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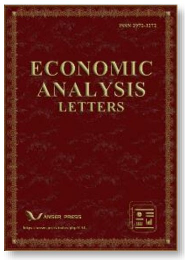

Long-Term Dependencies in Central European Stock Markets: A Crisp-Set Analysis

Rui Manuel Teixeira Dias [a,*], Mariana Chambino [b], Nicole Rebolo Horta [b]

[a] *Center for Studies and Advanced Training in Management and Economics (CEFAGE), University of Évora, Évora, Portugal*
[b] *School of Business and Administration, Polytechnic Institute of Setúbal, Setúbal, Portugal*

ABSTRACT

This paper intends to analyze efficiency, in its weak form, in the stock markets of Austria (ATX), Poland (WIG), the Czech Republic (PX Prague), Hungary (BUX), Croatia (CROBEX), Serbia (BELEX 15), Romania (BET), and Slovenia (SBI TOP), from February 16, 2018, to February 15, 2023. To achieve the research aim, we intend to answer the following research question: i) Have events in 2020 and 2022 heightened the persistence of Central European stock markets? Results suggest that persistence in returns has increased significantly during the first wave of Covid-19 and the Russian invasion in the year 2023, but we also saw that most stock markets already exhibit long memories, implying that the research question has been partially validated. This research can provide valuable insights to investors, policymakers, and others interested in financial risk management.

KEYWORDS

Events of 2020 and 2022; Central European markets; Persistence in returns; Portfolio diversification

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* Corresponding author: Rui Manuel Teixeira Dias
E-mail address: rui.dias@esce.ips.pt

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1. Introduction

Russia launches a full-scale military offensive and invades Ukraine on February 24, 2022, after tensions between the nations have been simmering since 2014 due to the Russian Federation's annexation of Crimea. Opinions point to the largest military offensive on European soil since World War II (1939 -1945). The effects of this event have contributed to financial market instability, with European stock markets dropping. The increase in geopolitical tensions may potentially impact capital outflows from emerging markets, which include certain countries in the region under consideration. We are currently in a difficult context, facing uncertainty, food and energy price inflation, and an economic downturn (Dias, Pardal, et al., 2022; Pardal, P., Dias, R., Teixeira, N. and Horta, 2022; Sun et al., 2022; Teixeira et al., 2022).

The study of the predictability of stock market returns is essential because it provides information on the degree to which future returns may be estimated based on historical data. This information can be used to validate investment decisions and better management risk. Furthermore, knowing return predictability can aid in identifying market inefficiencies and potential mispricing, which can promote investment strategies aiming at achieving above-market average returns. Furthermore, it can assist regulators and policymakers in developing policies that promote financial stability by decreasing systemic risk and maintaining fair and transparent markets (Fama, 1965, 1970, 1991; Fama and French, 1988).

In more recent studies, authors Zebende et al. (2022), Guedes et al. (2022) analyzed efficiency in G20 stock markets, in their weak form. Zebende et al. (2022) demonstrate that during the 2020 global pandemic, and for terms shorter than 5 days, stock markets tend to be efficient; however, for terms longer than 10 days, markets reject the random walk hypothesis, indicating persistence in their returns. Additionally, Guedes et al. (2022) demonstrate that stock markets in the 20 most developed economies (G20) exhibit persistence in their returns. The authors suggest that in certain markets, the random walk hypothesis is rejected, which has implications for investors since some returns may be expected, allowing arbitrage and opportunities for above-market average returns without incurring additional risk.

This research has two major contributions to literature. The first contribution is on the 2020 and 2022 events, which have the potential to disrupt financial markets in Central Europe. The Covid-19 pandemic wreaked havoc on the world economy, while Russia's invasion of Ukraine in 2022-2023 had far-reaching implications for global geopolitics. Studying the persistence of stock market returns throughout these events can assist researchers in understanding how financial markets responded to these shocks and identifying potential risk management strategies in the future. The second contribution is of an econometric nature since findings are compared between different econometric methods and mathematical models capable of assessing correlations in a non-stationary context.

In terms of structure, this paper is organized into 5 sections. In addition to the current introduction, section 2 describes the methodology. Section 3 provides the data, whereas section 4 includes the results. Section 5 outlines the paper's overall conclusions.

2. Methodology

The methodology used to answer the research question is structured as follows: first, we performed descriptive statistics (mean, standard deviation, asymmetry, and kurtosis), then we used the Jarque and Bera (1980) test to validate the time series distributions. To confirm the assumptions of stationarity of the time series we will use the summary table of panel unit root tests, namely the Breitung (2000), Levin, Lin, and Chu (2002), Im et al. (2003) tests, in validation the Dickey and Fuller (1981), Phillips and Perron (1988) tests with Fisher Chi-square transformation. We will use the Detrended Fluctuation Analysis (DFA) methodology to answer the research question, which is a tool for analyzing dimension and time dependency in non-stationary data series. Therefore, by assuming non-stationarity, it avoids spurious results when the study focuses on the long-term relations of time series.

2.1. Detrended Fluctuation Analysis DFA method

This method, proposed by Peng et al. (1994), was originally used to study DNA behavior. It is now widely employed in different areas, including finance and physics. Has been used in finance, namely in stock markets, to analyze the volatility and long-term dependence properties of time series such as stock prices or returns. In other words, this methodology is used to evaluate the behavior of financial series, identifying the long-term correlation in a time series, removing the trend, and then measuring its fluctuations. The DFA is interpreted as follows: $0 < \alpha < 0{,}5$: anti-persistent series; $\alpha = 0{,}5$: series presents a random walk; $0{,}5 < \alpha < 1$: persistent series.

The aim of this methodology, according to authors Zebende et al. (2022), Guedes et al. (2022), is to examine the relationship between x_k and x_{k+t} values at different moments.

Consider a dataset x_k with $k = 1,\ldots,t$ equidistant observations. The first step of DFA is to establish a new series:

$$x(t) = \sum_{k=1}^{t} x_k \quad (1)$$

The second step is obtaining the trend $z(t)$ of each fraction using the least squares method, then calculating the series subtracted from the trend (detrended), that is:

$$x_s(t) = x(t) - z(t) \quad (2)$$

The original application assumes that the trend present in each of the boxes is a linear trend, e.g., $Z(t) = at + b$ and subsequent applications indicate that it is likely to contain other polynomial trends (Kantelhardt, Koscielny-Bunde, Rego, Havlin e Bunde, 2001). The value of the trend equation is obtained for each box by using the least squares method, and then the root mean square deviation between the series is estimated $x(t)$ and $Z(t)$, where the DFA equation is given by:

$$F(s) = \sqrt{\frac{1}{2N} \sum_{t=1}^{2N} [x_s(t)]^2} \quad (3)$$

By estimating the mean of $F(s)$ for all boxes centralized at s, the value of the fluctuations $\langle F(s) \rangle$, as a function of s, is generated. This estimation will be repeated for all the distinct values of s, where a power-law process is expected, i.e.:

$$F(s)\rangle \sim s\alpha^{\alpha} \quad (4)$$

In brief, the usefulness of this methodology is to identify non-random patterns in time series data, such as persistent trends or cycles.

Table 1 shows the interpretation of the α_{DFA} exponents:

Table 1. Detrended Fluctuation Analysis αDFA.

Exponent	Signal type
αDFA < 0.5	long-range anti-persistent
αDFA ≃ 0.5	uncorrelated, white noise
αDFA > 0.5	long-range persistent

3. Data

The data are stock market price indexes from the Warsaw Stock Exchange WIG (Poland), Prague Stock Exchange PX (Czech Republic), Budapest Stock Exchange BUX (Hungary), Vienna Stock Exchange ATX (Austria), Zagreb Stock Exchange CROBEX (Croatia), Belgrade Stock Exchange BELEX15 (Serbia), Bucharest Stock Exchange BET (Romania), and Ljubljana Stock Exchange SBI TOP (Slovenia) for the period from February 16, 2018, to February 15, 2023. To make the investigation more robust, we divided the sample into four sub-periods: the first, named "Tranquil," spans the period from February 16, 2018, to December 31. 2019; the second, called "1st Wave", covers the period from 02 January 1, 2020, to December 31, 2020; the third, named "2nd Wave", which covers the year 2021; while the fourth concerns the conflict of the Russian invasion of Ukraine and covers the period from January 1, 2022, to February 15, 2023. The quotations are daily and obtained through the Thomson Reuters Eikon platform; they are in local currency to prevent exchange rate distortions.

Figure 1 show the evolution, in levels, of stock market in Austria (ATX), Poland (WIG), the Czech Republic (PX Prague), Hungary (BUX), Croatia (CROBEX), Serbia (BELEX 15), Romania (BET), and Slovenia (SBI TOP) from February 16, 2018, to February 15, 2023. The indexes analyzed plainly indicate significant structural breaks, highlighting the volatility to which these stock markets were subjected, notably in the first months of 2020, when the first wave of the Covid-19 pandemic occurred and the oil price war between Russia and Saudi Arabia erupted. In 2022, fluctuations in the time series can be seen in the first and second quarters of the year, suggesting structural breaks, a scenario that occurs as a result of the Russian invasion of Ukraine and the associated concerns over rising inflation.

Table 2. The country names and indexes used in this paper.

Country	Index
Poland	Warsaw Stock Exchange (WIG)
Czech Republic	Prague Stock Exchange (PX)
Hungary	Budapest Stock Exchange (BUX)
Austria	Vienna Stock Exchange (ATX)
Croatia	Zagreb Stock Exchange (CROBEX)
Serbia	Belgrade Stock Exchange (BELEX 15)
Romania	Bucharest Stock Exchange (BET)
Slovenia	Ljubljana Stock Exchange (SBI TOP)

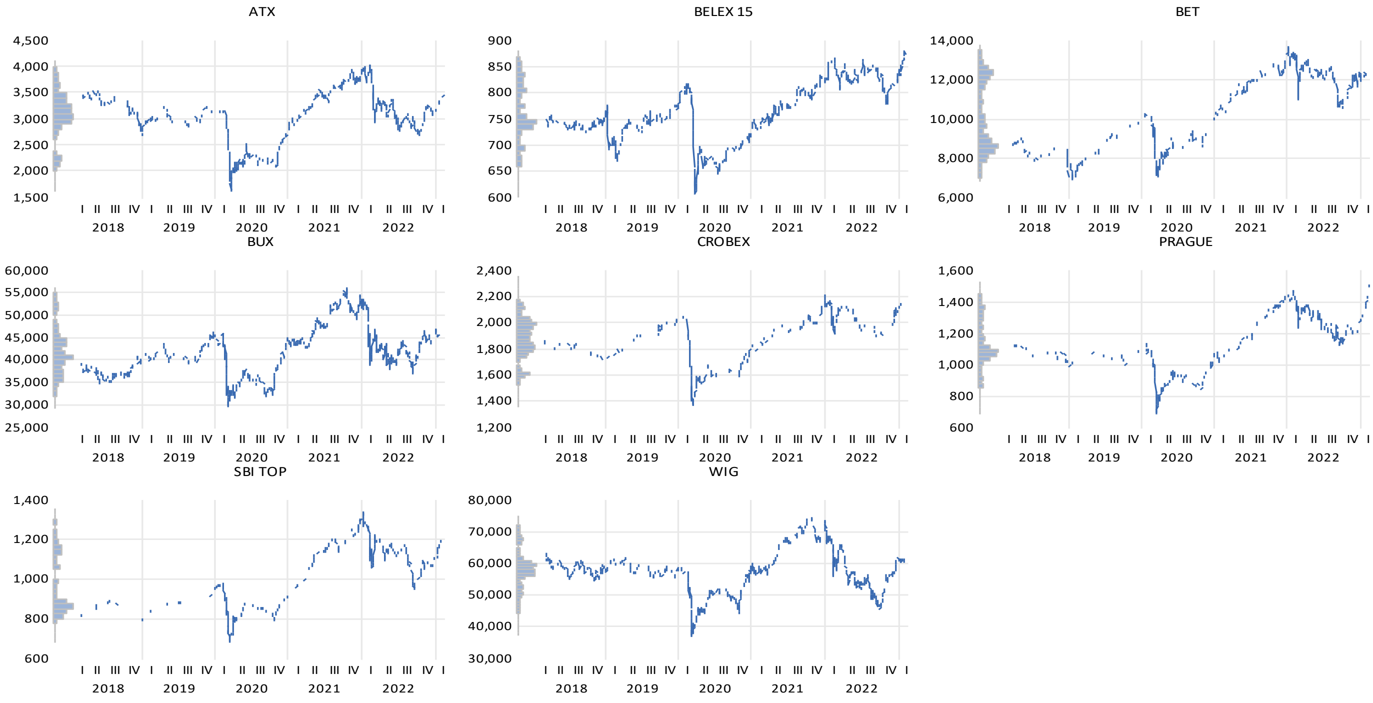

Figure 1. Evolution, in levels, of the financial markets under analysis, from February 16, 2018, to February 15,

2023.

Table 3 contains a summary of the major descriptive statistics, in returns, of the time series of the stock indexes of Austria (ATX), Poland (WIG), Czech Republic (PX Prague), Hungary (BUX), Croatia (CROBEX), Serbia (BELEX 15), Romania (BET), and Slovenia (SBI TOP). In relation to the average of returns, we found that the markets present positive values, with the exception of the Polish stock market (-6.76E-05); in terms of standard deviation, we noted that the BUX stock index (0.014293) presents the highest value, indicating a greater dispersion in relation to the average. To establish if we were dealing with normal distributions, we estimated the skewness and kurtosis and noticed that they have distinct values of 0 and 3, respectively, indicating that the asymmetries have values other than 0, and the kurtosis has values other than 3. To validate, we performed Jarque and Bera's (1980) test and found that H_0 is rejected at a 1% significance level.

In order to validate the stationarity assumptions of time series for the stock indexes of Austria (ATX), Poland (WIG), Czech Republic (PX Prague), Hungary (BUX), Croatia (CROBEX), Serbia (BELEX 15), Romania (BET), and Slovenia (SBI TOP), we estimate panel unit root tests, namely Breitung (2000), Levin, Lin, and Chu (2002), Im et al. (2003), in validation the Dickey and Fuller (1981), Phillips and Perron (1988) tests with Fisher Chi-square transformation. To achieve stationarity, we transform the original data, into logarithmic first differences, and confirm stationarity with the rejection of H_0 at a significance level of 1% (see table 4).

Table 3. Summary table of descriptive statistics, in returns, in respect of the stock markets under analysis from February 16, 2018, to February 15, 2023.

	ATX	BELEX 15	BET	BUX	CROBEX	PRAGUE	SBI TOP	WIG
Mean	1.15E-05	9.71E-05	0.000323	0.000161	0.000181	0.000243	0.000356	-6.76E-05
Std. Dev.	0.014923	0.007040	0.011431	0.014293	0.008237	0.010466	0.009180	0.013503
Skewness	-1.204209	-1.041144	-1.746042	-1.424042	-3.961425	-1.034033	-1.876232	-1.294956
Kurtosis	18.23537	14.70699	23.20574	14.86453	53.72062	14.36294	22.27107	16.84349
Jarque-Bera	12500.56	7428.836	22092.01	7822.327	138465.8	7008.713	20252.45	10421.63
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	1261	1261	1261	1261	1261	1261	1261	1261

Table 4. Summary table of panel unit root tests, in returns, for the stock markets under consideration, from February 16, 2018, to February 15, 2023.

Group unit root test: Summary				
Method	Statistic	Prob.**	sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-122.308	0.0000	8	10064
Breitung t-stat	-44.6855	0.0000	8	10056
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-79.1477	0.0000	8	10064
ADF - Fisher Chi-square	2015.90	0.0000	8	10064
PP - Fisher Chi-square	2107.13	0.0000	8	10072

*Notes: ** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.*

4. Empirical results

Table 5 and 6 shows the results of the Detrended Fluctuation Analysis (DFA) exponents applied to the time series of stock markets from Austria (ATX), Poland (WIG), the Czech Republic (PX Prague), Hungary (BUX), Croatia (CROBEX), Serbia (BELEX 15), Romania (BET), and Slovenia (SBI TOP). To provide robustness to the results, the sample was divided into four sub-periods: a first sub-period, which we refer to as Tranquil; a second, which covers the year 2020 and which we refer to as 1st Wave; a third sub-period, which we refer to as 2nd Wave, and which covers 2021; while the fourth sub-period concerns the conflict of the Russian invasion of Ukraine and covers the years 2022 and 2023.

Table 5 shows the DFA coefficient values for the Tranquil period, which spans from February 16, 2018, to December 31, 2020. We can verify the presence of long memories in the stock indexes SBI TOP (0.56), PX (0.55), ATX, BET, and WIG with a coefficient of 0.54, and the BELEX15 index (0.53). We find anti-persistence in the BUX stock market (0.43), whereas the CROBEX index shows equilibrium, indicating that the random walk hypothesis is not rejected.

Stock markets experienced tremendous volatility during the first wave of Covid-19, due to the global economic instability; for example, prominent indexes such as the S&P 500, Dow Jones, NIKKEI 225, DAX 30, CAC 40, and FTSE 100 showed very significant structural breaks in March 2020. Based on the results in table 5, concerning the year 2020, the stock indexes CROBEX (0.71), ATX (0.69), WIG (0.68), BELEX 15 (0.67), PX (0.67), BUX (0.63), BET (0.62), and SBI TOP (0.60) have shown increased persistence in their returns.

Table 6 shows the DFA exponents for the second wave of COVID-19, which spans the year 2021 and the Russian invasion of Ukraine (2022–2033). When we examine the year 2021, we observe that the indexes have greatly reduced their persistence in returns. For example, the stock indexes BELEX 15 (0.47), BUX (0.47), and ATX (0.43) exhibit anti persistence, suggesting that they had long memories in the year 2021. Although the stock markets CROBEX (0.60) and WIG (0.59) exhibit persistence in their returns on a lesser scale, the indexes SBI TOP (0.51), BET (0.49), and PX (0.51) show signs of equilibrium since the random walk hypothesis was not rejected.

Already in the years 2022–23, which include Russia's invasion of Ukraine, we see a persistence in returns, which is accentuated at 1st Wave Covid-19 levels. The stock indexes WIG (0.69), ATX (0.64), BET (0.58), CROBEX (0.58), SBI TOP (0.57), PX (0.57), BUX (0.56), and BELEX 15 (0.56) reveal that these markets are (in)efficient, implying that historical prices can provide some predictive ability over future stock price formation. In conclusion, these Central European stock markets exhibit persistent returns. According to the concept of persistence in returns, a stock that has performed well in the past is likely to continue to do so in the future, and a stock that has performed poorly in the past is probably going to continue performing poorly. The fact that we observed persistence in returns over the Tranquil period, the first wave of Covid-19, and the Russian invasion of Ukraine may be indicative of a persistent characteristic of these markets rather than a temporary anomaly.

Table 5. Detrended Fluctuation Analysis results, from February 16, 2018, to December 31, 2020.

Stock Index	DFA Exponent (Tranquil)	DFA Exponent (1st Wave: 2020)
ATX	0.54*** ≅ 0.0013 (R^2 = 0.99)	0.69*** ≅ 0.0055 (R^2 = 0.94)
BELEX15	0.53*** ≅ 0.0015 (R^2 = 0.98)	0.67***≅ 0.0059 (R^2 = 0.95)
BET	0.54*** ≅ 0.0039 (R^2 = 0.96)	0.62*** ≅ 0.0058 (R^2 = 0.94)
BUX	0.43*** ≅ 0.0015 (R^2 = 0.98)	0.63*** ≅ 0.0038 (R^2 = 0.95)
CROBEX	0.51 ≅ 0.0094 (R^2 = 0.99)	0.71*** ≅ 0.0056 (R^2 = 0.97)
PX	0.55*** ≅ 0.0010 (R^2 = 0.99)	0.67*** ≅ 0.0062 (R^2 = 0.96)
WIG	0.54*** ≅ 0.0074 (R^2 = 0.98)	0.68*** ≅ 0.0043 (R^2 = 0.94)
SBI TOP	0.56*** ≅ 0.0012 (R^2 = 0.99)	0.60*** ≅ 0.0069 (R^2 = 0.95)

Notes: The hypotheses are H_0: α = 0.5 and H_1: α ≠ 0.5.

Table 6. Detrended Fluctuation Analysis results, from January 1, 2021, to February 15, 2023.

Stock Index	DFA Exponent (2nd Wave: 2021)	DFA Exponent (Conflict in Ukraine: 2022-2023)
ATX	0.43*** ≅ 0.0023 (R^2 = 0.95)	0.64*** ≅ 0.0018 (R^2 = 0.94)
BELEX15	0.47*** ≅ 0.0021 (R^2 = 0.93)	0.56***≅ 0.0014 (R^2 = 0.95)
BET	0.49 ≅ 0.0139 (R^2 = 0.95)	0.58*** ≅ 0.0021 (R^2 = 0.95)

BUX	0.47*** ≅ 0.0031 (R^2 = 0.96)	0.56*** ≅ 0.0013 (R^2 = 0.96)
CROBEX	0.60 ≅ 0.0029 (R^2 = 0.95)	0.58*** ≅ 0.0031 (R^2 = 0.94)
PX	0.51 ≅ 0.0145 (R^2 = 0.94)	0.57*** ≅ 0.0065 (R^2 = 0.94)
WIG	0.59*** ≅ 0.0091 (R^2 = 0.95)	0.69*** ≅ 0.0067 (R^2 = 0.94)
SBI TOP	0.51 ≅ 0.00264 (R^2 = 0.94)	0.57*** ≅ 0.0026 (R^2 = 0.95)

Notes: The hypotheses are H_0: α = 0.5 and H_1: α ≠ 0.5.

5. Conclusion

The general conclusion to be retained and, supported by the results obtained, through the tests carried out with mathematical and econometric models demonstrate that the events that occurred in 2020, the global pandemic and oil price war between Saudi Arabia and Russia, as well as the current war in 2022 between Russia and Ukraine, have a significant impact on the memory properties of the Central European stock markets. In practice, we saw greater persistence during the first wave of Covid-19 and the Russian invasion during the year 2023. The persistence of returns in Central European stock markets, observed in both calm and turbulent periods, suggests that this phenomenon may be driven by specific characteristics of these markets. Even though it's possible that market inefficiencies may have an impact on the persistence of returns, more research would be required to establish the underlying causes. However, its conclusion provides a clear and concise summary of the pattern observed in the data. Lastly, these findings are relevant for international investors looking to diversify their portfolios efficiently, and they also provide an opportunity for market regulators to bring forward measures to ensure better information for investors.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

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