8th International Scientific Conference – ERAZ 2022 – Conference Proceedings
DOI: https://doi.org/10.31410/ERAZ.2022.71

Impact of Russia's Invasion of Ukraine on Central and Eastern European Capital Markets

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Received: July 1, 2022
Accepted: August 25, 2022
Published: December 30, 2022

Keywords:
Contagion effects;
Russian-Ukrainian invasion;
Portfolio diversification

Abstract: *On February 24th, 2022, Russia launched a full-scale military invasion against Ukraine, marking a sharp escalation to a conflict that began in 2014. Several analysts have called the invasion the largest military invasion in Europe since World War II. Considering these events this paper aims to test the efficient market hypothesis, in its weak form, in the capital markets of Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), the Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) over the period from April 25th, 2017, to April 22nd, 2022. The results show that the random walk hypothesis is not supported by the analyzed financial markets in this period with the occurrence of the 2020 global pandemic and the Russian invasion of Ukraine. The values of the variance ratios are less than unity, implying that the returns are autocorrelated over time and mean-reverting, and no differences between the financial markets have been identified. This has implications for investors, since some returns may be expected, creating arbitrage opportunities and abnormal returns, contrary to the assumptions of random walk and informational efficiency. In conclusion, we believe that investors should eventually exercise some caution, at least while this uncertainty persists, and invest in less risky markets to mitigate risk and improve the efficiency of their portfolios.*

1. INTRODUCTION

On February 21st, 2022, Putin recognized the Donetsk People's Republic and the Lugansk People's Republic, two self-proclaimed regions as states, controlled by pro-Russian separatists in Donbas. The next day, the Russian Federation Council unanimously authorized the use of military force and Russian troops entered both territories. On February 24th, Putin announced a "special military operation," supposedly to "demilitarize" and "denazify" Ukraine. Minutes later, missiles struck sites across Ukrainian territory, including Kiev, the capital. The Ukrainian Border Guard reported attacks on border crossings with Russia and Belarus. Shortly thereafter, Russian ground forces entered Ukraine. Ukrainian President Volodymyr Zelensky promulgated martial law and called for a general mobilization in the country.

Considering these events, it is pertinent to evaluate the crashes resulting from these events, as well as to test whether the capital markets of Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), the Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG), show signs of (in) efficiency due to uncertainty in the global economy in 2022. The results show that the

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capital markets, for the most part, exhibit significant structure breakdowns in March 2022 and that they are not efficient, in their weak form. These findings carry implications for investors, as some returns may be expected, creating opportunities for arbitrage and returns above market average without incurring additional risk.

In terms of structure, this paper is organized into 5 sections. Section 1 is represented by the current introduction. Section 2 presents a Literature Review of articles on the efficient market hypothesis in international financial markets. Section 3 describes the methodology and data. Section 4 contains the results. Section 5 refers to conclusions.

2. LITERATURE REVIEW

The European stock market is characterized by enormous connectivity between the different domestic markets in the region. These markets are also quite relevant because of their global financial importance. Authors such as Smith and Ryoo (2003), Borges (2010), Borges (2011), Sensoy and Tabak (2015), Caporale, Gil-Alana, and Poza (2020), Milos, Hatiegan, Milos, Barna, and Botoc (2020) have presented individual or group studies of the efficiency hypothesis, in its weak form, in various stock markets in Europe.

Borges (2010, 2011) has done extensive work on the European market and the study of its efficiency, at the weak form level. Borges (2010) tested the market efficiency in the main indices of the UK, France, Germany, Greece, and Portugal over the period 1993 to 2007. The results were not uniform, for the analysis of daily data the efficiency hypothesis for Portugal and Greece is rejected; however, after 2003 these two indices start to follow a martingale (heteroscedastic) behavior, that is, past price behavior does not help to predict future price fluctuations. Borges (2011) tests the random walk hypothesis, through the main Portuguese index, the PSI-20 in the period from 1993 to 2006. The results indicate that the Portuguese market from 2000 onwards has been showing behavior similar to the random walk hypothesis, which means that the Portuguese market has become more efficient, in its weak form, in recent years.

Caporale, Gil-Alana, and Poza (2020), Milos, Hatiegan, Milos, Barna, and Botoc (2020) tested market efficiency, in its weak form, in the capital markets of Europe. Caporale, Gil-Alana, and Poza (2020) analyzed the stock markets of Germany, the UK, France, Italy, and Spain, showing the presence of long memories, which may be disruptive to the market efficiency hypothesis, in its weak form. Milos, Hatiegan, Milos, Barna, and Botoc (2020) analyzed several Central and Eastern European markets. The results indicate that returns exhibited long-run correlations, which indicates that the stock markets under study reject the random walk hypothesis.

Pardal et al. (2021) analyzed the impact of the 2020 global pandemic on the banking sectors in the countries of the Czech Republic, Hungary, Poland, Romania, Russia, and Slovakia for the period from January 2nd, 2017, to August 10th, 2020. The authors show that the markets do not have the characteristics for an efficient diversification of portfolios. Meanwhile, the authors Dias, Heliodoro, Alexandre, Santos, and Vasco (2021) analyzed efficiency, in its weak form, in the foreign exchange markets in the period from September 3rd, 2018 to October 20th, 2020, suggesting persistence in these markets, showing the existence of high levels of arbitrage, i.e., investors may obtain returns above the market average without incurring in additional risk, which could compromise the implementation of efficient portfolio diversification strategies due to market imbalances.

In more recent studies, Zebende et al. (2022) analyzed market efficiency, in its weak form, in G-20 capital markets with intraday data from May 2019 to May 2020. To answer the research questions, they applied the DFA and DCCA methods, to identify or not two points: i) are the G-20 stock markets efficient, in their weak form? ii) with the opening/closing quotes, is it possible to identify any kind of memory in the G-20 capital markets? For this purpose, the authors divided the sample into two distinct time scales: period I, a time scale of less than five days, and period II, with a time scale of more than ten days. For the period of the 2020 global pandemic, the authors show that for time frames of less than 5 days, stock markets tend to be efficient, while for time frames longer than 10 days, stock markets tend to be inefficient. Meanwhile, Dias et al. (2022) measured capital market efficiency in Botswana, Egypt, Kenya, Morocco, Nigeria, South Africa, Japan, the UK, and the US over the period September 2nd, 2019, to September 2nd, 2020, suggesting that the random walk hypothesis is rejected and that investors with adjusted trading strategies will be able to achieve above average returns without incurring additional risk.

In summary, this paper aims to contribute to providing information to investors and regulators in Europe's equity markets where individual and institutional investors seek diversification benefits, as well as help promote the implementation of policies that contribute to the efficiency of these markets. Therefore, the context of this paper is to examine the market efficiency, in its weak form, and the predictability of these capital markets in this period of uncertainty in the global economy arising from the Russian invasion of Ukraine in 2022.

3. METHODOLOGY AND DATA

3.1. Data

The data analyzed are the prices index of 6 capital markets, namely, the stock indices of Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG), for the period from April 25th, 2017, to April 22nd, 2022. The price indices are daily and were obtained from the Thomson Reuters Eikon platform and are in local currency, to mitigate exchange rate distortions.

3.2. Methodology

The development of this research will take place in several stages. In the first stage, descriptive statistical measures will be used, as well as the Jarque and Bera (1980) goodness-fit test, to verify that the data follow a normal distribution. In the second stage, we will elaborate graphics, in levels, and in returns, to measure the evolution of the capital markets under analysis. To estimate stationarity, we will use the Levin, Lin, and Chu (2002), Im, Pesaran, and Shin (2003) test which postulates that the null hypothesis has unit roots, while the Hadri (2000) test, postulates stationarity under the null hypothesis; the interception of unit root tests will allow us to assess whether the time series has the characteristics of white noise. To validate the presence, or not, of structural breaks we will use the Clemente et al. (1998) test. This model will indicate the most significant crash, despite the existence of other breaks during the sample period.

In order to answer the research question, we will use the non-parametric test developed by Wright (2000), once it is a more resilient test to time series that do not exhibit normality and is quite consistent when they exhibit serial correlation. This author's methodology consists of two types of tests, the Rankings test for homoscedastic series and the Signs test for heteroscedastic series.

The variance (Rankings) test is based on the ordering of the yield series. We consider $r(r_t)$ as the profitability position, r_t, between $r_1, r_2, \dots, r_T$:

$$r'_{1t} = \frac{\left(r(r_t) - \frac{T+1}{2}\right)}{\sqrt{\frac{\frac{(T-1)(T+1)}{2}}{12}}} \tag{1}$$

$$r'_{2t} = \Phi^{-1}\left(\frac{r(r_t)}{T+1}\right) \tag{2}$$

Where Φ^{-1} translates that the cumulative inverse standardized normal distribution, r'_{2t} is a standardized linear transformation of the position of the returns and r'_{2t} is a standardized inverse normal transformation. Where translates that the cumulative inverse standardized normal distribution, is a standardized linear transformation of the position of the returns and is a standardized inverse normal transformation.

$$R_1(q) = \left(\frac{\frac{1}{Tq}\sum_{t=q+1}^{T}(r'_{1t} + r'_{1t-1} + \dots + r'_{1t-q})^2}{\frac{1}{T}\sum_{t=q+1}^{T}(r'_{1t})^2}\right) \times \left(\frac{2(2q-1)(q-1)}{3qT}\right)^{-1/2} \tag{3}$$

$$R_2(q) = \left(\frac{\frac{1}{Tq}\sum_{t=q+1}^{T}(r'_{2t} + r'_{2t-1} + \dots + r'_{2t-q})^2}{\frac{1}{T}\sum_{t=q+1}^{T}(r'_{2t})^2}\right) \times \left(\frac{2(2q-1)(q-1)}{3qT}\right)^{-1/2} \tag{4}$$

The rejection of the random walk hypothesis of the returns is generated by a simulation process, where the values of the statistics r'_{1t} and r'_{2t} are replaced by the simulated values r'^{*}_{1t} and r'^{*}_{2t}. Using bootstrap estimates, which result in the successive random generation of data, to simulate the statistical properties of the true sample distribution, the exact distribution of $R_1(q)$ and $R_2(q)$ can be approximated to a certain confidence level.

Wright's (2000) methodology proposes a second test, called sign-variance ratio, which considers the sign of the returns, r_t, to calculate the sign ratio, and it is heteroscedastic, so we can use the following test statistic, as follows:

$$S_1(q) = \left(\frac{\frac{1}{Tq}\sum_{t=q+1}^{T}(S_t + S_{t-1} + \dots + S_{t-q})^2}{\frac{1}{T}\sum_{t=q+1}^{T}(S_t)^2}\right) \times \left(\frac{2(2q-1)(q-1)}{3qT}\right)^{-1/2} \tag{5}$$

Where,

$$S_t = 2\upsilon(r_t, 0) \tag{6}$$

$$\upsilon(x_t, p) = \begin{cases} 0{,}5 & x_t > p \\ -0{,}5 & x_t \le p \end{cases}$$

The distribution of $S_1(q)$ can be approximated by $S_1^{*}(q)$ using bootstrap techniques, as was done for the variance ratio by rank. $S_1^{*}(q)$ is obtained from the sequence $\{S_t^{*}\}_{(t=1)}^{T}$, as each of its elements being able to register the values 1 or –1, with equal probability.

4. RESULTS

Figure 1 shows the evolution, in levels, of the 6 capital markets under analysis, namely, the Hungarian (BUX), Croatian (CROBEX), Russian (IMOEX), Czech (PX PRAGUE), Slovenian (SBITOP), and Polish (WIG) stock indices. From the graphical analysis we can verify the existence of structural breaks in 2020 and 2022, due to the global pandemic of 2020 and the Russian invasion of Ukraine. This evidence is validated by the authors Dias et al. (2022), Zebende et al. (2022) who show significant structural breaks in international capital markets. Figure 2 shows the evolution, in terms of returns, of the 6 stock markets under analysis and we can see the existence of extreme volatility, and the existence of a bear market period, between February, March and April 2020, characterized by a sharp drop in the index prices, due to the evolution of the global pandemic (Covid-19), and in 2022 due to the Russian invasion of Ukraine.

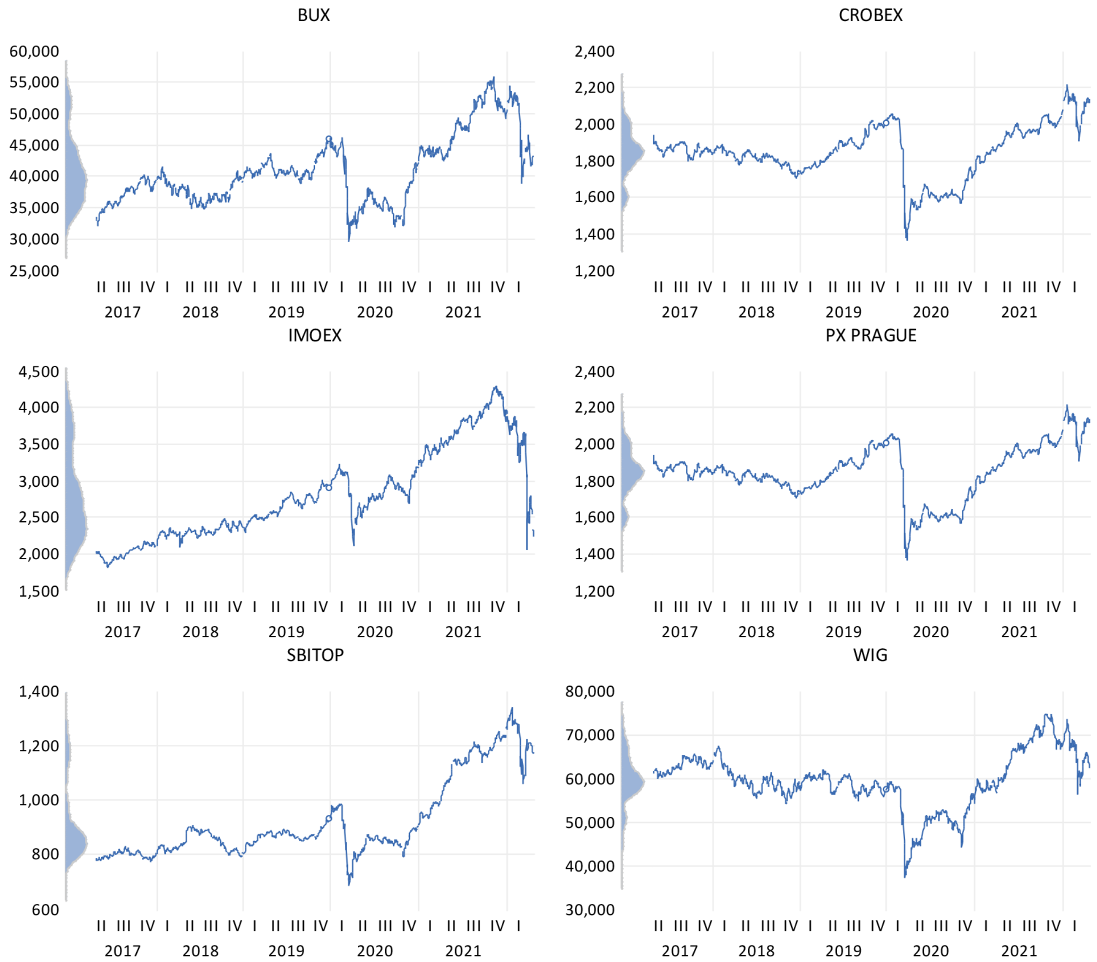

Figure 1. Evolution, in levels, of the 6 capital markets for the period April 25th, 2017, to April 22nd, 2022

Source: Own elaboration

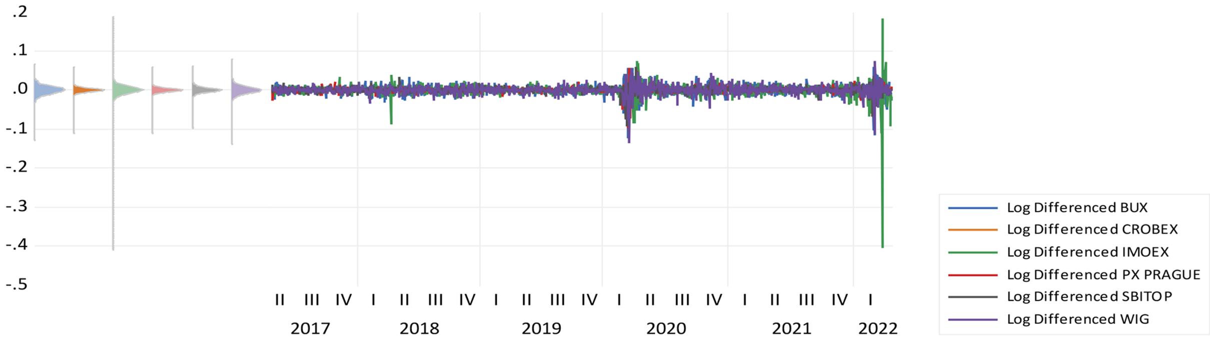

Figure 2. Evolution of returns of the 6 capital markets, in the period from April 25th, 2017, to April 22nd, 2022

Source: Own elaboration

Table 1 shows the main descriptive statistics of the 6 capital markets under analysis, namely, the Hungarian (BUX), Croatian (CROBEX), Russian (IMOEX), Czech (PX PRAGUE), Slovenian (SBITOP), and Polish (WIG) stock market indices, for the period from April 25th, 2017, to April 22nd, 2022. From the analysis we can see that the average returns are positive, except for the Polish stock market (WIG), while the market with the highest standard deviation is Russia (0.018017). The skewness of the time series is negative, most notably in the IMOEX index (-8.832515), while the kurtosis is greater than 3, which means the skewness and kurtosis coefficients are statistically different from those of a normal distribution.

Table 1. Descriptive statistics, in returns, of the 6 capital markets for the period April 25th, 2017, to April 22nd, 2022

	BUX	CROBEX	IMOEX	PX PRAGUE	SBITOP	WIG
Mean	0.000204	7.85E-05	8.90E-05	7.78E-05	0.000332	-3.68E-06
Median	0.000734	0.000356	0.000913	0.000356	0.000435	0.000107
Maximum	0.060033	0.056229	0.182620	0.056229	0.059589	0.074326
Minimum	-0.122684	-0.107323	-0.404674	-0.107323	-0.093825	-0.135265
Std. Dev.	0.013565	0.008276	0.018017	0.008276	0.008938	0.012624
Skewness	-1.679062	-3.909550	-8.832515	-3.909221	-2.026151	-1.644696
Kurtosis	17.91385	53.31174	218.3426	53.30916	24.74132	21.73712
Jarque-Bera	12103.71	134265.2	2417867.	134251.2	25331.61	18743.40
Probability	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	1243	1243	1243	1243	1243	1243

Source: Own elaboration

In tables 2, 3 and 4 we can examine the stationary nature of the data series, referring to the 6 capital markets under analysis, namely, the Hungarian (BUX), Croatian (CROBEX), Russian (IMOEX), Czech (PX PRAGUE), Slovenian (SBITOP), and Polish (WIG) stock indices. The Levin, Lin, and Chu (2002), Im, Pesaran, and Shin (2003) test postulate that the null hypothesis has unit roots, showing the stationarity of time series in first differences. The Hadri (2000) test, on the other hand, postulates stationarity in the null hypothesis and we can see that the stationarity hypothesis is validated in the first differences, showing that the data series are stationary, suggesting that we are facing a white noise (mean = 0; constant variance).

Table 2. Levin, Lin, and Chu (2002) stationarity test concerning the 6 capital markets for the period from April 25th, 2017, to April 22nd, 2022

Method				Statistic		Prob.**	
Levin, Lin & Chu t*				-78.7569		0.0000	
** Probabilities are computed assuming asymptotic normality							
Intermediate results on D(UNTITLED)							
	2nd Stage	Variance	HAC of		Max	Band-	
Series	Coefficient	of Reg	Dep.	Lag	Lag	width	Obs
D(BUX)	-0.90795	288598	7974.3	2	22	76.0	1238
D(CROBEX)	-0.74826	195.61	5.0673	2	22	81.0	1238
D(IMOEX)	-1.11734	2318.1	21.142	0	22	238.0	1240
D(PX PRAGUE)	-0.74826	195.61	5.0673	2	22	81.0	1238
D(SBITOP)	-0.86656	69.744	0.9807	1	22	162.0	1239
D(WIG)	-0.99787	479519	5627.6	0	22	180.0	1240
	Coefficient	t-Stat	SE Reg	mu*	sig*		Obs
Pooled	-0.95456	-63.189	1.005	-0.500	0.707		7433

Note: ***. **. *. represent significance at 1%. 5% and 10%, respectively

Source: Own elaboration

Table 3. Im et al. (2003) stationarity test concerning the 6 capital markets for the period April 25th, 2017, to April 22nd, 2022

Method						Statistic	Prob.**
Im, Pesaran and Shin W-stat						-64.8304	0.0000
** Probabilities are computed assuming asymptotic normality							
Intermediate ADF test results							
						Max	
Series	t-Stat	Prob.	E(t)	E(Var)	Lag	Lag	Obs
D(BUX)	-18.316	0.0000	-1.514	0.754	2	22	1238
D(CROBEX)	-15.755	0.0000	-1.514	0.754	2	22	1238
D(IMOEX)	-39.583	0.0000	-1.532	0.735	0	22	1240
D(PX PRAGUE)	-15.755	0.0000	-1.514	0.754	2	22	1238
D(SBITOP)	-21.790	0.0000	-1.530	0.745	1	22	1239
D(WIG)	-35.112	0.0000	-1.532	0.735	0	22	1240
Average	-24.385		-1.523	0.746			

Source: Own elaboration

Note: ***. **. *. represent significance at 1%. 5% and 10%, respectively

Table 4. Hadri's (2000) stationarity test concerning the 6 capital markets for the period April 25th, 2017, to April 22nd, 2022.

Method			Statistic	Prob.**
Hadri Z-stat			-1.62866	0.9483
Heteroscedastic Consistent Z-stat			-0.69101	0.7552
* Note: High autocorrelation leads to severe size distortion in Hadri test, leading to over-rejection of the null.				
** Probabilities are computed assuming asymptotic normality				
Intermediate results on D(UNTITLED)				
		Variance		
Series	LM	HAC	Bandwidth	Obs
D(BUX)	0.0585	338068.0	11.0	1241
D(CROBEX)	0.1289	352.5232	18.0	1241
D(IMOEX)	0.2773	2259.988	9.0	1241
D(PX PRAGUE)	0.1289	352.5232	18.0	1241
D(SBITOP)	0.0816	107.6805	13.0	1241
D(WIG)	0.0725	518298.4	6.0	1241

Source: Own elaboration

In figure 3 we can observe the most significant structure breaks in the capital markets of Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PX PRAGUE), Slovenia (SBITOP), and Poland (WIG) during the period from April 25th, 2017, to April 22nd, 2022.

The test results of Clemente et al. (1998) show that the crashes occurred on different dates, namely in 2017 and 2022; however, we also see crashes in the first months of 2020, but those were not the most significant crashes. The stock markets of Croatia (CROBEX), the Czech Republic (PX PRAGUE), and Slovenia (SBITOP), show the most significant structural breaks in May 2017, while the stock indices of Hungary (BUX), Russia (IMOEX), and Poland (WIG) break sharply in March 2022. These results are in line with events that occurred on February 24th, 2022, when Russia launched a full-scale military invasion against Ukraine, one of its neighbors to the southwest, marking a sharp escalation of a conflict that began in 2014.

In Table 5 are presented the results of the nonparametric version of Wright's (2000) variance test, which includes the Rankings and Signs Variance Ratios tests. In both cases, the statistics were calculated for lags of 2 to 16 days. The time series represent the capital markets of Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), the Czech Republic (PX PRAGUE), Slovenia

(SBITOP), and Poland (WIG) over the period from April 25th, 2017, to April 22nd, 2022. Based on the Rank Score Variance Ratio test and the Sign Variance Ratio test, we can see that the random walk hypothesis is rejected in all stock markets; we find that the values of the variance ratios are less than unity, which implies that the returns exhibit significant autocorrelation. Under these conditions, markets tend to overreact to information, eventually correcting it in the following days, whether it is good news or bad news. The high price sensitivity to the arrival of new information may have been due to the climate of pessimism and uncertainty experienced by investors during the sample period. These findings are validated by Dias, Heliodoro, Teixeira, and Godinho (2020), Dias, Santos, et al. (2021), Dias, Alexandre, et al. (2021), Dias, Heliodoro, et al. (2021), Zebende et al. (2022), Dias et al. (2022).

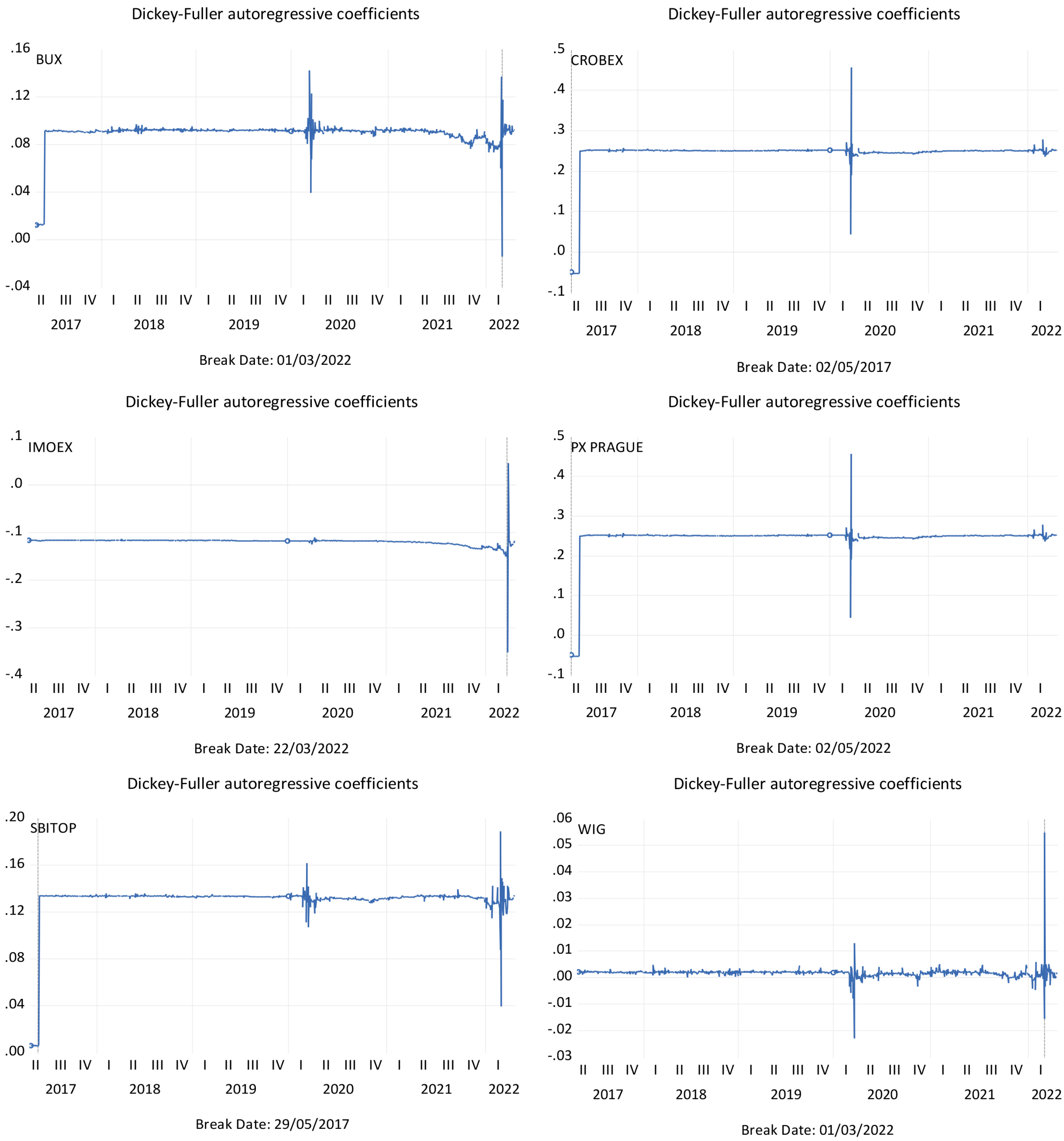

Figure 3. Stationarity tests with Clemente et al. (1998) structure breaks on returns, concerning the 6 capital markets, for the period from April 25th, 2017, to April 22nd, 2022

Source: Own elaboration

Table 5. Tests of Wright's (2000) Variance Ratios of Rankings and Signals, in returns, concerning the 6 capital markets, for the period from April 25th, 2017, to April 22nd, 2022

Null Hypothesis: BUX is a random walk (Rank Score Variance Ratio)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		15.39338	1241	0.0000
Wald (Chi-Square)		308.9323	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.563034	0.028387	-15.39338	0.0000
3	0.352490	0.042316	-15.30166	0.0000
4	0.277035	0.053107	-13.61348	0.0000
5	0.239133	0.062192	-12.23416	0.0000
6	0.214908	0.070174	-11.18784	0.0000
7	0.174045	0.077369	-10.67553	0.0000
8	0.166874	0.083969	-9.921853	0.0000
9	0.154280	0.090098	-9.386639	0.0000
10	0.142905	0.095844	-8.942571	0.0000
11	0.134406	0.101270	-8.547369	0.0000
12	0.118853	0.106424	-8.279622	0.0000
13	0.120160	0.111342	-7.902172	0.0000
14	0.107677	0.116053	-7.688895	0.0000
15	0.108104	0.120583	-7.396532	0.0000
16	0.106183	0.124950	-7.153416	0.0000

Null Hypothesis: BUX is a martingale (Sign Variance Ratio Test)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		10.24758	1241	0.0000
Wald (Chi-Square)		131.5036	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.709106	0.028387	-10.24758	0.0000
3	0.582057	0.042316	-9.876628	0.0000
4	0.512490	0.053107	-9.179847	0.0000
5	0.472683	0.062192	-8.478847	0.0000
6	0.444803	0.070174	-7.911762	0.0000
7	0.416600	0.077369	-7.540498	0.0000
8	0.407736	0.083969	-7.053382	0.0000
9	0.391172	0.090098	-6.757374	0.0000
10	0.375181	0.095844	-6.519098	0.0000
11	0.365028	0.101270	-6.270074	0.0000
12	0.347838	0.106424	-6.127983	0.0000
13	0.343458	0.111342	-5.896651	0.0000
14	0.334753	0.116053	-5.732246	0.0000
15	0.332796	0.120583	-5.533153	0.0000
16	0.323731	0.124950	-5.412334	0.0000

Null Hypothesis: CROBEX is a random walk (Rank Score Variance Ratio)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		16.53611	1241	0.0000
Wald (Chi-Square)		287.2557	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.530595	0.028387	-16.53611	0.0000
3	0.359361	0.042316	-15.13928	0.0000
4	0.285767	0.053107	-13.44905	0.0000
5	0.233669	0.062192	-12.32201	0.0000
6	0.208093	0.070174	-11.28496	0.0000
7	0.183544	0.077369	-10.55276	0.0000
8	0.163079	0.083969	-9.967039	0.0000
9	0.143412	0.090098	-9.507262	0.0000
10	0.129609	0.095844	-9.081300	0.0000
11	0.125272	0.101270	-8.637563	0.0000
12	0.116834	0.106424	-8.298593	0.0000
13	0.112543	0.111342	-7.970583	0.0000
14	0.100979	0.116053	-7.746609	0.0000
15	0.094906	0.120583	-7.505991	0.0000
16	0.094294	0.124950	-7.248568	0.0000

Null Hypothesis: CROBEX is a martingale (Sign Variance Ratio Test)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		11.43982	1241	0.0000
Wald (Chi-Square)		135.3006	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.675262	0.028387	-11.43982	0.0000
3	0.554123	0.042316	-10.53676	0.0000
4	0.501209	0.053107	-9.392274	0.0000
5	0.463658	0.062192	-8.623961	0.0000
6	0.446414	0.070174	-7.888797	0.0000
7	0.434097	0.077369	-7.314342	0.0000
8	0.422240	0.083969	-6.880646	0.0000
9	0.411944	0.090098	-6.526828	0.0000
10	0.406446	0.095844	-6.192890	0.0000
11	0.404879	0.101270	-5.876567	0.0000
12	0.405855	0.106424	-5.582824	0.0000
13	0.403955	0.111342	-5.353304	0.0000
14	0.398296	0.116053	-5.184712	0.0000
15	0.392103	0.120583	-5.041317	0.0000
16	0.388598	0.124950	-4.893189	0.0000

Null Hypothesis: IMOEX is a random walk (Rank Score Variance Ratio)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		16.28978	1241	0.0000
Wald (Chi-Square)		269.8408	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.537588	0.028387	-16.28978	0.0000
3	0.378394	0.042316	-14.68952	0.0000
4	0.282109	0.053107	-13.51794	0.0000
5	0.227304	0.062192	-12.42436	0.0000
6	0.198489	0.070174	-11.42182	0.0000
7	0.181024	0.077369	-10.58533	0.0000
8	0.171787	0.083969	-9.863340	0.0000
9	0.161911	0.090098	-9.301939	0.0000
10	0.150869	0.095844	-8.859484	0.0000
11	0.144551	0.101270	-8.447190	0.0000
12	0.138369	0.106424	-8.096233	0.0000
13	0.134383	0.111342	-7.774428	0.0000
14	0.131503	0.116053	-7.483594	0.0000
15	0.128559	0.120583	-7.226899	0.0000
16	0.129416	0.124950	-6.967478	0.0000

Null Hypothesis: IMOEX is a martingale (Sign Variance Ratio Test)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		11.26950	1241	0.0000
Wald (Chi-Square)		135.6293	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.680097	0.028387	-11.26950	0.0000
3	0.569165	0.042316	-10.18131	0.0000
4	0.504432	0.053107	-9.331580	0.0000
5	0.463658	0.062192	-8.623961	0.0000
6	0.443191	0.070174	-7.934728	0.0000
7	0.431334	0.077369	-7.350051	0.0000
8	0.418614	0.083969	-6.923830	0.0000
9	0.404065	0.090098	-6.614276	0.0000
10	0.402256	0.095844	-6.236609	0.0000
11	0.397260	0.101270	-5.951796	0.0000
12	0.398335	0.106424	-5.653493	0.0000
13	0.394533	0.111342	-5.437923	0.0000
14	0.390699	0.116053	-5.250178	0.0000
15	0.388665	0.120583	-5.069830	0.0000
16	0.389807	0.124950	-4.883515	0.0000

Null Hypothesis: PX PRAGUE is a random walk (Rank Score Variance Ratio)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		16.53611	1241	0.0000
Wald (Chi-Square)		287.2557	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.530595	0.028387	-16.53611	0.0000
3	0.359361	0.042316	-15.13928	0.0000
4	0.285767	0.053107	-13.44905	0.0000
5	0.233669	0.062192	-12.32201	0.0000
6	0.208093	0.070174	-11.28496	0.0000
7	0.183544	0.077369	-10.55276	0.0000
8	0.163079	0.083969	-9.967039	0.0000
9	0.143412	0.090098	-9.507262	0.0000
10	0.129609	0.095844	-9.081300	0.0000
11	0.125272	0.101270	-8.637563	0.0000
12	0.116834	0.106424	-8.298593	0.0000
13	0.112543	0.111342	-7.970583	0.0000
14	0.100979	0.116053	-7.746609	0.0000
15	0.094906	0.120583	-7.505991	0.0000
16	0.094294	0.124950	-7.248568	0.0000

Null Hypothesis: PX PRAGUE is a martingale (Sign Variance Ratio Test)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		11.43982	1241	0.0000
Wald (Chi-Square)		135.3006	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.675262	0.028387	-11.43982	0.0000
3	0.554123	0.042316	-10.53676	0.0000
4	0.501209	0.053107	-9.392274	0.0000
5	0.463658	0.062192	-8.623961	0.0000
6	0.446414	0.070174	-7.888797	0.0000
7	0.434097	0.077369	-7.314342	0.0000
8	0.422240	0.083969	-6.880646	0.0000
9	0.411944	0.090098	-6.526828	0.0000
10	0.406446	0.095844	-6.192890	0.0000
11	0.404879	0.101270	-5.876567	0.0000
12	0.405855	0.106424	-5.582824	0.0000
13	0.403955	0.111342	-5.353304	0.0000
14	0.398296	0.116053	-5.184712	0.0000
15	0.392103	0.120583	-5.041317	0.0000
16	0.388598	0.124950	-4.893189	0.0000

Null Hypothesis: SBITOP is a random walk (Rank Score Variance Ratio)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		17.71766	1241	0.0000
Wald (Chi-Square)		343.0607	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.497055	0.028387	-17.71766	0.0000
3	0.368036	0.042316	-14.93429	0.0000
4	0.282955	0.053107	-13.50200	0.0000
5	0.238358	0.062192	-12.24662	0.0000
6	0.219849	0.070174	-11.11743	0.0000
7	0.197786	0.077369	-10.36868	0.0000
8	0.180607	0.083969	-9.758302	0.0000
9	0.168574	0.090098	-9.227982	0.0000
10	0.156820	0.095844	-8.797393	0.0000
11	0.152481	0.101270	-8.368885	0.0000
12	0.142515	0.106424	-8.057277	0.0000
13	0.144032	0.111342	-7.687765	0.0000
14	0.134564	0.116053	-7.457217	0.0000
15	0.134348	0.120583	-7.178890	0.0000
16	0.135833	0.124950	-6.916123	0.0000

Null Hypothesis: SBITOP is a martingale (Sign Variance Ratio Test)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		12.51851	1241	0.0000
Wald (Chi-Square)		174.5721	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.644641	0.028387	-12.51851	0.0000
3	0.549825	0.042316	-10.63832	0.0000
4	0.502015	0.053107	-9.377100	0.0000
5	0.466237	0.062192	-8.582500	0.0000
6	0.440505	0.070174	-7.973005	0.0000
7	0.428571	0.077369	-7.385760	0.0000
8	0.413376	0.083969	-6.986207	0.0000
9	0.403349	0.090098	-6.622226	0.0000
10	0.397099	0.095844	-6.290416	0.0000
11	0.399604	0.101270	-5.928648	0.0000
12	0.396186	0.106424	-5.673684	0.0000
13	0.400979	0.111342	-5.380026	0.0000
14	0.395994	0.116053	-5.204550	0.0000
15	0.397690	0.120583	-4.994985	0.0000
16	0.400282	0.124950	-4.799678	0.0000

Null Hypothesis: WIG is a random walk (Rank Score Variance Ratio)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		17.03826	1241	0.0000
Wald (Chi-Square)		314.5094	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.516341	0.028387	-17.03826	0.0000
3	0.345801	0.042316	-15.45974	0.0000
4	0.263097	0.053107	-13.87592	0.0000
5	0.214357	0.062192	-12.63253	0.0000
6	0.202986	0.070174	-11.35774	0.0000
7	0.181900	0.077369	-10.57401	0.0000
8	0.174534	0.083969	-9.830623	0.0000
9	0.157243	0.090098	-9.353753	0.0000
10	0.147304	0.095844	-8.896673	0.0000
11	0.144879	0.101270	-8.443954	0.0000
12	0.134658	0.106424	-8.131105	0.0000
13	0.134942	0.111342	-7.769405	0.0000
14	0.130704	0.116053	-7.490483	0.0000
15	0.125781	0.120583	-7.249937	0.0000
16	0.125674	0.124950	-6.997426	0.0000

Null Hypothesis: WIG is a martingale (Sign Variance Ratio Test)

Joint Tests		Value	df	Probability
Max |z| (at period 2)		12.00755	1241	0.0000
Wald (Chi-Square)		154.5818	15	0.0000
Individual Tests				
Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.659146	0.028387	-12.00755	0.0000
3	0.547677	0.042316	-10.68910	0.0000
4	0.476229	0.053107	-9.862646	0.0000
5	0.435294	0.062192	-9.080036	0.0000
6	0.424926	0.070174	-8.195009	0.0000
7	0.412916	0.077369	-7.588110	0.0000
8	0.402498	0.083969	-7.115759	0.0000
9	0.386874	0.090098	-6.805073	0.0000
10	0.384206	0.095844	-6.424935	0.0000
11	0.381437	0.101270	-6.108041	0.0000
12	0.377921	0.106424	-5.845308	0.0000
13	0.377673	0.111342	-5.589348	0.0000
14	0.377115	0.116053	-5.367224	0.0000
15	0.378781	0.120583	-5.151802	0.0000
16	0.382353	0.124950	-4.943168	0.0000

Source: Own elaboration

5. CONCLUSION

The general conclusion to be retained and supported by the results obtained, through the tests performed with econometric and mathematical models, is that the global pandemic of 2020 and the Russian invasion of Ukraine in 2022 had a significant impact on the memory properties of the markets analyzed. We further verify that prices are not i.i.d. This has implications for investors, as some returns may be expected, creating opportunities for arbitrage and unusual profits. These findings also open room for market regulators to take steps to ensure better information in these regional markets.

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