	14.796***	8.098***	5.832***	5.037***	3.79***
CAC=> WIG20	17.856***	3.229***	1.839	1.328	1.096	1.076	1.065
WIG20=> CAC	10.703***	1.98*	1.177	0.924	1.115	1.183	1.179
UKX=> WIG20	11.044***	1.028	1.117	0.962	1.001	0.857	0.89
WIG20=> UKX	5.938***	2.81***	1.955*	1.495	1.365	1.493***	1.4***
CAC=> DAX	15.677***	39.694***	24.009***	14***	13.382***	10.553***	25.76***
DAX=> CAC	73.529***	15.67***	8.913***	7.159***	5.084***	4.345***	5.203***
UKX=> DAX	2.834**	5.218***	2.986**	2.584**	2.677***	2.565***	6.912***
DAX=> UKX	8.178***	6.85***	7.965***	5.219***	4.391***	4.23***	5.093***
UKX=> CAC	72.369***	14.004***	6.576***	3.722***	2.741***	2.441***	2.243***
CAC=> UKX	0.119	6.779***	3.994***	2.704**	2.802***	3.165***	2.838***

Note: pairwise Granger causality (=>) tests for the common window adjusted for the U-shape.

Table 6a. VAR mean – variance, CGARCH, CEE-3 and DAX

	Returns to returns				**Volatility to volatility**			
	BUX	PX50	WIG20	DAX	BUX	PX50	WIG20	DAX
BUX(-1)	-0.011	0.008*	0.005	0.005	0.419***	0.002	-0.023*	0.042***
BUX(-2)	0.014*	0.012***	0.036***	-0.001	0.154***	0.005	0.026*	-0.019***
BUX(-3)	0.001	-0.001	0.013	0.011*	0.101***	0.009**	0.044***	-0.012*
PX50(-1)	0.003	0.144***	-0.005	-0.012	0.006	0.364***	-0.014	-0.002
PX50(-2)	0.005	0.061***	-0.012	-0.005	0.042**	0.091***	-0.034	-0.026*
PX50(-3)	0.033**	0.020***	0.007	-0.002	0.008	0.110***	-0.004	-0.017
WIG20(-1)	0.012**	0.006*	-0.052***	-0.001	-0.002	0.001	0.423***	0.043***
WIG20(-2)	0.014***	0.005	-0.058***	0.003	0.006	0.000	0.156***	-0.015***
WIG20(-3)	0.016***	0.004	-0.022***	0.002	0.004	-0.003*	0.106***	-0.013***
DAX(-1)	0.025***	0.035***	0.101***	-0.032***	0.024***	0.009**	0.015	0.509***
DAX(-2)	0.032***	0.019***	0.056***	-0.028***	-0.009	-0.003	0.001	0.012
DAX(-3)	0.015	0.007	0.043***	-0.018**	-0.002	-0.002	-0.006	0.010

Notes: *, ** and *** indicate that the coefficient estimates are statistically significant at the 10%, 5% and 1% levels, respectively. The table reports only the coefficients from returns to returns and from volatility to volatility, but not from returns to volatility or from volatility to returns.

Table 6b. VAR mean – variance, CGARCH, CEE-3 and CAC

	Returns to returns				**Volatility to volatility**			
	BUX	PX50	WIG20	CAC	BUX	PX50	WIG20	CAC
BUX(-1)	-0.011	0.008*	0.005	0.007	0.419***	0.002	-0.023*	0.002
BUX(-2)	0.014*	0.013***	0.036***	-0.001	0.155***	0.005	0.027*	0.002
BUX(-3)	0.001	-0.001	0.013	0.007	0.100***	0.009**	0.043***	-0.007*
PX50(-1)	0.003	0.144***	-0.006	-0.006	0.006	0.364***	-0.018	-0.009
PX50(-2)	0.005	0.061***	-0.013	-0.015	0.042***	0.091***	-0.032	-0.003
PX50(-3)	0.033**	0.020***	0.006	0.005	0.007	0.110***	-0.003	-0.015**
WIG20(-1)	0.013**	0.006**	-0.052***	-0.002	-0.002	0.001	0.422***	0.000
WIG20(-2)	0.014***	0.005*	-0.058***	0.002	0.007	0.000	0.156***	0.003
WIG20(-3)	0.016***	0.005	-0.022***	0.001	0.004	-0.004*	0.106***	0.004*
CAC(-1)	0.034***	0.039***	0.119***	0.018**	0.015	0.021***	0.073***	0.334***
CAC(-2)	0.031***	0.017***	0.055***	-0.023***	-0.008	-0.010	0.061**	0.122***
CAC(-3)	0.018	0.001	0.047***	-0.004	-0.007	-0.002	-0.029	0.109***

Notes: see Table 6a.

Table 6c. VAR mean – variance, CGARCH, CEE-3 and UKX

	Returns to returns				**Volatility to volatility**			
	BUX	PX50	WIG20	UKX	BUX	PX50	WIG20	UKX
BUX(-1)	-0.011	0.007*	0.006	0.003	0.410***	0.001	-0.022*	-0.001
BUX(-2)	0.014*	0.012***	0.037***	0.001	0.141***	0.003	0.028**	0.001
BUX(-3)	0.001	-0.001	0.013	-0.001	0.062***	0.002	0.057***	-0.003*
BUX(-4)	0.015**	0.005	0.006	0.002	0.091***	0.014***	-0.030**	0.006***
PX50(-1)	0.004	0.145***	-0.003	-0.003	-0.001	0.357***	-0.015	-0.009**
PX50(-2)	0.004	0.059***	-0.010	-0.004	0.038**	0.086***	-0.036	0.002
PX50(-3)	0.029**	0.016**	0.011	-0.001	-0.004	0.087***	-0.024	-0.006
PX50(-4)	0.012	0.021***	-0.036**	-0.001	0.027*	0.058***	0.047*	0.000
WIG20(-1)	0.013**	0.007**	-0.051***	-0.002	-0.003	0.001	0.411***	0.000
WIG20(-2)	0.014***	0.006*	-0.058***	0.004	0.005	0.001	0.140***	0.000
WIG20(-3)	0.016***	0.005	-0.022***	0.002	0.003	-0.003	0.058***	0.002**
WIG20(-4)	0.005	0.005*	-0.003	-0.004	0.002	-0.002	0.113***	0.001
UKX(-1)	0.045***	0.040***	0.129***	0.046***	0.073**	0.077***	0.101*	0.398***
UKX(-2)	0.019	0.011	0.060***	-0.003	-0.029	-0.043**	0.011	0.120***
UKX(-3)	0.019	0.010	0.057***	0.009	-0.003	-0.004	-0.070	0.122***
UKX(-4)	0.025*	-0.001	-0.005	0.003	-0.015	-0.010	0.035	0.094***

Notes: see Table 6a.

Table 6d. VAR mean – variance, CGARCH, CEE-3, DAX, CAC and UKX

	Returns to returns						Volatility to volatility					
	BUX	PX50	WIG20	DAX	CAC	UKX	BUX	PX50	WIG20	DAX	CAC	UKX
BUX(-1)	-0.010	0.007*	0.004	0.005	0.006	0.002	0.418***	0.002	-0.023*	0.042***	0.001	0.000
BUX(-2)	0.014*	0.012***	0.036***	-0.001	0.000	0.001	0.154***	0.005	0.028**	-0.021***	0.001	0.002
BUX(-3)	0.001	-0.001	0.013	0.010	0.007	-0.001	0.100***	0.008**	0.045***	-0.011	-0.008**	-0.001
PX50(-1)	0.003	0.144***	-0.006	-0.013	-0.005	-0.004	0.006	0.364***	-0.016	-0.001	-0.010	-0.009**
PX50(-2)	0.005	0.061***	-0.012	-0.006	-0.013	-0.003	0.042**	0.091***	-0.033	-0.030**	-0.004	0.002
PX50(-3)	0.033**	0.020***	0.007	-0.002	0.004	0.000	0.008	0.109***	-0.004	-0.016	-0.016**	-0.004
WIG20(-1)	0.012**	0.006*	-0.053***	-0.002	-0.003	-0.003	-0.002	0.000	0.422***	0.042***	0.000	0.000
WIG20(-2)	0.014**	0.005*	-0.058***	0.002	0.002	0.004	0.006	0.001	0.156***	-0.018***	0.002	0.000
WIG20(-3)	0.016***	0.005	-0.022***	0.001	0.001	0.002	0.004	-0.004*	0.106***	-0.010***	0.003	0.003***
DAX(-1)	0.010	0.027***	0.064***	-0.111***	0.114***	0.089***	0.026***	0.001	-0.010	0.554***	0.026***	0.002
DAX(-2)	0.029*	0.021**	0.039*	-0.076***	-0.005	-0.010	-0.008	0.002	-0.023	-0.042***	0.013**	0.009***
DAX(-3)	0.007	0.015*	0.025	-0.063***	-0.016	-0.004	0.000	-0.004	-0.003	0.000	-0.009*	0.000
CAC(-1)	0.015	0.010	0.041	0.101***	-0.115***	0.055***	-0.024	0.007	0.072**	-0.158***	0.295***	0.007
CAC(-2)	0.005	-0.002	0.006	0.047***	-0.031**	0.037***	0.000	-0.007	0.092***	0.181***	0.106***	-0.014***
CAC(-3)	0.010	-0.017	0.009	0.040***	-0.007	0.017*	-0.007	0.003	-0.017	0.033*	0.092***	-0.013***
UKX(-1)	0.018	0.007	0.035	0.044***	0.063***	-0.072***	0.062*	0.067***	0.073	0.050	0.045**	0.404***
UKX(-2)	-0.011	-0.005	0.017	0.014	0.023*	-0.023**	-0.021	-0.038**	-0.043	-0.079**	-0.012	0.136***
UKX(-3)	0.008	0.010	0.032	0.051***	0.035***	0.001	-0.002	-0.009	-0.033	0.107***	0.108***	0.173***

Notes: see Table 6a.

Appendix

Table A1. The CEE Stock Markets: Market Capitalization and Domestic and Foreign Issues

	Budapest			Prague			Warsaw		
Year	Local issues (%)	Foreign issues (%)	MC ratio to GDP (%)	Local issues (%)	Foreign issues (%)	MC ratio to GDP (%)	Local issues (%)	Foreign issues (%)	MC ratio to GDP (%)
1990	100.0	0.0	0.5	-	-	-	-	-	-
1991	100.0	0.0	1.5	-	-	-	100.0	0.0	0.2
1992	100.0	0.0	1.6	-	-	-	100.0	0.0	0.3
1993	100.0	0.0	2.3	-	-	-	100.0	0.0	3.8
1994	100.0	0.0	4.2	100.0	0.0	29.5	100.0	0.0	3.3
1995	100.0	0.0	6.0	100.0	0.0	32.6	100.0	0.0	3.7
1996	98.2	1.8	12.9	100.0	0.0	32.5	100.0	0.0	6.2
1997	99.7	0.3	36.6	100.0	0.0	27.8	100.0	0.0	9.3
1998	99.7	0.3	29.7	100.0	0.0	21.2	100.0	0.0	13.1
1999	99.7	0.3	38.7	100.0	0.0	23.5	100.0	0.0	20.1
2000	99.1	0.9	28.3	100.0	0.0	20.6	100.0	0.0	18.2
2001	99.5	0.5	19.4	100.0	0.0	14.7	100.0	0.0	13.8
2002	99.8	0.2	19.5	73.2	26.8	19.8	100.0	0.0	14.2
2003	99.6	0.4	18.8	70.4	29.6	25.3	83.5	16.5	20.6
2004	99.8	0.2	26.1	67.7	32.3	35.5	73.5	26.5	33.0
2005	99.8	0.2	31.9	67.7	32.3	44.8	72.5	27.5	43.9
2006^{E}	99.8	0.2	37.7	67.2	32.8	54.1	71.5	28.5	54.8

Source: Budapest Stock Exchange, Prague Stock Exchange, Warsaw Stock Exchange.
Note: HUF, CZK and PLN stand for Hungarian forint, Czech koruna and Polish złoty, respectively. MC stands for market capitalization.

Table A2. Unit Root Tests: Stock Market Indices

	ADF		PP		KPSS	
Log Levels						
	trend	constant	Trend	constant	trend	Constant
BUX	-2.08	0.45	-2.07	0.45	1.3***	16.37***
PX-50	-1.32	0.17	-1.43	0.12	0.81***	16.05***
WIG-20	-2.89	-2.45	-2.88	-2.45	1.56***	12.84***
CAC	-3.51**	-2.03	-3.48**	-2.02	2.39***	13.81***
DAX	-3.10	-2.36	-3.07	-2.35	2.17***	11.63***
UKX	-3.04	-0.71	-3.08	-0.72	1.2***	13.69***
1st differences						
BUX	-131.06***	-131.06***	-131.07***	-131.06***	0.05	0.1*
PX-50	-127.21***	-127.21***	-127.31***	-127.31***	0.06	0.07*
WIG-20	-96.1***	-96.09***	-133.13***	-133.13***	0.08	0.21*
CAC	-132.22***	-132.23***	-132.24***	-132.24***	0.03	0.06*
DAX	-133.04***	-133.04***	-133.06***	-133.06***	0.06	0.11*
UKX	-131.13***	-131.13***	-131.13***	-131.13***	0.02	0.06*
2nd differences						
BUX	-31.23***	-31.23***	-8538.53***	-8532.35***	0.04	0.07*
PX-50	-34.6***	-34.6***	-1826.20***	-1762.97***	0.07	0.1*
WIG-20	-35.81***	-35.81***	-5157.04***	-5122.51***	0.09	0.1*
CAC	-36.96***	-36.96***	-4026.91***	-3960.52***	0.06	0.15*
DAX	-37.05***	-37.05***	-4363.98***	-4361.66***	0.02	0.02
UKX	-33.32***	-33.32***	-3347.09***	-3341.80***	0.03	0.03

Notes: ADF, PP, and KPPS are the Augmented Dickey-Fuller, the Phillips-Perron, and the Kwiatowski-Phillips-Schmidt-Shin unit root tests, respectively, for the case including only a constant. In parentheses is the lag length chosen using the Shwartz information criterion for the ADF test, and the Newey West kernel estimator for the PP and KPSS tests. *, ** and *** denote the rejection of the null hypothesis. For the ADF and PP tests, the null hypothesis is the presence of a unit root, whereas for the KPSS tests, the null hypothesis is stationarity.

Table A3. Unit Root Tests: Component GARCH Series

	ADF		PP		KPSS	
	trend	constant	Trend	constant	trend	Constant
Log Levels						
CGARCH						
BUX	-24.01***	-24.01***	-120.56***	-120.59***	0.13*	0.15*
PX-50	-23.5***	-23.3***	-122.8***	-124.21***	0.31***	1.24***
WIG-20	-21.42***	-21.19***	-122.82***	-123.91***	0.42***	1.72***
CAC	-11.57***	-9.47***	-73.7***	-75.52***	0.23***	13.36***
DAX	-34.07***	-28.9***	-115.44***	-128.02***	0.32***	7.5***
UKX	-20.72***	-20***	-125.8***	-129.31***	0.09	2.76***
CGARCH – permanent component						
BUX	-25.79***	-25.79***	-85.65***	-85.66***	0.19**	0.19*
PX-50	-25.71***	-25.5***	-90.02***	-90.94***	0.29***	1.31***
WIG-20	-22.97***	-16.56***	-89.02***	-89.87***	0.54***	2.34***
CAC	-10.9***	-8.93***	-71.28***	-70.82***	0.14*	6.65***
DAX	-33.25***	-31.17***	-84.98***	-93.46***	0.33***	7.64***
UKX	-22.79***	-21.78***	-90.41***	-93.19***	0.12*	3.66***
1st differences						
CGARCH						
BUX	-39.35***	-39.35***	-1609.65***	-1609.52***	0.05	0.05*
PX-50	-41.4***	-41.4***	-1772.95***	-1772.91***	0.01	0.01
WIG-20	-37.75***	-37.75***	-999.3***	-999.27***	0.01	0.03
CAC	-46.51***	-46.51***	-3039.35***	-3033.87***	0.03	0.04*
DAX	-36.38***	-36.39***	-1467.15***	-1467.31***	0.01	0.01
UKX	-44.69***	-44.7***	-1010.45***	-1010.58***	0.01	0.02
CGARCH – permanent component						
BUX	-40.5***	-40.5***	-1188.07***	-1187.87***	0.04	0.06*
PX-50	-40.22***	-40.22***	-1839.32***	-1838.91***	0.02	0.02
WIG-20	-39.44***	-39.44***	-804.43***	-804.36***	0.01	0.03
CAC	-53.57***	-53.58***	-3930.56***	-3929.99***	0.13*	0.14*
DAX	-36.54***	-36.54***	-1032.23***	-1032.23***	0.01	0.01
UKX	-39.1***	-39.1***	-818.96***	-819.08***	0.01	0.01

Notes: See Table A2.