

# Long memory in stock returns: Evidence from the Eastern European markets

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**Abstract.** This essay aims to analyze the impact of the 2020 global pandemic on the memory properties of the Eastern Europe stock markets, from the period between 1 January 2016 to 2 September 2020, the sample was divided in two subperiods: 1 January 2016 to 30 August 2019 (before Covid 19) and 2 September 2019 to 2 September 2020 (after Covid 19). To perform this analysis, different approaches were undertaken to analyze whether if: (i) the global pandemic (Covid-19) accentuated the exponents *Detrended Fluctuation Analysis (DFA)* and the *Detrended Cross-Correlation Analysis (pDCCA)* in the Eastern European stock markets?. The daily returns do not have normal distributions, they have negative asymmetries, leptocubic, and also exhibit conditional heteroscedasticity. The exponents *Detrended Fluctuation Analysis (DFA)*, during the Covid-19 period, range from 0.64 to 0.75, showing significant long memories in all markets, except for the SLOVAKIA market (0.45). When we compared the 2 subperiods, we found that 41 pairs of markets have cross-correlation coefficients without trend ( $\lambda_{DCCA}$ ) strong (out of 45 possible), and 4 pairs of markets decreased the *rhoDCCA* in particular the markets ESTONIA-SLOVAKIA, LITHUANIA-SLOVAKIA, HUNGARY-SLOVAKIA, POLAND-SLOVAKIA. These findings show that the assumption of the market efficiency hypothesis may be in question, since the prediction of market movement can be improved if we consider the out-of-lag movements of the other markets, enabling the occurrence of arbitrage operations and some difficulties in portfolio diversification.

**Keywords:** Eastern European markets; long memories; arbitration; portfolio diversification.

## 1 Introduction

International financial markets have seen a succession of major setbacks in recent months, triggered by Covid-19, followed by a series of collapses, the oil war, and currency fluctuations. The economic turbulence associated with the coronavirus pandemic in 2019-

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2020 has serious repercussions on financial markets, notably on the stock, bond and commodity markets (including crude oil and gold). The main events were an oil price war between Russia and Saudi Arabia after an OPEC agreement was not reached, which led to the collapse of oil prices, and a significant drop in stock markets in March 2020 [1].

Financial instability is a very important factor for society since a financial crisis or a stock market crash can directly or indirectly affect the level of economic well-being of the inhabitants of a country. If a given stock market is strongly linked to the stock market of another country, the financial stability of the former depends in part on the financial stability of the second. Thus, the occurrence of significant causation between markets may question the diversification of portfolios [2].

Statistical physicists began to analyze financial data, creating an interdisciplinary research area called Econophysics [3]. To answer the research question, we will use the *Detrended Fluctuation Analysis (DFA)* methodology, and Zebende's *Detrended Cross-Correlation Analysis (DCCA)* [4]. *DFA* is used to analyze the dependency pattern of a given time series and is typically identified as a way to study the level of efficiency of financial markets. While *DFA* analyzes the behavior of individual time series, *rhoDCCA* will be applied to analyze the far-reaching correlations between central European stock markets.

This essay aims to analyze the memory properties of eastern European stock markets from 1 January 2016 to 2 September 2020. To perform this analysis, different approaches were undertaken to analyze whether: (i) the global pandemic (Covid-19) accentuated the exponents *Detrended Fluctuation Analysis (DFA)* and the *Detrended Cross-Correlation Analysis (pDCCA)* in the Eastern European stock markets?. The results suggest that the exponents *Detrended Fluctuation Analysis (DFA)* exhibit long memories, which may show some predictability in these regional markets. However, despite our findings, the hypotheses of anomic profitability have not been tested without incurring additional risk. The cross-correlation coefficients trendless  $\lambda_{DCCA}$  show 41 pairs of markets with strong *rhoDCCA* ( $\cong 0.666 \rightarrow \cong 1.000$ ). The Estonia-Slovakia, Lithuania-Slovakia, Hungary-Slovakia, Poland-Slovakia markets decreased *rhoDCCA*. These findings show that the stock markets analyzed have high *rhoDCCA* levels, which may question the hypothesis of portfolio diversification.

This essay adds two main contributions to the literature. The first contribution concerns the study of risk diversification in eastern European markets. As far as we know there are studies that have analyzed risk diversification in these regional markets, namely the authors Filipovski and Tevdovski [5], Ferreira [6], Muharam, Mawardi, Arfinto, and Najmudin [7], Moagar-Poladian, Clichici, and Stanciu [8], but the research questions, the sample, and the approach were different from those followed in this paper.

The second contribution is econophysical in nature, due to the comparative models *Detrended Fluctuation Analysis (DFA)* and *Detrended Cross-Correlation Analysis (pDCCA)* that have the possibility of evaluating correlations in the context of non-stationarity. *DFA* is an analysis method that examines temporal dependence on non-stationary data series. This technique by assuming that time series are non-stationary avoids spurious results when the analysis focuses on the relationships of the data series in the long

term. *Zebende's trendless cross-correlation coefficient (pDCCA)* [4] is a method for quantifying the level of cross-correlation between two non-stationary time series.

In terms of structure this test is organized in 5 sections. Section 1 is represented by the current introduction. Section 2 presents a Literature Review regarding the presence of long memories in international stock markets. Section 3 describes the data and methodology. Section 4 contains the results. Finally, section 5 presents the general conclusions of the work.

## 2 Literature Review

The theme on the efficient market hypothesis (EMH) has motivated other studies to analyze the implications in the market efficiency hypothesis, according to which the current price of assets reflects all available information at a given time, and the price adjusts rapidly as new and unforeseen information comes to market. The hypothesis of reversal of the mean, also called negative series correlation, has been interpreted as an efficient correction mechanism in developed markets and a sign of a speculative bubble in emerging financial markets [9].

Nisar and Hanif [10], Mehla and Goya [11], El Khamlichi, Sarkar, Arouri, and Teulon [12], Li, Nishimura, and Men [13], tested the random walk hypotheses in asian markets. Nisar and Hanif [10] show that South Asian stock markets reject the hypothesis of random walk evidencing (in) market efficiency in its weak form. Mehla and Goya [11] examined india's stock market, showing that the market does not show the characteristics of random walk and, as such, is not efficient in weak form. El Khamlichi, Sarkar, Arouri, and Teulon [12] suggest that Islamic indices have the same level of (in)efficiency as benchmarks but MSCI and FTSE indices are less inefficient. Li, Nishimura, and Men [13] examined the fractal dimensions of 30 stock exchanges from 2006 to 2013, the authors argue that most markets are efficient, under the assumption of non-arbitration.

Ngene, Tah, and Darrat [14], Ali, Shahzad, Raza, and Al-Yahyaee [15], Pernagallo and Torrisi [16] investigated whether international markets follow the random walk hypothesis. Ngene, Tah, and Darrat [14] examined 18 emerging markets in the presence of multiple unscheduled and successive structural breakdowns. When single break tests are used, the random walk hypothesis is rejected. However, when double-level change tests are used in the mean and due tolerance is made to various structural breaks, the results are consistent with the random walk hypothesis in most markets. Ali, Shahzad, Raza, and Al-Yahyaee [15] using MF-DFA analysis, they show that developed markets are relatively more efficient, followed by BRICS stock markets. Comparative analysis of efficiency shows that almost all Islamic stock markets, with the exception of Russia, Jordan and Pakistan, are more efficient than their conventional peers. Pernagallo and Torrisi [16] analyzed whether the behavior of daily profitability of the stock indexes of 12 emerging economies corroborate the hypothesis of "fat tails" and whether these series show long memory. Hurst exponents range from 0.51 to 0.62 showing significant long memories.

Lahmiri, Bekiros, and Bezzina [17], Lahmiri and Bekiros [18] tested the presence of long memories in the stock markets. Lahmiri, Bekiros, and Bezzina [17] show that long-term price fluctuations are persistent, while short-term price fluctuations are anti-persistent. In addition, the level of anti-persistence and the content of information in short-term fluctuations are similar in the four European markets. Lahmiri and Bekiros [18] tested the efficient market hypothesis, in its weak form, on the Casablanca Stock Exchange (CSE),

Dow Jones and S&P500 stock markets. The authors show that prices are potentially predictable in the 3 markets and, in all industrial sectors.

Caporale, Gil-Alana, and Poza [19], Milos, Hatiegan, Milos, Barna, and Botoc [20] analyzed the central European stock markets. Caporale, Gil-Alana, and Poza [19] show that these regional markets have high levels of integration, which could call into question portfolio diversification. Milos, Hatiegan, Milos, Barna, and Botoc [20] verified the presence of long memories and long-term correlations, showing that stock markets are not efficient, in their weak form, and have not yet reached a mature stage of development.

In summary, this work aims to contribute to the provision of information to investors and regulators in the stock markets of Eastern Europe, where individual and institutional investors seek diversification benefits, as well as to help promote the implementation of policies that contribute to the efficiency of these markets. Therefore, the aim of this trial is to analyze the impact of the global 2020 pandemic on the memory properties of Eastern European stock markets.

## 3 Methodology

### 3.1 Data

The data used for the preparation of the paper were the prices index (diaries) of the stock markets of CZECH REP, BULGARIA, CROATIA, ESTONIA, LITHUANIA, HUNGARY, POLAND, SLOVAKIA, SLOVENIA, RUSSIA, from 1 January 2016 to 2 September 2020 and the sample was divided in two subperiods: from 1 January 2016 to 30 August 2019 (before Covid) and from 2 September 2019 to 2 September 2020 (Covid-19). The source of the information used was the DataStream platform with local currency quotes to mitigate exchange rate distortions.

### 3.2 Methodology

The development of the research took place through several stages. The characterization of the sample used was performed through descriptive statistics, the adherence test of Jarque and Bera [21] to verify if the data follow a normal distribution. In order to answer the research question, we will use the *Detrended Fluctuation Analysis (DFA)* methodology, and *Detrended Cross-Correlation Analysis (pDCCA)*. *DFA* is an analysis method that examines temporal dependence on non-stationary data series. This technique by assuming that time series are non-stationary avoids spurious results when the analysis focuses on the relationships of the data series in the long term. *DFA* has the following interpretation:  $0 < \alpha < 0,5$ : anti-persistent series;  $\alpha = 0,5$  series features *random walk*;  $0,5 < \alpha < 1$ : persistent series. The function of this technique is to examine the relationship between values  $x_k$  and  $x_{k+t}$  at different moments [22]. The non-trend cross-correlation coefficient (*pDCCA*) from Zebende [4] is a method to quantify the level of cross-correlation between two non-stationary time series. The coefficient is based on the *DFA* [23] and *DCCA* [23] methods. The cross-correlation coefficient depends on the length of the box  $s$  (time scale). One of the advantages of this cross-correlation coefficient is centered on the possibility of measuring the correlations between two non-stationary time series at different time scales. The function of this technique is to examine the relationship between values  $x_k$  and  $x_{k+t}$  at different moments [24]. Tables 2 and 3 show the interpretation of exponents  $\alpha_{DFA}$  and *pDCCA*.

**Table 1.** Detrended Fluctuation Analysis

Exponent	Type of signal
$\alpha_{DFA} < 0.5$	long-range anti-persistent
$\alpha_{DFA} \approx 0.5$	uncorrelated, white noise
$\alpha_{DFA} > 0.5$	long-range persistent

Source: Own processing.

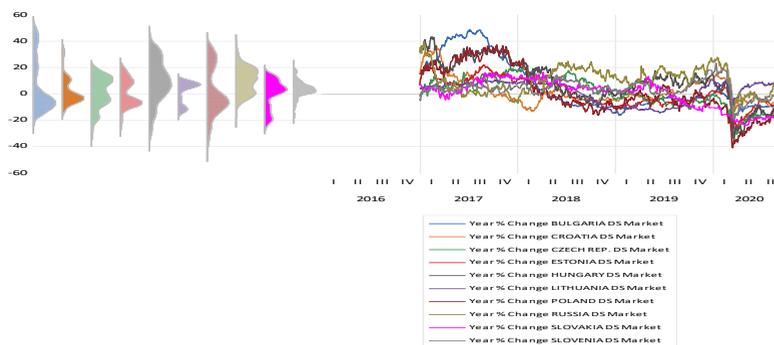
**Table 2.** Detrended cross-correlation coefficient, *pDCCA*, levels

Weak	Medium	Strong
$\cong 0.000 \rightarrow \cong 0.333$	$\cong 0.333 \rightarrow \cong 0.666$	$\cong 0.666 \rightarrow \cong 1.000$

Source: Own processing.

### 4 Results

Figure 1 shows the evolution, in % of the differences, of the 10 stock markets in Eastern Europe. In all series, a relatively high dispersion around the mean is noted, as well as a relatively synchronized behavior between the data series. Through graphical analysis, high volatility is observed, especially in January, February and March 2020.



**Fig. 1.** Evolution, in % of differences, of the 10 stock markets, in the period from 1 January 2016 to 2 September 2020

Source: Own processing.

Table 3 shows the main descriptive statistics of the ten East European stock markets, yields present positive diary means, with the exception of CZECH REP, POLAND and SLOVAKIA. The HUNGARY market has the highest standard deviation (0.011803), while the LITHUANIA market has the highest level of kurtosis (70.51083) and asymmetry (-3.432789). In addition, the Jarque-Bera test confirms that we are faced with time series that do not follow a normal distribution, evidence confirmed by the levels of asymmetry (< 0) and kurtosis (> 3).

**Table 3A.** Descriptive statistics on profitability of the 5 stock markets from 1 January 2016 to 2 September 2020

	BULGARIA	CROATIA	CZECH REP	ESTONIA	HUNGARY
Mean	6.95E-05	3.26E-05	-9.64E-05	2.32E-05	0.000229
Std. Dev.	0.005066	0.005983	0.008566	0.007335	0.011803
Skewness	-2.145286	-1.497950	-1.551421	-4.697442	-1.507607
Kurtosis	29.18512	16.07891	18.42601	69.25563	18.52451
Jarque-Bera	35760.87***	9144.195***	12575.48***	227448.8***	12703.09***
Sum	0.084769	0.039718	-0.117520	0.028329	0.278575
Sum Sq. Dev.	0.031259	0.043601	0.089366	0.065531	0.169668
Observations	1219	1219	1219	1219	1219

Source: Own processing.

**Table 3B.** Descriptive statistics on profitability of the 5 stock markets from 1 January 2016 to 2 September 2020

	LITHUANIA	POLAND	SLOVAKIA	RUSSIA	SLOVENIA
Mean	8.69E-05	-6.88E-05	-6.47E-06	0.000373	8.13E-05
Std. Dev.	0.005160	0.011463	0.007668	0.010603	0.007269
Skewness	-3.432789	-1.457475	-0.536518	-1.151359	-2.258049
Kurtosis	70.51083	20.33156	8.716673	20.08998	33.40669
Jarque-Bera	233887.9	15688.53	1718.371	15103.92	47996.20
Sum	0.105954	-0.083915	-0.007889	0.454651	0.099117
Sum Sq. Dev.	0.032434	0.160038	0.071624	0.136931	0.064355
Observations	1219	1219	1219	1219	1219

Source: Own processing.

In table 4 we can see the *DFA* exponents referring to the 10 financial markets of Eastern Europe. Period I regarding the Pre-Covid time scale and we can verify the presence of long memories in the markets BULGARIA (0.54), CROATIA (0.59), ESTONIA (0.55), LITHUANIA (0.59), SLOVENIA (0.55). The CZECH REP. (0.41), HUNGARY (0.44), POLAND (0.46), SLOVAKIA (0.36), RUSSIA (0.48) markets show signs of anti-persistence, i.e. the presence of short-term memories. In period II the covid-19-time scale is contained, and we found that the exponents *Detrended Fluctuation Analysis (DFA)* range from 0.64 to 0.75, showing significant long memories in all markets, except for the SLOVAKIA market (0.45). These findings show that prices do not fully reflect the information available and that price changes are not i.i.d. This situation has implications for investors, as some profitability can be expected, creating opportunities for arbitration and abnormal income. These results are corroborated by the authors Lahmiri and Bekiros [18], Milos, Hatiegan, Milos, Barna, and Botoc [20] who evidence long memories in the profitability of the stock markets.

**Table 4.** DFA exponent for index and return. The values of the linear adjustments for  $\alpha$  DFA always had  $R^2 > 0.99$

Stock market	DFA exponent (before crisis)	DFA exponent (Covid period)
CZECH REP. DS Market	0.41 $\cong$ 0.0039	0.68 $\cong$ 0.0024
BULGARIA DS Market	0.54 $\cong$ 0.0076	0.74 $\cong$ 0.0074
CROATIA DS Market	0.59 $\cong$ 0.0058	0.72 $\cong$ 0.0012
ESTONIA DS Market	0.55 $\cong$ 0.0008	0.73 $\cong$ 0.0049
LITHUANIA DS Market	0.59 $\cong$ 0.0003	0.64 $\cong$ 0.0062
HUNGARY DS Market	0.44 $\cong$ 0.0011	0.65 $\cong$ 0.0007
POLAND DS Market	0.46 $\cong$ 0.0097	0.66 $\cong$ 0.0034
SLOVAKIA DS Market	0.36 $\cong$ 0.0041	0.45 $\cong$ 0.0039
SLOVENIA DS Market	0.55 $\cong$ 0.0056	0.75 $\cong$ 0.0011
RUSSIA DS Market	0.48 $\cong$ 0.0041	0.71 $\cong$ 0.0012

Note: The hypotheses are  $H_0: \alpha = 0.5$  and  $H_1: \alpha \neq 0.5$ .

Source: Own processing.

Table 5 shows the *Detrended cross-correlation coefficient* for *pDCCA* period from January 1, 2016 to September 2, 2020. Period I comprises the time lapse from January 1, 2016 to August 30, 2019 (Pre-Covid), and we can verify that *rhoDCCA* shows 28 cross-correlation coefficients trendless ( $\lambda_{DCCA}$ ) weak ( $\cong 0.000 \rightarrow \cong 0.333$ ), and 17 medium correlation coefficients ( $\cong 0.333 \rightarrow \cong 0.666$ ), in 45 possible pairs. When we analyzed period II (Covid) we found 36 cross-correlation coefficients trendless ( $\lambda_{DCCA}$ ) strong ( $0.666 \rightarrow \cong 1,000$ ), and 9 weak correlation coefficients ( $\cong 0.000 \rightarrow \cong 0.333$ ). When compared the 2 subperiods we found 41 pairs of markets cross-correlation coefficients trendless ( $\lambda_{DCCA}$ ) strong (out of 45 possible), and 4 pairs of markets decreased *rhoDCCA*, namely ESTONIA-SLOVAKIA, LITHUANIA-SLOVAKIA, HUNGARY-SLOVAKIA, POLAND-SLOVAKIA. These findings show that the stock markets analyzed have high levels *rhoDCCA*, which may question the hypothesis of efficient portfolio diversification.

**Table 5.** Summary table of coefficients, *pDCCA* referring to the 10 stock markets, in the period from 01/01/2016 to 02/09/2020

Index	$\rho DCCA$ (before Covid-19)		$\rho DCCA$ (Covid-19)		Tendência
	$pDCCA$	Time scale (days)	$pDCCA$	Time scale (days)	
CZECH REP. / BULGARIA	<b>0.13</b>	n > 236 days	0.91	n > 64 days	↑
CZECH REP. / CROATIA	<b>0.19</b>	n > 102 days	0.88	n > 60 days	↑
CZECH REP. / ESTONIA	<b>0.26</b>	n > 66 days	0.86	n > 56 days	↑
CZECH REP. / LITHUANIA	0.34	n > 138 days	0.85	n > 64 days	↑
CZECH REP. / HUNGARY	0.42	n > 22 days	0.88	n > 56 days	↑
CZECH REP. / POLAND	0.41	n > 187 days	0.87	n > 64 days	↑
CZECH REP. / SLOVAKIA	<b>0.03</b>	n > 166 days	<b>0.23</b>	n > 64 days	↑
CZECH REP. / SLOVENIA	0.36	n > 210 days	0.93	n > 64 days	↑

CZECH REP. / RUSSIA	<b>0.28</b>	n > 14 days	0.83	n > 62 days	↑
BULGARIA / CROATIA	<b>0.08</b>	n > 210 days	0.89	n > 64 days	↑
BULGARIA / ESTONIA	<b>0.29</b>	n > 236 days	0.86	n > 60 days	↑
BULGARIA / LITHUANIA	<b>0.10</b>	n > 26 days	0.80	n > 58 days	↑
BULGARIA / HUNGARY	<b>0.15</b>	n > 236 days	0.86	n > 60 days	↑
BULGARIA / POLAND	0.42	n > 42 days	0.81	n > 64 days	↑
BULGARIA / SLOVAKIA	<b>0.06</b>	n > 156 days	<b>0.28</b>	n > 64 days	↑
BULGARIA / SLOVENIA	<b>0.11</b>	n > 85 days	0.90	n > 62 days	↑
BULGARIA / RUSSIA	<b>0.19</b>	n > 75 days	0.80	n > 60 days	↑
CROATIA / ESTONIA	0.35	n > 166 days	0.84	n > 64 days	↑
CROATIA / LITHUANIA	<b>0.28</b>	n > 166 days	0.79	n > 58 days	↑
CROATIA / HUNGARY	<b>0.17</b>	n > 176 days	0.83	n > 64 days	↑
CROATIA / POLAND	<b>0.19</b>	n > 147 days	0.87	n > 64 days	↑
CROATIA / SLOVAKIA	<b>0.11</b>	n > 198 days	<b>0.20</b>	n > 64 days	↑
CROATIA / SLOVENIA	0.35	n > 138 days	0.93	n > 62 days	↑
CROATIA / RUSSIA	0.33	n > 223 days	0.80	n > 64 days	↑
ESTONIA / LITHUANIA	0.44	n > 187 days	0.84	n > 56 days	↑
ESTONIA / HUNGARY	0.36	n > 210 days	0.83	n > 64 days	↑
ESTONIA / POLAND	0.35	n > 198 days	0.77	n > 64 days	↑
<b>ESTONIA / SLOVAKIA</b>	<b>0.40</b>	<b>n &gt; 223 days</b>	<b>0.14</b>	<b>n &gt; 64 days</b>	↓
ESTONIA / SLOVENIA	0.36	n > 138 days	0.87	n > 64 days	↑
ESTONIA / RUSSIA	<b>0.31</b>	n > 198 days	0.72	n > 64 days	↑
LITHUANIA / HUNGARY	<b>0.11</b>	n > 108 days	0.69	n > 45 days	↑
LITHUANIA / POLAND	<b>0.26</b>	n > 130 days	0.79	n > 60 days	↑
<b>LITHUANIA / SLOVAKIA</b>	<b>0.32</b>	<b>n &gt; 166 days</b>	<b>0.12</b>	<b>n &gt; 64 days</b>	↓
LITHUANIA / SLOVENIA	0.53	n > 236 days	0.83	n > 64 days	↑
LITHUANIA / RUSSIA	<b>0.16</b>	n > 130 days	0.76	n > 64 days	↑
HUNGARY / POLAND	0.53	n > 96 days	0.80	n > 62 days	↑
<b>HUNGARY / SLOVAKIA</b>	<b>0.22</b>	<b>n &gt; 122 days</b>	<b>0.19</b>	<b>n &gt; 58 days</b>	↓
HUNGARY / SLOVENIA	<b>0.20</b>	n > 90 days	0.85	n > 62 days	↑
HUNGARY / RUSSIA	<b>0.29</b>	n > 236 days	0.81	n > 48 days	↑
<b>POLAND / SLOVAKIA</b>	<b>0.18</b>	<b>n &gt; 236 days</b>	<b>0.08</b>	<b>n &gt; 62 days</b>	↓
POLAND / SLOVENIA	0.46	n > 122 days	0.86	n > 64 days	↑
POLAND / RUSSIA	0.49	n > 14 days	0.87	n > 62 days	↑
SLOVAKIA / SLOVENIA	<b>0.12</b>	n > 147 days	<b>0.20</b>	n > 64 days	↑
SLOVAKIA / RUSSIA	<b>0.10</b>	n > 130 days	<b>0.16</b>	n > 36 days	↑
SLOVENIA / RUSSIA	<b>0.15</b>	n > 20 days	0.80	n > 64 days	↑

Source: Own processing.

## 5 Conclusion

The overall conclusion to be withheld and sustained in the results obtained, through tests carried out with econophysical models, shows that the global pandemic has a significant impact on the adjustment of the financial markets of Eastern Europe. The results indicate that these regional markets have significant persistence during the Covid period, which motivates some arbitrage opportunities. Additionally, *Detrended cross-correlation coefficient pDCCA* increased in the Covid period when compared to the previous subperiod, which may call into question the hypothesis of portfolio diversification. These findings also make room for market regulators to take steps to ensure better information among international financial markets. In conclusion, we consider that investors should diversify their portfolios, and invest in less risky markets, with the purpose of mitigating risk and improving the efficiency of their portfolios.

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