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A Multiple Fluctuations and Detrending Analysis of Financial Market Efficiency: Comparison of Central and Eastern European Stock Indexes

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Abstract: *The analysis of stock market behaviour is still a very appealing topic because it can give investors information about where to invest their money. In this context, a dynamic investigation of Austria's (ATX), Serbia's (BELEX 15), Hungary's (BUX), Croatia's (CROBEX), Russia's (IMOEX), Czech Republic's (PX PRAGUE), Slovenia's (SBITOP), and Poland's (WIG) capital markets is carried out from September 18th, 2017, to September 15th, 2022. The results suggest that most indexes are far from being absent of long-term dependency, which may be interpreted as inefficiency; that is, throughout the Tranquil period, the stock market indexes SBI TOP (0.59), AEX (0.54), WIG (0.54), PRAGUE (0.53), and BELEX 15 (0.52) exhibit dependence over time. The CROBEX (0.47) and BUX (0.44) indexes indicate anti persistence, however, the Russian market shows equilibrium (0.49 ≅ 0.0126), indicating that the random walk hypothesis is not rejected. When we look at the behaviour of the markets under consideration during the Stress subperiod, we see that persistence was significantly higher in the capital markets under analysis, except for the Russian market, which demonstrates some equilibrium. To conclude, we suggest that policymakers must take a comprehensive approach to improve the efficiency of international financial markets during times of stress due to uncertainty in the global economy and its influence on the memory properties of capital markets.*

1. INTRODUCTION

The evolution of capital markets is changing in the wake of recent financial crises; the dynamism of capital markets causes the need for research on predictability in capital markets (i.e., we can anticipate future prices based on a series of previous prices). Investors usually fail to make a substantial profit, but anomalies in stock prices that deviate from their intrinsic value are detected (Bagão et al., 2020; Dias & Santos, 2020a, 2020b; Silva et al., 2020).

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According to the literature, a financial market is efficient when the competition among its various participants is equal, followed by the principle of maximum benefit, which leads to an equilibrium situation in which market prices of any security are a good estimate of the theoretical or intrinsic price (Dias, Pardal et al., 2021; Dias, Heliodoro, Alexandre, Santos & Vasco, 2021; Dias & Carvalho, 2021; Santos et al., 2021; Vasco et al., 2021).

One of the fundamental concepts of financial theory is market efficiency, in which financial asset prices provide appropriate signals for the acquisition of resources. The market efficiency hypothesis assumes that an investor cannot acquire an exceptional risk-adjusted return. However, several empirical investigations have demonstrated that an investor may achieve a higher return than the market average (Dias, Pardal, et al., 2022; Guedes et al., 2022; Horta et al., 2022; Sun et al., 2022).

Given the events of 2020, the oil price war between Russia and Saudi Arabia, and the Russian invasion of Ukraine in 2022, it is necessary to assess the presence of long memories in the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) from September 18th, 2017, to September 15th, 2022. The findings indicate that global economic uncertainty has had an impact on the memory properties of the capital markets studied; this evidence suggests that returns are autocorrelated over time, indicating some predictability in price formation.

This research has two major additions to the literature. Given the importance of these regional markets in the global competitive context, as well as the need for more empirical studies, particularly confirmatory on the financial dynamics in these markets, it was deemed extremely relevant to study the Central and Eastern European stock markets, with the Russian invasion of Ukraine in 2022 in mind. The second contribution is of an economic and econophysical nature, with results comparing econometric methodologies, econophysical models, and mathematical models capable of evaluating correlations in a non-stationary context.

This article is divided into five sections in terms of structure. Section 2 is a review of the literature on predictability in international capital markets. The methods and data are described in Section 3. The results are presented in Section 4. The fifth section concludes.

2. LITERATURE REVIEW

Several pieces of research have been conducted to investigate the implications of the Efficient Market Hypothesis (EMH), which argues that the present price of assets reflects all available information at a particular moment and that the price changes swiftly as new and unexpected information enters the market (Fama & French, 1988).

Smith and Ryoo (2003) tested predictability in European emerging markets, namely the indexes of Greece, Hungary, Poland, Portugal, and Turkey, and suggested that, except for Turkey, markets' returns are predictable (Istanbul). Borges (2010), on the other hand, examined the occurrence of long memories in the capital markets of the United Kingdom, France, Germany, Spain, Greece, and Portugal during the period from January 1993 to December 2007. The author demonstrates that daily and weekly returns are not normally distributed since they are skewed and leptokurtic, and they also display conditional heteroscedasticity. Overall, the

random walk hypothesis is refuted in daily data for Portugal and Greece, whereas weekly data for France and the United Kingdom demonstrate long memories. In Germany and Spain, the random walk hypothesis is not rejected.

Later, authors Santos et al. (2020) examined persistence in Argentina, Brazil, Chile, Colombia, Peru, and Mexico's capital markets from January 2018 to July 2020, demonstrating that stock index returns have a non-linear nature or a significant non-linear characteristic, except for Argentina's capital market. In a complementary way, the authors show that the DFA exponents show long-range memories, namely the Colombian (0.72), Chilean (0.66), Brazilian (0.58) and Peruvian (0.57) markets. The Argentinean market does not reject the random walk hypothesis, while the Mexican market shows some anti-persistence (0.41). Meanwhile, Dias and Santos (2020a) examined efficiency in its weak form in the capital markets of Botswana, Egypt, Kenya, Morocco, Nigeria, and South Africa from September 2nd, 2019, to September 2nd, 2020. The authors emphasize that the variance ratios are less than one, implying that the returns are autocorrelated over time and that there is a reversion to the mean, with no differences seen between the markets studied.

Dias, Heliodoro, Alexandre, Santos, and Farinha (2021) investigated the predictability of Eastern European capital markets, discovering that daily returns do not have normal distributions, have negative asymmetries, are leptokurtic, and show conditional heteroscedasticity. During the 2020 worldwide pandemic period, the DFA exponents vary from 0.64 to 0.75, indicating significant long memories in all markets except for Slovakia's capital market (0.45). Additionally, Vasco et al. (2021) examined predictability in the capital markets of Brazil, China, South Korea, USA, Spain, and Italy from December 2nd, 2020, to May 12th, 2020. The authors demonstrate that the 2020 worldwide pandemic has a considerable influence on the efficiency of these markets, implying that the stock markets studied are somewhat predictable.

In more recent studies, Dias, Pardal, et al. (2022) examined the presence of long memories in nine capital markets in Europe from June 5th, 2017, to June 3rd 2022, and found that the 2020 global pandemic and the Russian invasion of Ukraine made the markets predictable, implying that the random walk hypothesis is significantly rejected. Guedes et al. (2022), on the other hand, assess whether the recent 20 years' financial crises have affected efficiency in G20 capital markets from January, 2nd, 2000, to February 5th, 2021. The authors demonstrate that markets exhibit symptoms of (in) efficiency in each sliding window (1000 days), namely asymmetries, non-Gaussian distributions, and DFA exponents higher than 0.5. In addition, Zebende et al. (2022) used intraday data to measure market efficiency in G20 capital markets, implying and taking into account the DFA method that markets tend to be efficient for maturities of less than 5 days, while stock markets tend to be inefficient for maturities greater than 10 days. Dias, Pereira et al. (2022), on the other hand, tested the efficient market hypothesis, in its weak form, in the capital markets of Botswana, Egypt, Kenya, Morocco, Nigeria, South Africa, Japan, the United Kingdom, and the United States from September 2nd, 2019, to September 2nd, 2020. The authors show that returns are autocorrelated over time, implying that the random walk hypothesis is rejected in all markets studied, with no differences between mature and emerging economies.

In summary, the goal of this study is to aid investors and regulators in European capital markets where individual and institutional investors seek diversification advantages, as well as to support the implementation of policies that contribute to the efficiency of international capital markets.

3. DATA

The data analysed are the capital market pricing indexes of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) from September 18th, 2017, to September 15th, 2022. The sample was divided into two sub-periods: the Tranquil period, which spans the years September 18th, 2017, to December 30th, 2019, while the Stress period, which extends from January 2nd, 2020, to September 15th, 2022. The quotations are obtained daily using the DataStream platform and are in local currency to mitigate exchange rate distortions.

Table 1. The name of countries and their indexes used in this paper

Country	Index
Austria	ATX
Serbia	BELEX 15
Hungary	BUX
Croatia	CROBEX
Russia	IMOEX
Czech Republic	PX PRAGUE
Slovenia	SBITOP
Poland	WIG

Source: Own elaboration

4. METHODOLOGY

The investigation will proceed in stages. In the first step, we will create graphs in levels to better comprehend market fluctuations and potential structural breaks. In a subsequent stage, we will characterize the sample using descriptive statistics to determine if the data has a normal distribution. To determine if the time series represent white noise (mean = 0; constant variance), we will employ the panel stationarity summary test, which combines the tests of Levin et al. (2002); Im et al. (2003) and Dickey and Fuller (1981); Phillips and Perron (1988) with Fisher transformation. To validate residual stability, we will use the CUSUM square test; to understand when the most significant structural break occurs, we will use the test of Clemente et al. (1998). To solve the study issue, we will use the econophysical technique of Detrended Fluctuation Analysis (DFA). DFA is a method for analysing time dependency in nonstationary time series. By assuming that time series are nonstationary, this method prevents spurious results when the study focuses on the long-run relationships of time series. Peng et al. (1994) developed this methodology, which has its roots in the study of DNA behaviour. This approach was then used to investigate the behaviour of financial series. The DFA interprets it as follows: $0 < \alpha < 0.5$: anti persistent series; $\alpha = 0.5$ series presents random walk; $0.5 < \alpha < 1$ persistent series.

5. RESULTS

Figure 1 depicts the evolution, in levels, of the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) from September 18th, 2017, to September 15th, 2022. The graphs show the instability caused by the 2020 global pandemic, but also by the start of Russia's invasion of Ukraine, which altered the international socioeconomic, financial, and political scene, resulting in the emergence of a scenario marked by enormous unpredictability and uncertainty, as reflected in the expressive correction movements in the major world stock market

indexes and the activation of volatility. Dias, Pardal, et al. (2022); Teixeira, Dias, Pardal, and Horta (2022) support these findings by demonstrating significant structural breaks triggered by the 2020 and 2022 events.

Table 2 shows the descriptive statistics, return, of the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) from September 18th, 2017, to September 15th, 2022. According to the findings, the WIG and ATX indexes are the only ones with negative average returns. Among the stock market indexes analysed, the SBI TOP has the highest average daily return (0.000291). In turn, the Russian index (IMOEX) has the highest standard deviation (0.018450), while the BELEX 15 has the lowest (0.006947). To determine if the time series follow a normal distribution, we examine the asymmetry of the data and check for negative and non-zero asymmetries; also, we check that the kurtosis have values other than 3, indicating non-Gaussian distributions. In addition, we estimated the Jarque and Bera (1980) test, which confirms the rejection of the data's normality hypothesis, exhibiting that the time series do not have normal distributions.

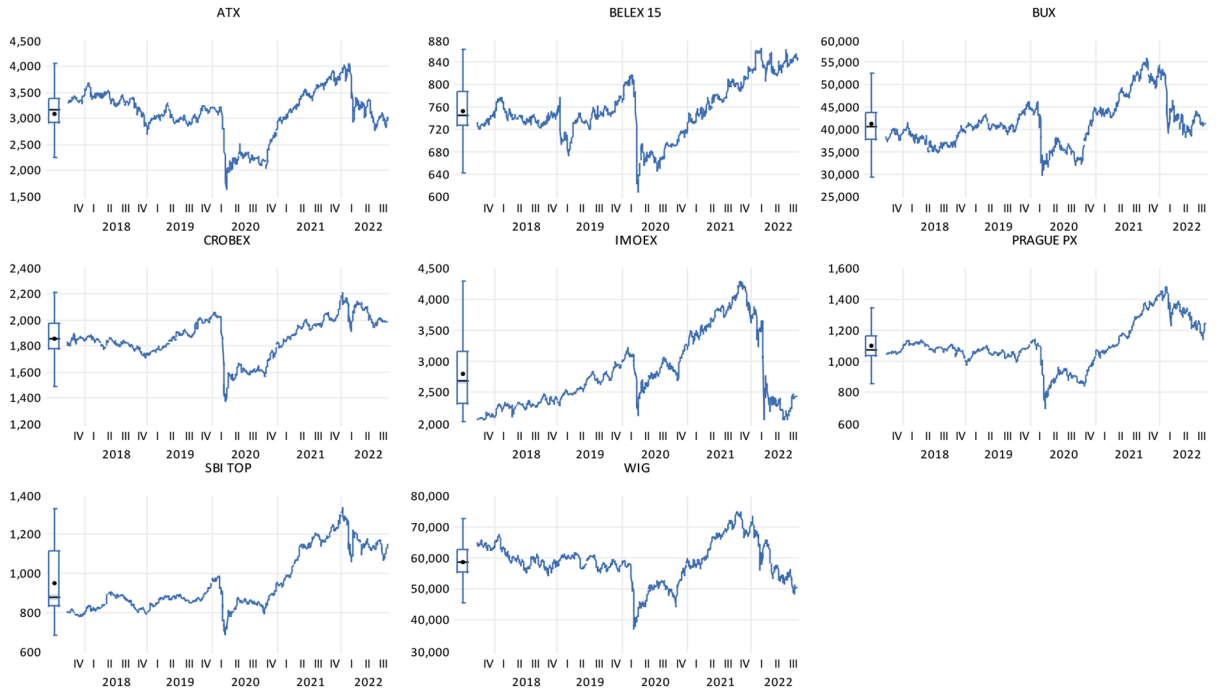


Figure 2. Evolution, in levels, of the European capital market fluctuation for the period from September 18th, 2017, to September 15th, 2022

Source: Own elaboration

Table 2. Summary descriptive statistics, in returns, of Europe's capital markets for the period from September 18th, 2017, to September 15th, 2022

	ATX	BELEX 15	BUX	CROBEX	IMOEX	PRAGUE	SBI TOP	WIG
Mean	-8.49E-05	0.000117	5.49E-05	7.80E-05	0.000137	0.000137	0.000291	-0.000195
Std. Dev.	0.014819	0.006947	0.014134	0.008240	0.018450	0.010112	0.009027	0.013147
Skewness	-1.231871	-1.068310	-1.477502	-3.907048	-8.081235	-1.194789	-1.980833	-1.403024
Kurtosis	18.69780	15.33660	15.46578	53.60873	196.4023	15.81751	23.65061	18.53894
Jarque-Bera	13224.21	8210.143	8596.194	137343.2	1972739.	8903.676	23157.21	13058.80
Probability	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Observations	1257	1257	1257	1257	1257	1257	1257	1257

Source: Own elaboration

Table 3 presents the panel stationarity summary test, which contains the tests of Levin et al. (2002), and Im et al. (2003), as well as the tests of Dickey and Fuller (1981), Phillips and Perron (1988) with Fisher transformation. The applied tests presume the existence of unit roots in the observable components of the time series as the null hypothesis. When the results of the LLC test are compared, we can see that stationarity is reached in the first differences with a significance of 1%.

Table 3. Summary panel stationarity tests
for the period from September 18th, 2017, to September 15th, 2022

Group unit root test: Summary				
Method	**Statistic**	**Prob.****	**Cross sections**	**Obs**
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-102.439	0.0000	8	10034
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-85.9182	0.0000	8	10034
ADF - Fisher Chi-square	1179.10	0.0000	8	10034
PP - Fisher Chi-square	795.875	0.0000	8	10040

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

Source: Own elaboration

Figure 2 depicts the CUSUM square test, which was applied to time series from the capital markets of Austria (ATX), Servia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) from September 18th, 2017, to September 15th, 2022. The CUSUM square model is a diagnostic test for detecting structural changes in time series residuals. Because the red line corresponds to the cumulative total, the null hypothesis (stability) is not rejected at a 5% significance level if the blue line remains within the confidence interval. Because all of the tests had statistics that fall beyond the critical bands of the 95 percent confidence interval, the results suggest the presence of instability.

Through the test of Clemente et al. (1998), we can validate the most substantial break in the structure of the time series in Figure 3. All of the indexes under consideration have significant structural breaks; the SBI TOP and CROBEX indexes break in 2017, while the ATX and BELEX 15 markets break in March 2020, coinciding with the 2020 pandemic. The BUX, IMOEX, PRAGUE, and WIG markets all had significant structural breaks in the first quarter of 2022, most likely as a result of their closeness to Russia. These findings are consistent with Dias and Santos (2020a), Dias and Carvalho (2021), Dias, Pereira, et al. (2022), Teixeira, Dias, Pardal, and Horta (2022), Dias, Pardal, et al. (2022), Horta et al. (2022), which reveal significant breaks in structure due to events in 2020 and 2022.

In order to investigate the price movement of the stock market indexes of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) from September 18th, 2017 to September 15th, 2022, the DFA exponents were estimated for two sub-periods, Tranquil and Stress, with the first characterized by relative stability in international financial markets while the second by significant market complexity due to events such as the Covid-19 pandemic crisis and Russia's invasion of Ukraine in 2022.

We can see the DFA exponents of the stock market indexes SBI TOP (0.59), AEX (0.54), WIG (0.54), PRAGUE (0.53), and BELEX 15 (0.52) throughout the Tranquil period, and we can verify

values more than 0.5. The CROBEX (0.47) and BUX (0.44) indexes exhibit anti-persistence, however, the Russian market exhibits equilibrium (0.49 ≅ 0.0126), indicating that the random walk hypothesis is not rejected.

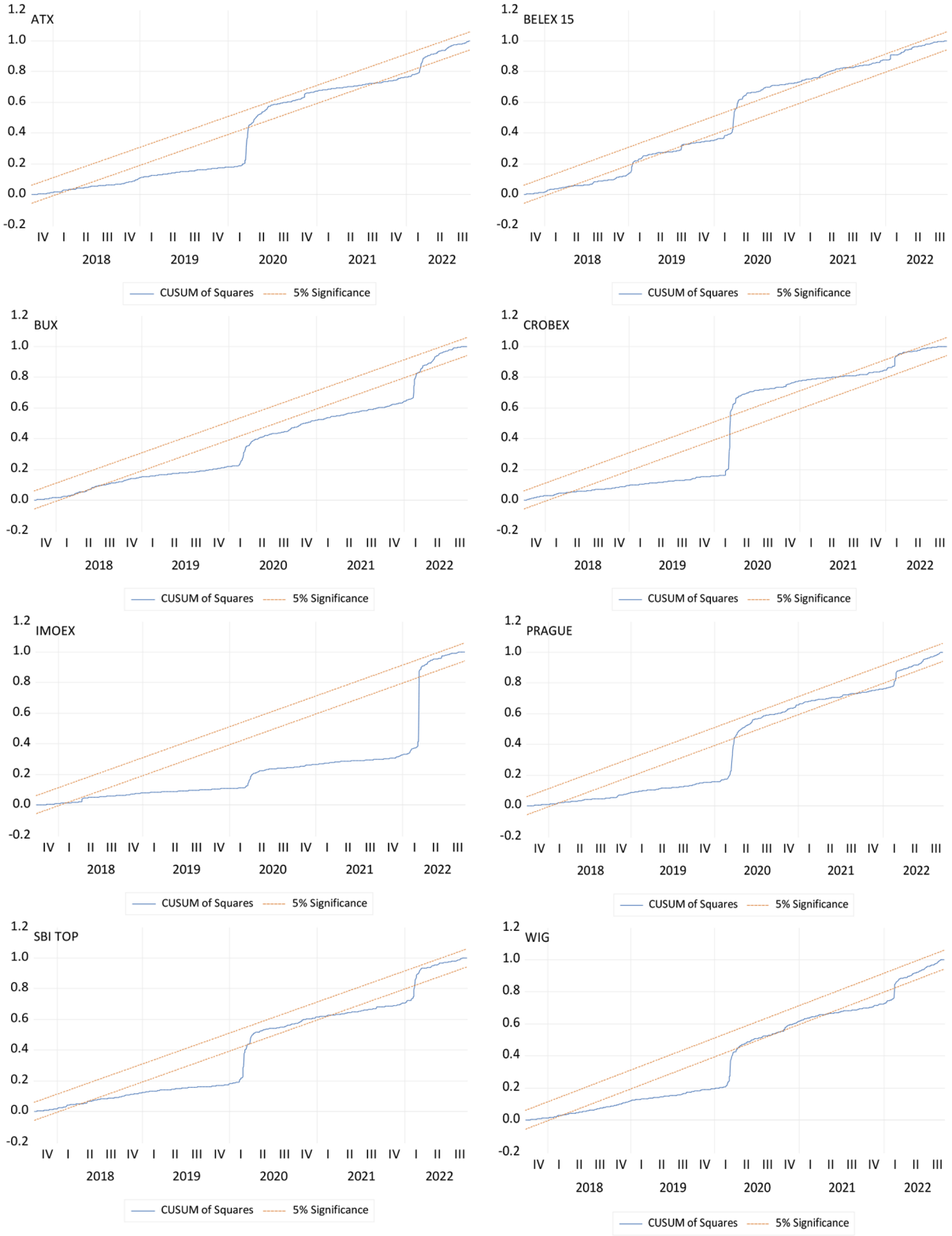
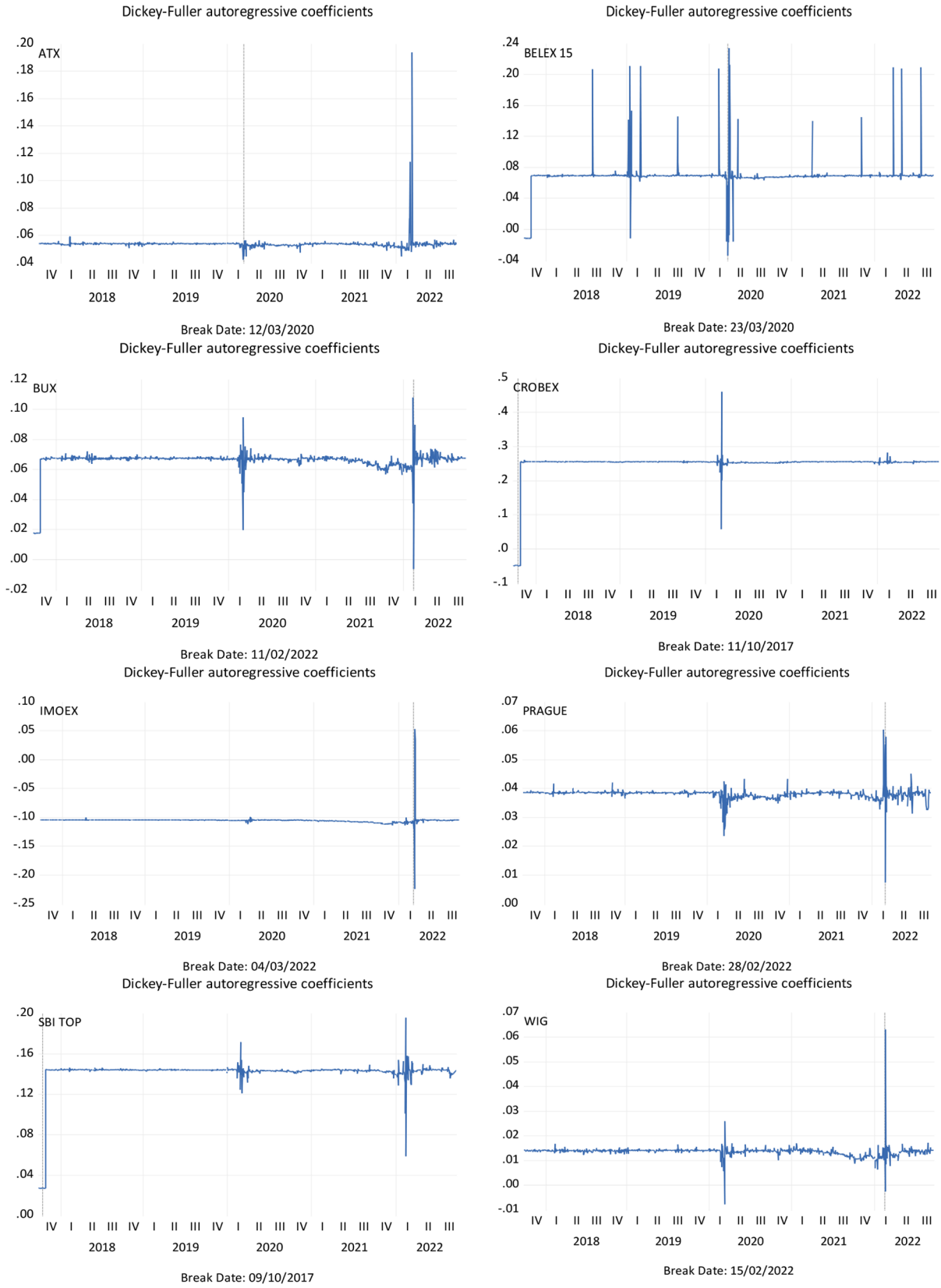


Figure 3. CUSUMSQ test applied to European capital markets for the period from September 18th, 2017, to September 15th, 2022

Source: Own elaboration



Note: Data worked by the author (software: Eviews12)

Figure 4. Clemente et al. (1998) stationarity test postulating structure breaks, over the period September 18th, 2017, to September 15th, 2022

Source: Own elaboration

During the Stress period, we can see that persistence increased. As we can see, the indexes CROBEX (0.69), SBI TOP (0.65), PRAGUE (0.64), BELEX 15 (0.64), AEX (0.62), WIG (0.60), BUX (0.59) all have significant exponents above 0.5, with the exception of the Russian capital market (IMOEX (0.49 ≅ 0.0208), which shows signs of equilibrium during a period of uncertainty. These findings are consistent with the findings of the authors Guedes et al. (2022), Teixeira, Dias, Pardal and Styles (2022), Dias, Pardal, et al. (2022), Horta et al. (2022), Zebende et al. (2022), Dias, Pereira, et al. (2022), who demonstrate the existence of long memories during stressful periods in international financial markets.

Table 4. DFA exponent for index and return (
the values of the linear adjustments for α DFA always had $R^2 > 0.99$)

Stock market	DFA exponent (Tranquil)	DFA exponent (Stress)
AEX	0.54 ≅ 0.0012***	0.62 ≅ 0.0014***
BELEX 15	0.52 ≅ 0.0025***	0.64 ≅ 0.0018***
BUX	0.44 ≅ 0.0136***	0.59 ≅ 0.0017***
CROBEX	0.47 ≅ 0.0017***	0.69 ≅ 0.0427***
IMOEX	**0.49 ≅ 0.0126**	**0.49 ≅ 0.0208**
PRAGUE	0.53 ≅ 0.0098***	0.64 ≅ 0.0014***
SBI TOP	0.59 ≅ 0.0096***	0.65 ≅ 0.0095***
WIG	0.54 ≅ 0.0038***	0.60 ≅ 0.0011***

Note: The hypotheses are H0: α = 0.5 and H1: α ≠ 0.5. ***, **, *, that represent significance at 1%. 5% and 10%, respectively.

Source: Own elaboration

6. CONCLUSION

The general conclusion to be retained and sustained by the results obtained employing econometric and econophysical models is that the global pandemic of 2020 and the Russian invasion of Ukraine in 2022 impacted the memory properties of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland's capital markets (WIG). This has implications for investors because certain returns may be expected, which opens up the potential for arbitrage and extraordinary returns. These findings also suggest that market regulators should take initiatives to improve information disclosure in these regional markets.

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