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Impact of the Russia-Ukraine War on Market Efficiency of Cryptocurrencies and G-20 Countries: An Analysis via Fractal Theory

Impacto da Guerra Rússia-Ucrânia na eficiência do mercado de criptomoedas e dos países do G-20: Uma Análise via Teoria Fractal

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Abstract: The purpose of this research is to analyze the efficiency behavior of emerging, developed and cryptocurrency markets before and after the invasion of Ukraine. In methodological terms, a study was made of the multifractal properties and entropy of the series of returns in a 5-minute frequency from 02/14/2022 to 03/31/2022 of market indices of the G-20 countries and the 10 largest cryptocurrencies by market capitalization. It was possible to verify an increase in the degree of randomness of the series analyzed after the Russian invasion, meeting what was expected of an efficient market. However, none of the markets behaved completely at random, and the existence of positive long-term correlations in returns was identified, which became more expressive in developed countries. The cluster analysis, which revealed that after the invasion, the behavior of the markets became more homogeneous, indicating that geopolitical uncertainties have the ability to make the behavior of the markets converge in the short term. Therefore, investors should bear in mind the need to readjust their predictive models to suit new market behavior, as well as to reduce abnormal profitability expectations, given the greater degree of randomness in the markets.

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Keywords: War between Russia and Ukraine; Geopolitical Risk; Market Efficiency.

Resumo: O objetivo desta pesquisa é analisar o comportamento da eficiência dos mercados emergentes, desenvolvidos e de criptomoedas antes e depois da invasão da Ucrânia. Em termos metodológicos, foi feito um estudo das propriedades multifratais e entropia da série de retornos em uma freqüência de 5 minutos de 14/02/2022 a 31/03/2022 dos índices de mercado dos países do G-20 e das 10 maiores moedas criptográficas por capitalização de mercado. Foi possível verificar um aumento no grau de aleatoriedade da série analisada após a invasão russa, atendendo ao que se esperava de um mercado eficiente. Entretanto, nenhum dos mercados se comportou completamente ao acaso, e foi identificada a existência de correlações positivas de longo prazo nos retornos, que se tornaram mais expressivas nos países desenvolvidos. A análise de cluster, que revelou que após a invasão, o comportamento dos mercados se tornou mais homogêneo, indicando que as incertezas geopolíticas têm a capacidade de fazer o comportamento dos mercados convergir no curto prazo. Portanto, os investidores devem ter em mente a necessidade de reajustar seus modelos de previsão para adequá-los ao novo comportamento do mercado, bem como para reduzir expectativas anormais de lucratividade, dado o maior grau de aleatoriedade nos mercados.

Palavras-chave: Guerra entre Rússia e Ucrânia; Risco Geopolítico; Eficiência de Mercado.

Introduction

It is observed that, in evolutionary terms, the financial market has become an increasingly complex system due, above all, to advances in the field of telecommunications, presenting a constant flow of information, an increase in the number of investors, as well as different temporal perspectives of analysis (Wątorek et al., 2021). Such transformations affect not only the daily life of agents, but also the behavior of the market as a whole, providing the existence of phenomena that contradict its efficiency, such as speculative bubbles and information asymmetry.

On this topic, events such as Subprime crisis in 2008, the emergence of the global Covid-19 pandemic in early 2020 and, more recently, the invasion of Ukraine by Russia put the theory of market efficiency defended by Fama (1970; 1991) to the test. More specifically, the invasion of Ukraine by Russia is characterized as a result of the escalation of a scenario of geopolitical uncertainty that, according to Carney (2016) and Caldara and Iacoviello (2018), are associated with the risks of outbreaks of wars, terrorist acts, as well as tensions between countries that may affect international relations, which may result in different adverse scenarios with local and global impacts. In the midst of this context, this study is more directly interested in the impacts on the financial market, with emphasis on its degree of volatility (Wang et al., 2020) and with regard to exchange rates (Beckmann & Czudaj, 2017).

This invasion has greatly increased the uncertainty that the world economy was experiencing as a result of the impacts of the Covid-19 pandemic. The numerous and varied sanctions imposed on Russia have generated a great impact on several economic and financial segments, highlighting the increase in volatility in the stock market, commodity prices and exchange rates, leveraging a scenario of escalating inflation worldwide, as well as reducing estimates of global gross domestic product (GDP) growth.

This study aims to analyze the behavior of the efficiency of markets in the G-20 countries, as well as that of 10 cryptocurrencies with the highest market capitalization before and after the invasion of Russia in February 2022.

In methodological terms, intraday data were analyzed, at a frequency of 5 minutes, from 02/14/2022 to 03/31/2022, thus covering 10 days before the start of the invasion and 35 days after the fact occurred. Initially, the entropy of the time series was analyzed through the Shannon entropy via wavelet transformation (SEW), an adaptation of the methodologies of Lahmiri and Bekiros (2020), Aslam et al. (2020). After that, the Hurst exponent was used through a multifractal detrended fluctuation analysis (MFDFA) to measure, respectively, the presence of long-term memory (LTM) and the degree of randomness of the time series. Finally, hierarchical cluster analysis was used to verify the existence of patterns of behavior among the markets selected for the study.

It is possible to list, as justifications for the present study, three points that deserve to be highlighted. First, the need to identify the impacts of the Russian invasion of Ukraine on the financial market, and in view of the few works on the subject so far, it is worth mentioning the studies by Boungou and Yatié (2022) and Hossain and Masum (2022). Second, it is necessary to better understand the differences between the behavior of emerging and developed markets, a relevant topic, both from

a theoretical and operational point of view, given the growing trend of global portfolio diversification, as pointed out by Harjoto and Rossi. (2021) and Uddin et al. (2021). Finally, it is possible to highlight the better understanding of the characteristics of the cryptocurrency market, a segment of the recent financial market that has shown rapid expansion and attractiveness in recent decades. Despite the fact that cryptocurrencies have been the subject of research regarding the effects of crises (Sahoo, 2021; Montasser et al., 2021; Mnif et al., 2020), the impact of political crises is not yet seen in a consensual way, in the specific literature, being, therefore, an intriguing gap to be analyzed.

Regarding the contributions of this research, the relevance of the topic is reinforced by analyzing an ongoing geopolitical conflict whose repercussions affect both national and global financial systems. The originality of this study lies in explicitly addressing the impact of geopolitical risk on market efficiency through a fractal framework that combines Shannon entropy and multifractal detrended fluctuation analysis (MFDFA). While prior studies (e.g., Boungou & Yatié, 2022; Hossain & Masum, 2022) examined market reactions to the Russia–Ukraine war mainly in terms of returns and volatility, they did not investigate how such shocks alter the informational efficiency of markets in the sense of the Efficient Market Hypothesis. Furthermore, although cryptocurrencies have been studied in the context of crises, the literature has not provided a clear understanding of how political conflicts reshape their efficiency dynamics in comparison to emerging and developed equity markets. By filling this gap, the paper advances knowledge on the interaction between geopolitical risk and market efficiency.

The findings also have theoretical implications, as they suggest that geopolitical shocks not only increase volatility but can also modify the degree of persistence and randomness of asset prices, which challenges the assumption of homogeneous market responses embedded in the EMH. This insight extends the existing literature by integrating geopolitical risk into the debate on efficiency. In practical terms, the results highlight the need for investors and policymakers to recalibrate predictive models and adjust expectations of abnormal profitability when facing heightened geopolitical uncertainty

Theoretical Framework

Historical Geopolitical Tensions: From the End of the Soviet Union to the Invasion of Ukraine

The end of the Union of Soviet Socialist Republics (USSR), which took place in December 1991, also resulted in its fragmentation in several sovereign nations. However, the emergence of these new independent countries was not fully accepted by the former Soviets, thus giving rise to geopolitical

disputes ever since in order to recover Russian hegemony based on its history, culture and territories (Sergunin, 2016).

According to the aforementioned author, this desire to recover the original territory of the Russian empire can be justified for three reasons. The first one concerns the territorial space itself, which has a great wealth of natural resources, such as natural gas and oil, which would serve as a catapult for the country's economy. Second, there is the link between Europe and China, a situation in which Russia would serve as a commercial bridge between the continents. Finally, the last reason has to do with the expansion of Russian influence in Europe, which ends up being blocked by buffer states, especially Ukraine, Belarus and Moldova.

Another point worth mentioning in order to understand the general panorama of tensions involves the growth of the North Atlantic Treaty Organization (NATO) in recent decades. Established in 1949, this supranational organization has expanded its membership to aggregating Eastern European countries from 1990 onwards, thus further reducing Russian influence in Europe (Hanappi, 2022). In addition to this, the author also highlights the increase in the American presence in Europe, both economically and militarily, which resulted in increased pressures against Russia.

Indeed, for some authors such as Sakwa (2008) and Hahn (2018), the end of the USSR started a new period of tension, a New Cold War, with the western pole composed of the members of the European Union (EU) and NATO, while the eastern pole would be formed, above all, by Russia, China and other Asian powers. However, unlike the first Cold War, in this new clash there is an absence of ideological conflict, with the search for expanding the field of influence and economic expansion being the main driving forces for the tension (Gessen, 2017).

On February 24, 2022, Russia carried out a full-scale military invasion of Ukraine. However, since 2014, the tension between Ukraine and Russia had already intensified, especially after the incorporation of Crimea by Russia, in addition to separatist pressures in the Donbas region. In addition to that, since 2021, the presence of Russian military personnel on the border with Ukraine has already increased, and on February 21, 2022, Putin recognized the People's Republic of Donetsk and the People's Republic of Lugansk, two regions of Ukraine that started to consider themselves as independent countries, and with a pro-Russia stance. Thus, the outbreak of a new conflict between the countries was a matter of time. From a chronological point of view, Table 1 summarizes the timeline of the invasion.

Table 1

Timeline of the Main Facts of the Russian Invasion into Ukraine

Period	Main Events
March-April 2021	Start of new Russian military movements on the border with Ukraine.
February 17, 2022	Increase in separatist fighting in Donbas.
February 21, 2022	Russian recognition of the Donetsk People's Republic and the Lugansk People's Republic, and the beginning of Russian occupation of Donbas.
February 22, 2022	UK announces sanctions against Russian banks.
February 23, 2022	Ukraine announces a national state of emergency.
February 24, 2022	Russia Invades Ukraine, US Announces Sanctions Against Russian Banks.
February 25, 2022	United Nations Security Council creates resolution to demand Russia's departure from Ukrainian territory, and Organization for Economic Cooperation and Development (OECD) cancels Russia's accession process.
February 27, 2022	EU countries begin to close their airspace to Russian aircrafts, and use funds from the European Peace Facility to purchase war material for Ukraine. Also, Turkey closes access to the Black and Azov Seas to Russian warships.
February 28, 2022	Ukraine requests EU entry and Switzerland breaks neutrality against Russia.
March 03, 2022	Start of operations to evacuate Ukrainian civilians.
March 10, 2022	Ukrainian ceasefire request for civilian evacuation was denied by Russian government at meeting in Antalya.
March 14, 2022	A new round of negotiations between the countries begins, ending on March 17, 2022 without any agreement.
March 25, 2022	Rússia declara que a primeira etapa da operação militar está concluída
March 27, 2022	Ukraine declares that Ukrainians in Russian-controlled cities have no access to water or food, highlighting the inhumanity of the Russian operation.
March 28 2022	Russia declares Ukraine's neutrality and its non-membership to NATO as fundamental points towards the end of the invasion.
March 31, 2022	Ukrainian government declares that supplies delivered by humanitarian groups were taken by Russian troops.

Source: Elaborated by the author

As a result of the invasion, several Western countries began to impose sanctions on Russia. The sanctions generally refer to the closure of EU, US and Canadian airspace to Russia, limitations on the Central Bank of Russia's access to its international reserves, exclusion of Russian banks from the international banking system, exclusion of the country from organizations international agreements and termination of contracts and partnerships with companies and the Russian government.

Market Efficiency, Geopolitical Uncertainties and the Financial Market

According to the propositions of Fama (1970) and Fama (1991), the Efficient Market Hypothesis (EMH) considers that the prices of financial assets follow a random walk model, which, although in the short term they may present deterministic trends, these trends do not remain in the long term, so that arbitrage in a systemic way is unfeasible. In a simplified way, the EMH can be divided into three forms: the weak form, in which past information on an asset's prices is incorporated into market prices; the semi-strong form, which in turn determines that asset prices absorb past information and current

public information; and, finally, the strong form, in which there would be no privileged information in the market.

Risk is one of the central variables for financial and economic analysis (Galbraith, 1977), with direct consequences for EMH. According to Carney (2016) and Caldara and Iacoviello (2018), geopolitical uncertainties (GPU), that is, increased risk due to the outbreak of wars, terrorist acts and tensions between countries with the potential to affect international relations, are able to produce adverse effects on the global economy. Among such effects, it is possible to mention the speed of recovery from crises (Baker et al., 2016), the degree of market volatility (Wang et al., 2020), the capital structure of companies (Zhang et al., 2015), exchange rates (Beckmann & Czudaj, 2017), as well as in the financial market itself.

Regarding this last topic, three perspectives can be defined in the literature associates with GPU: stock price, cryptocurrency and commodities In this study, In this study, the first two points were the focus of the analyses. About the first one, among the articles about this perspective is the one by Bekiros et al. (2016), who performed a Granger causality analysis to measure the impact of GPU at micro and macro levels in equity markets, confirming that such a source of uncertainty is relevant to understanding the variations in share prices.

These analyzes were later corroborated by studies such as those by Balcilar et al. (2018), Gkillas et al. (2018) and Kannadhasan and Das (2020), who also highlight the asymmetric effects of this risk in different markets as well as its association with increases in price volatility. Furthermore, studies such as the one by Kyriazis (2021) emphasize that the negative effects of the GPU affect the volatility of shares in times of low market to a greater degree. These conclusions are in line with the analyzes of Frey and Kucher (2001), who argue that the financial market reflects the historical evaluation of events, as well as future expectations, with such forecasts dependent on individual and sociocultural factors of investors.

In the second group of analysis, it was found ambiguous evidence on the effects of the GPU. The study by Al Mamun et al. (2020), for example, highlights that GPUs are positively associated with the degree of volatility and risk premium of Bitcoin, in contrast with works such as those by Elsayed et al. (2022), which identified Bitcoin as an asset with hedging potential for the GPU.

As a matter of fact, studies such as the one by Aysan et al. (2019) more clearly showed the ambiguity of the effects of GPUs in this market. Although the authors have found a negative relationship between geopolitical effects and cryptocurrency returns through estimators via Ordinary Least Squares, an inverse relationship was also identified when considering the quantile estimation.

Therefore, the impact of the metric used on the results is evident, which, in turn, validates current studies to identify the geopolitical effects on cryptocurrencies.

Nevertheless, these studies focus primarily on volatility, returns, or contagion effects. To the best of our knowledge, there is a limited numbers of studiesthat has yet examined how geopolitical shocks affect the persistence and randomness of asset prices from a fractal perspective. This is precisely the gap addressed in this paper, by combining multifractal detrended fluctuation analysis and Shannon entropy to capture the efficiency dynamics of financial markets under geopolitical risk.

Effects of the Ukraine Invasion on the Financial Market

After the invasion of Ukraine, the global economy clearly felt the consequences, both as a result of the invasion and the sanctions applied. In Russia, particularly, both its stock market (MOEX) and its exchange rate suffered significant drops, around 35.86% and 28.23%, respectively, in recent months, as a result of the invasion. Furthermore, although in March it was possible to observe the beginning of a recovery in the MOEX index, it stabilized at values around 1400 points below its maximum value in the analyzed semester. Figure 1 illustrates these drops.

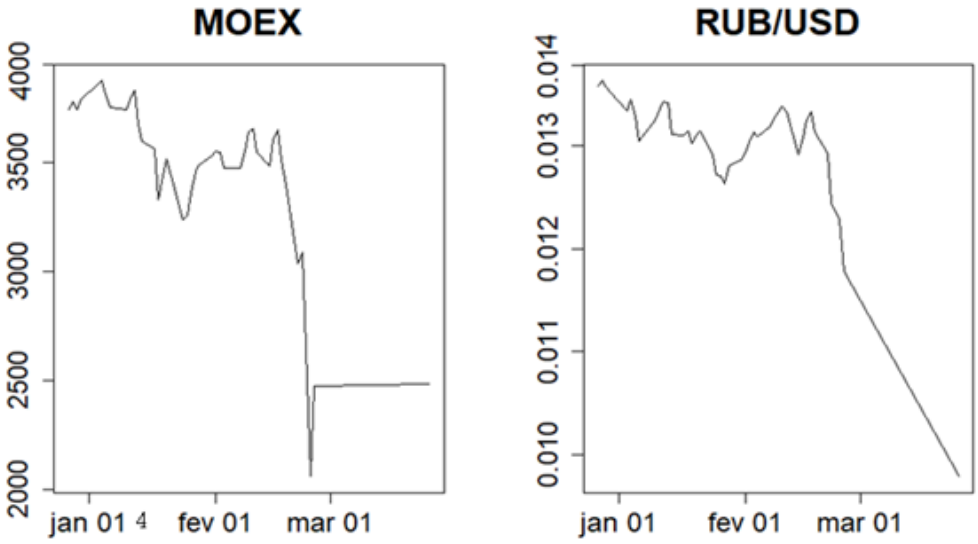

Figure 1
MOEX and Russian Ruble Exchange Rates in the Last Six Months
Source: Elaborated by the author

When analyzed in global terms, in addition to the residual impacts left by the crisis that was caused by the pandemic, sanctions on Russia had a great impact on several sectors of the world economy. According to data from the International Monetary Fund (IMF), the expected inflation for

the year 2022 is higher than the inflation observed in the year 2021, equivalent to 3.9% for emerging markets and 5.9% for developed markets, and suffering reductions to 2 .1% and 4.7% in 2023, respectively. In addition to this, the absence of currency appreciation against the dollar is also expected.

With regard to commodities, the IMF identified the maintenance of the upward trend, especially in energy, agriculture, metals and minerals and fertilizers. Finally, with regard to the economic activity index, although these indices have shown improvements, both in terms of industry and service, since the peak of the pandemic, in 2022 there was a drop compared to the end of 2021, which made the IMF reduced the expectation of world GDP growth by 0.5 percentage points, falling to 4.4%, with great emphasis on the USA and China, whose drops in expectations were 1.2 and 0.8 percentage points, respectively. Given this scenario, both reports from the Institute of Applied Economic Research (IPEA) and the Brazilian Central Bank point to a slowdown in world recovery, which should reduce even further as a result of the invasion.

It is therefore interesting to understand the impacts of Russia's conflicts with Ukraine, both for academic and risk management purposes. In this way, it is clear and perceptible, once again, the validation of the present study and the analyzes about the financial market of the G-20 countries and cryptocurrencies.

According to what was explained in the introduction, as it is a recent event, studies that specifically analyze the effects of the Russian invasion are still scarce. Among the studies identified, we can mention those carried out by Boungou and Yatié (2022), who analyzed the return of stock markets in 94 countries, from January 22, 2022 to March 3, 2022, through the analysis of panel data, controlling the fixed effect of time. Their results point to a negative relationship between the start of the invasion and market returns.

Another study focused on this topic was carried out by Hossain and Masum (2022), who evaluated the effects of the invasion on the stock and commodity markets. Among the conclusions they reached, the following stand out:

- The increase in the volatility of the assets analyzed after the invasion; the negative relationship between equity returns and geopolitical risk;
- The positive relationship between stock returns and geopolitical risk in the case of oil-exporting countries (Canada and Norway);
- The conclusion that part of the invasion's negative impact on the world economy derives from its negative effects on European countries.

With a focus on the cryptocurrency market, Yatie (2022) analyzed, through a DCC-GARCH model, the returns of Bitcoin and Ethereum, from November 2021 to March 15, 2022, using Wikipedia trends as a proxy to capture the effects of uncertainty and fear. As a result, negative effects of the invasion were found in the two selected cryptocurrencies, in line with the literature that highlights the inefficiency of these assets to hedge geopolitical risk.

Although initial studies assessed the short-term impacts of the Russia–Ukraine invasion on stock and commodity markets, they did not evaluate how the event altered informational efficiency across markets with different levels of development, nor in the cryptocurrency market. By addressing these aspects, the present research introduces a novel contribution that expands the scope of the literature on the financial consequences of geopolitical conflicts.

Methodology

Data and Variables

The empirical analysis carried out in this research is divided into two approaches. The first one aims to verify not only the impacts of the invasion, but also the differences in these impacts as a result of the country's degree of development and, for that, market indexes of the G-20 countries were analyzed. The mentioned group is composed of countries that represent about 80% of the GDP of the world economy. Among its members are 19 countries, 9 with developed economies and 10 emerging countries, in addition to an EU representative. The choice of market indices that were analyzed was based on the study by Singh et al. (2020), which had a similar objective, however, with a focus on the effects of the Covid-19 pandemic, and the availability of information from Stooq, which is a free online database that provides high-frequency financial data. This base was used in previous studies, such as the one by Bieszk-Stolorz and Dmytrów (2021). It is worth noting that no South African market index was found in the base, so this country was not considered in the sample. Table 2 presents the indices selected for each country.

Table 2

Market Indices of the G-20 Countries Analyzed

G20 country	Market Index	Acronym	Degree of Economic Development
Argentina	S&P Merval	MERV	Emerging
Australia	All Ordinaries	AOR	Developed
Brazil	Ibovespa	BVSP	Emerging
Canada	S&P/TSX Composite	OSPTX	Developed

China	Shangai Composite Index	SSEC	Emerging
France	CAC 40	CAC	Developed
Australia	DAX	DAX	Developed
India	BSE SENSEX	BSE	Emerging
Indonesia	IDX Composite	IDXC	Emerging
Australia	FTSE MIB	FTSEMIB	Developed
Japan	Nikkei 225	N225	Developed
Mexico	IPC Mexico	MXX	Emerging
Russia	MOEX Russia	MOEX	Developed
Saudi Arabia	Tadawul All Share	TASI	Emerging
South Korea	Composite Index	KOSPI	Emerging
Turkey	BIST 100	XU100	Emerging
United Kingdom	FTSE 250 Index	FTSE250	Developed
USA	Down Jones Industrial Average Index	DJI	Developed

Source: Elaborated by the author

The second approach was to measure the effects of the Ukrainian invasion on the cryptocurrency market. To this end, 10 cryptocurrencies with the greatest market capitalization were selected. The selected cryptocurrencies are shown in Table 3. It should be mentioned that for the present work, cryptocurrencies whose objective is to pair with the dollar were not considered, thus excluding from the list Theter and USD Coin, whose capitalization is, respectively, of $81, 58 and $51.85 billion.

The window of analysis encompasses intraday data (with an interval of 5 minutes), from 02/14/2022 to 03/31/2022, that is, 10 days before the start of the invasion (about 600 observations), and 35 days after the event (about 2,100 observations) for each asset. It is necessary to mention that the exact number of observations for each analyzed asset varies according to the specific holidays that occur in each country, the trading hours, as well as the periods when trading on local stock exchanges was prohibited. This time frame of analysis was due to the availability of data in the collection base on 04/01/2022, and it was not possible to have access to previous data.

Table 3

Cryptocurrencies Not Linked to the Dollar and with Higher Market Capitalization

Cryptocurrency	Ticker	Capitalization (USD – billion)
Bitcoin	BTC	904.43
Ethereum	ETH	412.17
Binance	BNB	72.36
Ripple	XRP	42.21
Cardano	ADA	41.12

Terra	LUNA	36.62
Solana	SOL	36.29
Avalanche	AVAX	25.05
Polkadot	DOT	22.26
Dogcoin	DOGE	19.43

Source: Adapted from https://coinmarketcap.com/, accessed March 29, 2022.

From the asset price series, the logarithm returns of each time series were calculated and, after that, the return series were divided into two periods, a composite with data from 02/14/2022 to 02/23/2022, and another with data from 02/24/2022 to 12/31/2022. For the analyses, the free software R was used.

Shannon Entropy Via Wavelet Transform

The first metric that was used is based on the study by Lahmiri and Bekiros (2020), and it is the SEW. Developed by Shannon (1948), the index allows calculating the randomness of information in a time series via a wavelet transformed methodology according to Equation 1 (Li & Zhou, 2016).

$$\begin{cases} d_{0,0}(t) = r(t) \\ d_{i,2j-1}(t) = \sqrt{2}\sum_k h(k) d_{i-1,j}(2t-k) \\ d_{i,2j}(t) = \sqrt{2}\sum_k g(k) d_{i-1,j}(2t-k) \end{cases} \quad (1)$$

In the equation, h(k) is the high filter, g(k) the low filter, and $d_{i,j}$ the coefficients of the wavelet packets of the i-th level of the j-th node. Starting from these values, it is possible to measure the informational level of the k-th coefficient of the j-th node at the i-th level through its entropy or energy level $E_{i,j,k} = \left\| d_{i,j,k} \right\|^2$. Then, we can group all the energy level for a node at a given level so that $E_{i,j} = \sum E_{i,j,k}$ and, finally, the probability of the kth coefficient is given by $\rho_{i,j,k} = {E_{i,j,k}}/{E_{i,j}}$.

After calculating the probabilities of each kth coefficient, the SEW is calculated according to Equation 2. For the analyses, the wavethresh package was used, using the filter number 10 of the "DaubExPhase" family, which is the default of the R's function *wp*.

$$SEW_{i,j} = \sum \rho_{i,j,k} \log(\rho_{i,j,k}) \quad (2)$$

Multifractal Detrended Fluctuation Analysis

As described by Kantelhardt et al. (2002), the MFDFA procedure for a possibly non-stationary time series Z_t is composed of five steps, described below. If N corresponds to the number of observations of this time series, a new time series X(k) is constructed according to Equation 3, in which $k = 1, \dots N$ e $\bar{z}$ the arithmetic mean of the time series Z_t.

$$X(k) = \sum_{t=1}^{N}(z_t - \bar{z}) \quad (3)$$

Then X(k) is divided into $N_s = \text{int } {}^{N}/_{S}$ groups of the same size s. To avoid problems of deregulation of the groups at the end of the sample, which can occur when N is not a multiple of s, the same procedure is repeated starting at the end of the series and then $2N_s$ groups are obtained. From these sets, the local trend is estimated according to a least squares fit (Equation 4), in which $v = 1, 2 \dots N$, and Equation 5, with $v = N_{s+1} \dots 2N_s$ e $x_v(j)$ the polynomial fit for each segment of v considering the indicator of the relative position of segment (j), varying from 1 to s.

$$F^2(s, v) = \frac{1}{s}\sum_{j=1}^{s}\{X[(v-1)s + j] - x_v(j)\}^2 \quad (4)$$

$$F^2(s, v) = \frac{1}{s}\sum_{j=1}^{s}\{X[N - (v - N_s)s + j] - x_v(j)\}^2 \quad (5)$$

Based on these results, it is possible to construct the q-th order fluctuation function of the time series (Equation 6). The q parameter allows identifying segments with greater and lesser fluctuation, with negative and positive values indicating low and high fluctuation, respectively.

$$F_{q(s)} = \begin{cases} \left\{\frac{1}{2N_s}\sum_{v=1}^{2N_s}[F^2(s,v)]^{q/2}\right\}^{1/q} \text{ if } q \neq 0 \\ \exp\left\{\frac{1}{4N_s}\sum_{v=1}^{2N_s}\ln[F^2(s,v)]\right\} \text{ if } q = 0 \end{cases} \quad (6)$$

Finally, by repeating this procedure for different sizes s, it is possible to identify a relationship such as $F_{q(s)} \sim s^{h(q)}$. With a value of h(q) = 0.5 the series is considered random, h(q) > 0.5 indicates persistence of LTM and $h(q) < 0{,}5$, anti-persistence. In this study, this analysis was performed using R's *MFDFA* package. As for the model specifications, as in Aslam et al. (2020), q was considered between -10 and 10, that is, the q-th moments of fractal analysis ranged from -10 to 10, while the s scale was constructed in the interval $[10, \left\lfloor \frac{N}{5} \right\rfloor]$.

Hierarchical Cluster Analysis

As was done by Lahmiri and Bekiros (2020), cluster analysis was performed to verify the behavior of previously calculated metrics from a multivariate point of view, both before and after the invasion. As this is an exploratory analysis, we chose to use the hierarchical clustering methodology. For this study, the Euclidean distance and Ward's methodology were used to group the clusters and the the number of clusters, according to the silhouette graph. For the calculations, the *stats* and *factoextra* packages were used.

Analyses And Discussions Of Results

Descriptive Statistics

To begin the analyses, averages and standard deviation of the 18 market indices of the G-20 countries and the 10 selected cryptocurrencies were calculated, taking into account the period before the invasion of Russia and the period after the invasion. After that, two statistical tests were performed on each of the two subsamples: the Dickey-Fuller test, to verify the stationarity of the series of returns, and the Kolmogorov-Smirnov test, to verify the normality of the data. Finally, tests were performed to verify the difference in mean, median and variance, before and after the invasion. The results are shown in Table 4.

From the results obtained, it is initially verified the stationarity of the return series. As for normality, in general the tests allow the non-rejection of the null hypothesis of normality at a significance of 1%, except for the pre-invasion period for the SSEC index, whose significance is 5%, IDXC and OSPTX, whose significance is 10 %, and MERV which, in turn, indicates the non-normality of returns. Therefore, it appears that, except for the case of MERV in the period before 02/24/2022, the performance of the test to compare the average is adequate.

From the comparison tests of mean and median, it can be concluded that, in general, the means of returns in the second subsample are higher than those observed in the first. This finding is justified insofar as, although between 02/24/2022 and 02/28/2022 the market indices and cryptocurrency quotes fell, a correction movement took place later, so that the growth trend observed before the invasion was maintained after a few days of low. Among the exceptions observed, the IDXC, MERV, SSEC and TASI, market indices of emerging countries, stand out. Regarding the standard deviation, it was observed that, in general, there was an increase in volatility in the selected markets after the invasion. Carrying out the analysis of the increase in risk for the three groups analyzed, the average increase in volatility in emerging countries was 56%, with emphasis on Russia and China, whose increases were 173% and 117%, respectively.

Russia is the epicenter of the GPUs analyzed, and its market being the most affected is not surprising. In the case of China, the increase in volatility is justified by having openly positioned itself in favor of Russia, which had a negative impact on investors. When these countries are removed from the sample, the average increase in risk drops to 27%, the same value as that observed in the group of developed countries. With respect to cryptocurrencies, their incremental average was 6%.

Table 4

Summary of Descriptive Statistics of Market Indices of G-20 Countries and Cryptocurrencies Analyzed Before and After the Invasion of Russia

	Asset	Pre-Invasion					Post-Invasion					Comparison		
		Annualized Standard Deviation	Annualized Mean	Annualized Median	Dickey-Fuller	Kolmogorov-Smirnov	Annualized Standard Deviation	Annualized Mean	Annualized Median	Dickey-Fuller	Kolmogorov-Smirnov	t Testt	W Test	F Teste
EMERGING	BVSP	0.0133	-0.0060	-0.0131	-8.4458***	0.0777***	0.0197	0.0094	0.0000	-11.9498***	0.0867***	-1.5243	815,981	0.4569***
	IDXC	0.0121	0.0140	0.0066	-6.5254***	0.0666*	0.0164	0.0053	-0.0029	-10.5406***	0.1114***	0.7017	246,232	0.5453***
	KOSPI	0.0257	0.0001	0.0046	-8.253***	0.1611***	0.0204	0.0026	0.0000	-12.1655***	0.1577***	-0.134	527,527.5	1.5789***
	MERV	0.0220	0.0131	-0.0033	-7.7422***	0.0453	0.0315	0.0075	-0.0104	-10.5571***	0.1234***	0.2958	529,369	0.49***
	MOEX	0.0808	-0.0385	-0.0426	-10.0966***	0.1784***	0.2204	0.0141	0.0000	-8.0708***	0.2576***	-0.3506	202,921.5	0.1345***
	MXX	0.0193	-0.0114	0.0000	-8.5203***	0.0994***	0.0196	0.0140	0.0000	-12.5869***	0.0723***	-1.8343*	653,985	0.9637
	SENSEX	0.0216	0.0038	0.0180	-8.5566***	0.1054***	0.0258	0.0091	0.0039	-11.1009***	0.1273***	-0.3115	573,418.5	0.7042***
	SSEC	0.0152	0.0072	0.0132	-7.8063***	0.0869**	0.0330	-0.0112	-0.0139	-10.1209***	0.1126***	0.9764	273,827.5*	0.2116***
	TASI	0.0152	0.0165	0.0040	-7.8733***	0.1369***	0.0173	0.0102	-0.0020	-11.7112***	0.1454***	0.4814	396,523.5	0.7759***
	XU100	0.0267	-0.0010	-0.0012	-10.2298***	0.1105***	0.0240	0.0186	0.0154	-13.99***	0.125***	-1.1459	961,186	1.2345***
DEVELOPED	AOR	0.0155	-0.0009	0.0034	-8.1274***	0.082***	0.0144	0.0065	0.0033	-13.021***	0.1075***	-0.6491	598,283	1.1579**
	CAC	0.0237	-0.0030	0.0164	-9.5813***	0.0996***	0.0327	0.0027	0.0072	-14.1928***	0.111***	-0.3455	1,095,478.5	0.5254***
	DAX	0.0251	-0.0094	0.0017	-9.7272***	0.1177***	0.0338	0.0022	0.0018	-13.5297***	0.111***	-0.6708	1,114,768.5	0.5506***
	DJI	0.0219	-0.0215	-0.0237	-7.4325***	0.0991***	0.0242	0.0095	0.0045	-12.4157***	0.1174***	-1.7671*	461,382**	0.8134***
	FTSE250	0.0154	-0.0124	-0.0047	-9.6058***	0.1626***	0.0200	0.0041	0.0036	-12.407***	0.1419***	-1.5799	1,074,664.5*	0.5938***
	FTSEMIB	0.0239	-0.0037	0.0087	-9.7882***	0.1063***	0.0336	-0.0013	0.0010	-13.1422***	0.1093***	-0.1408	1,126,447	0.5091***
	N225	0.0324	-0.0156	-0.0110	-7.1302***	0.2246***	0.0307	0.0083	0.0028	-11.0148***	0.1618***	-0.8675	333,168.5	1.1186
	OSPTX	0.0128	-0.0149	-0.0106	-7.8141***	0.0547*	0.0138	0.0085	0.0069	-13.6184***	0.0767***	-2.363**	539,563.5**	0.8533**
CRYPTOCURRENCY	ADA	0.0478	-0.0134	0.0000	-15.469***	0.0911***	0.0480	0.0065	0.0000	-21.494***	0.0828***	-1.3485	19,108,526.5	0.9904
	AVAX	0.0569	-0.0047	-0.0034	-14.4937***	0.0387***	0.0573	0.0059	0.0033	-22.3956***	0.0579***	-0.5996	19,204,344.5	0.9867
	BNB	0.0323	-0.0046	0.0000	-14.7502***	0.0639***	0.0307	0.0043	0.0000	-21.6864***	0.0761***	-0.903	19,107,949	1.1113***
	BTC	0.0294	-0.0083	-0.0044	-14.3335***	0.0777***	0.0333	0.0049	0.0062	-22.2234***	0.1015***	-1.4037	19,093,793	0.7794***
	DOGE	0.0399	-0.0075	0.0000	-14.9617***	0.0924***	0.0434	0.0028	0.0000	-22.0273***	0.1074***	-0.8167	18,998,178.5	0.8451***
	DOT	0.0460	-0.0104	0.0000	-14.4228***	0.0673***	0.0465	0.0080	0.0000	-21.8836***	0.0697***	-1.2951	19,178,250.5	0.9769
	ETH	0.0398	-0.0069	-0.0029	-14.9048***	0.0632***	0.0368	0.0065	0.0019	-21.5969***	0.0808***	-1.1149	19,154,405.5	1.1725***
	LUNA	0.0516	0.0141	0.0000	-14.2994***	0.0542***	0.0591	0.0140	0.0000	-21.8231***	0.0653***	0.006	19,362,597.5	0.7625***
	SOL	0.0500	-0.0074	0.0000	-14.5918***	0.048***	0.0513	0.0103	0.0001	-22.1396***	0.061***	-1.1381	19,136,966	0.9511*
	XRP	0.0495	-0.0052	0.0000	-14.5394***	0.0636***	0.0396	0.0040	0.0056	-21.8535***	0.0913***	-0.6306	19,064,267	1.5606***

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

Source: Elaborated by the author

Four points from Table 1 are worth mentioning. First, although markets have recovered quickly from the fall after the invasion, the degree of variability of returns has increased, that is, an increase in risk can be seen. Second, Russia and China were the markets most affected by the invasion.

Furthermore, excluding extreme values from these countries, it appears that the average risk increments between markets in emerging countries are similar. However, the latter group has a greater concentration of markets that did not recover from the initial shock of the invasion, and a certain asymmetry between these two groups can be verified, thus corroborating previous studies such as those by Balcilar et al. (2018) and Kannadhasan and Das (2020). Finally, regarding the cryptocurrency market, the results indicate that they were little affected by the invasion, both in terms of average return and risk, corroborating the analyzes by Elsayed et al. (2022).

Market Efficiency Analysis

For the analysis of EMH in its weak form, econophysics metrics were selected to verify the degree of randomness of the series of returns of the assets selected for the study and the existence of long-term correlations. First, the SEW was calculated to measure the degree of randomness of the time series, and for SEW=1 the series is completely random and for SEW=0, the series is deterministic. As for the LTM effect, the MFDFA was used considering 21 fluctuation functions ($q \subset [-10.10]$). This allows computing the Hurst exponent (h(q)), which, as previously mentioned, allows verifyingthe existence of positive ($h(q)<0.5$), negative ($h(q)<0.5$) LTM, or no effect ($h(q)=0.5$).

Table 5 presents a simplification of the SEW and MFDFA analyses, considering the mean and amplitude of the calculated h(q) for the two subsamples. It is also observed that, in general, this second metric varies between 1 and 0. However, some results of the software indicated values greater than 1, which, according to Bryce and Sprague (2012), can be found in a DFA analysis on non-stationary time series, or when the trend elimination process cannot be performed. In these cases, the value of h(q) is not interpretable and, therefore, they were removed from the mean and range calculations.

Table 5

Hurst Exponent via MFDFA and Shannon Entropy of Market Indices of G-20 Countries and Cryptocurrencies Analyzed Before and After the Invasion of Russia

	Asset	Pre-Invasion					Post-Invasion				
		SEW	Max h(q)	Min h(q)	Mean h(q)	Range h(q)	SEW	Max h(q)	Min h(q)	Mean h(q)	Range h(q)
EMERGING	BVSP	0,0793	0,2613	0,9078	0,5931	0,6465	0,5585	0,3933	0,7204	0,5729	0,3271
	IDXC	0,0310	0,4391	0,9228	0,7054	0,4837	0,2018	0,3122	0,8288	0,5680	0,5166
	KOSPI	0,1945	0,1592	0,9751	0,4878	0,8159	0,4298	0,2949	0,6895	0,5300	0,3946
	MERV	0,1544	0,3294	0,7985	0,5916	0,4691	0,9439	0,3263	0,8191	0,5788	0,4928
	MOEX	0,8039	0,0142	0,8689	0,5612	0,8547	8,5811	0,2415	0,9034	0,4173	0,6619
	MXX	0,1298	0,2414	0,7604	0,5327	0,5190	0,5359	0,3647	0,6515	0,5284	0,2868
	SENSEX	0,1494	0,2832	0,8356	0,6026	0,5524	0,6909	0,3434	0,8313	0,6042	0,4879
	SSEC	0,0466	0,2601	0,9212	0,6199	0,6611	0,7776	0,3957	0,7050	0,5619	0,3093
	TASI	0,0563	0,3093	0,9248	0,6548	0,6155	0,2860	0,2214	0,6624	0,4841	0,4410
	XU100	0,2791	0,1770	0,8796	0,5644	0,7026	0,9200	0,3067	0,6582	0,4975	0,3515
DEVELOPED	AOR	0,0808	0,3665	0,7639	0,5871	0,3974	0,2571	0,3190	0,6268	0,4970	0,3078
	CAC	0,2368	0,0467	0,8886	0,4947	0,8419	1,6907	0,3468	0,6826	0,5406	0,3358
	DAX	0,2619	0,0960	0,7228	0,4444	0,6268	1,8228	0,3240	0,7537	0,5563	0,4297
	DJI	0,1178	0,2207	0,7419	0,5205	0,5212	0,6416	0,4230	0,8356	0,6216	0,4126
	FTSE250	0,1039	0,0203	0,5514	0,8485	0,8025	0,6849	0,4029	0,8423	0,6326	0,4394
	FTSEMIB	0,2398	0,0139	0,8164	0,4815	0,8025	1,7966	0,3570	0,7480	0,5749	0,3910
	N225	0,1959	0,1289	0,9860	0,3895	0,8571	0,8163	0,2082	0,8866	0,5802	0,6784
	OSPTX	0,0530	0,3557	0,9722	0,5536	0,6165	0,2778	0,4310	0,6568	0,5414	0,2258
CRYPTOCURRENCY	ADA	0,3232	0,4656	0,5653	0,5071	0,0997	0,7064	0,2582	0,6317	0,4606	0,3735
	AVAX	0,4538	0,4803	0,6423	0,5399	0,1620	0,9758	0,2996	0,6839	0,4862	0,3843
	BNB	0,1601	0,4008	0,5840	0,5089	0,1832	0,4645	0,2345	0,6109	0,4530	0,3764
	BTC	0,1312	0,3000	0,5671	0,4671	0,2671	0,5138	0,3307	0,7590	0,5561	0,4283
	DOGE	0,2319	0,3914	0,6027	0,5186	0,2113	0,8504	0,1707	0,6487	0,4464	0,4780
	DOT	0,3035	0,2914	0,6196	0,4637	0,3282	0,9959	0,3159	0,6924	0,5092	0,3765
	ETH	0,2315	0,3038	0,6365	0,4794	0,3327	0,6358	0,2970	0,7319	0,5253	0,4349
	LUNA	0,3695	0,3190	0,6384	0,4906	0,3194	0,7220	0,3686	0,6725	0,5307	0,3039
	SOL	0,3556	0,4175	0,6495	0,5217	0,2320	0,7982	0,2751	0,6473	0,4671	0,3722
	XRP	0,3373	0,3287	0,6596	0,5230	0,3309	0,7134	0,2730	0,6519	0,4828	0,3789

Source: Elaborated by the author

About the first metric is analyzed, the SEW, it can be seen that the degree of randomness after the invasion for all assets showed an increase movement. Before the invasion, the Russian and cryptocurrency markets in general had a degree of entropy greater than 0.3, and for the MOEX the result points to a level of 0.8039. Even before the invasion, as discussed in section 2.1, Russia has already made moves towards the invasion, being the focus of several news globally. In this context, it is not uncommon that, with a high level of daily ambiguous information about the country and its international relations, the Russian market would present a high level of entropy.

Observing the period after the invasion, a reduction in the deterministic effects in the analyzed markets can be seen. With regard to emerging countries, the average increase was 4.6746, this being the group that generally showed the greatest gain in randomness of price changes. Next, we can see the developed markets, with an increase of 3.2516. Finally, the cryptocurrency market, whose increase was 1.7160. These results indicate, in principle, that emerging markets would be the most fragile in scenarios with high GPU, while the cryptocurrency market would be the most stable.

It is necessary, however, to evaluate this conclusion in more depth. First, although it is evident that cryptocurrencies had smaller entropy variations, this group has an average entropy of 0.7376 after the invasion, while emerging and developed markets average values of 0.6203 and 0, 6235, respectively. Therefore, it is observed that, although there is a degree of minor variations for this group, its entropy level is the highest among the three selected, leading to the conclusion that the cryptocurrency market is the closest to a market that follows the random walk model. In addition, it is interesting to note that ETH, BTC and BNB, the three cryptocurrencies with the highest market capitalization, remained with a lower entropy degree than the general average, both before the invasion (0.1971) and after (0.6743), indicating that they are the most fragile from the point of view of EMH in their weak form.

These results extend previous findings in the literature by demonstrating that geopolitical shocks affect not only volatility but also the degree of persistence and randomness of asset returns. Such evidence suggests that the Efficient Market Hypothesis needs to be reconsidered in contexts of geopolitical uncertainty, as markets may temporarily deviate from expected efficiency patterns. This advances the theoretical debate by integrating geopolitical risk as a structural determinant of efficiency levels.

Furthermore, although at first the entropy level for emerging and developed markets was similar before and after the invasion, reinforcing the existence of deterministic patterns that allow arbitrage in

a systemic way, the degree of variation of the SEW behaved in a heterogeneous way, and also following a geographic pattern, as can be identified in Figure 2.

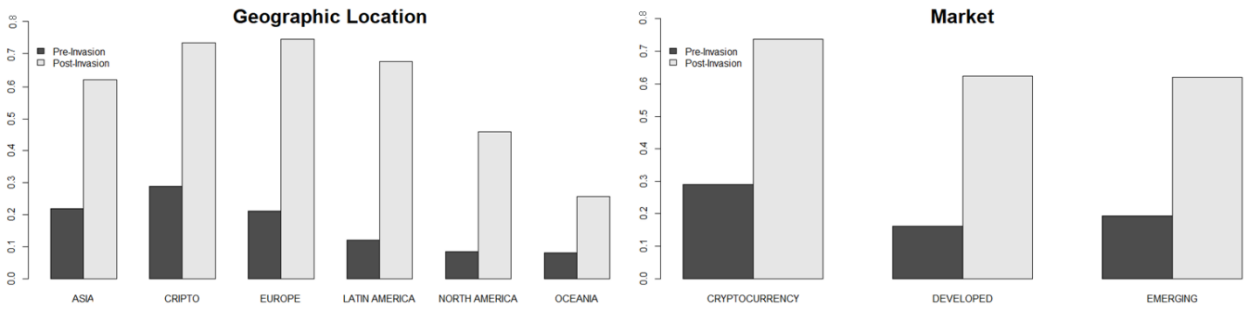

Figure 2

Comparison of Shannon's Mean Entropy by Geographic Location and Market

Source: Elaborated by the author

First, it should be noted the increase in entropy in China, greater than 15 times, reaching an entropy level of 0.7776. In this way, it can be seen that the Chinese market, which was previously far from what was expected of a random walk, started to behave in a predominantly deterministic way. A possible cause for this fact may be the declaration of support for Russia which, in turn, generated a greater degree of uncertainty and ambiguity in investors, thus eliminating deterministic effects. When China is excluded, the average entropy increment of Asian countries went from 4.6367 to 2.7967, a value below the global average of variations (3.4452).

With regard to the countries of the Americas, with the exception of Mexico, both Latin American and North American countries showed variations above the global average, especially Brazil (6.0462) and Argentina (5.1138). As for European countries, with the exception of the United Kingdom, with an increase of 5.5937, the other countries showed an average increase of 2.1265.

According to what was observed, although the time series showed efficiency gains, they did not behave purely randomly in any of the analyzed periods. In this particular aspect, one can verify the existence of deterministic and trend effects in the returns of the analyzed assets.

When we move on to the MFDFA analyses, it is first noticed that on average, the average values of h(q) per group before the invasion were about 0.5913 for emerging markets, 0.5399 for developed markets and 0.5019 for cryptocurrency market. After the invasion, the values were changed to 0.5343, 0.5680 and 0.4917, respectively.

These results indicate that, on average, emerging countries had a greater presence of long-term average maintenance than the others before the invasion. However, after the event, there was a

reduction in this effect, thus indicating that there was an expectation for significant changes in the short term. Such an effect was not found for the group of developed countries, since, for these, there was an increase in the presence of long-term correlations. In the case of cryptocurrencies, a change of around -2% was observed in the index, reflecting its low change from the moment of the invasion.

When analyzing the individual variations, it can be seen that Japan is the market whose variation before and after the invasion, about 48.97%, was the highest among the analyzed assets. In addition, Germany, the USA and Italy presented variations of more than 19%. Therefore, it is corroborated that the markets of developed countries, especially those from Europe, started to show a movement of maintaining the long-term average after the invasion, thus rejecting the idea that the changes in the short term would be significant for the long term.

An exception to this view was the UK market, which had an average h(q) of 0.8485 before the invasion and 0.6325 after the invasion. In fact, the results indicate that FTSE250 had a higher degree of LTM in both subsamples. However, in the second period, their values were no longer discrepant with those observed in developed markets, showing a difference of 1.73% with the American h(q), the second highest h(q) after the invasion.

It is interesting to note that, in addition to the United Kingdom, the countries that presented reductions in h(q) above 9% are located mostly in Asia, namely: Saudi Arabia (-26.07%), Russia (-25.65%), Indonesia (-19.48%), Australia (-15.36), Turkey (-11.86%) and China (-9.36%). This fact raises the hypothesis that the behavior in relation to the degree of LTM may not be limited to the degree of development of the country, but also to the geographic and political position that was taken after the invasion. Thus, it can be seen that, at first, the European countries and the USA present a similar behavior, being these countries against the invasion, while, in general, the Asian countries that are economic partners of Russia, present an opposite behavior. Figure 3 graphically shows what was discussed earlier.

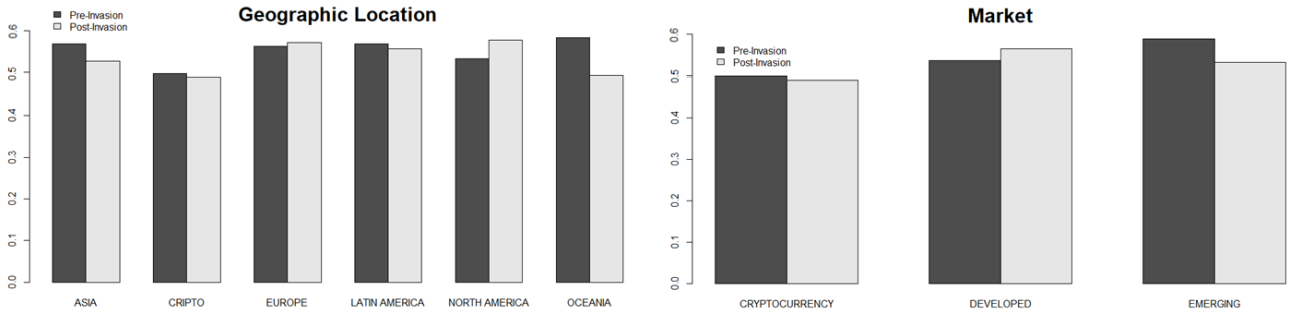

Figure 3

Comparison of Mean Hurst Exponents by Geographic Location and Market

Source: Elaborated by the author

We conclude, therefore, that in general the GPU end up increasing the randomness of asset returns due to the perception of risk. In this sense, there is consistency with what was exposed by Hossain and Masum (2022). Furthermore, the asymmetry regarding the degree of LTM effect in countries due to their location is also consistent with the conclusions of Kannadhasan and Das (2020) and Balcilar et al. (2018). Finally, it can be noted that among the assets analyzed, those belonging to the cryptocurrency market showed a greater gain in randomness, with this increase being inversely proportional to the market capitation of cryptocurrencies. In this sense, the conclusions are in line with studies that highlight the hedging capacity for GPU, as explained by Al Mamun et al. (2020) and Elsayed et al. (2022).

Clusters Analysis

In order to broaden the scope of results, a hierarchical cluster analysis was performed considering all the h(q) calculated, the SEW, the mean, median and standard deviation of the assets/markets analyzed before and after the invasion. Figure 4 shows the results of these groupings.

Starting in the pre-invasion period, according to the silhouette graph, it would be possible to identify four clusters from the data obtained, namely: the one composed of cryptocurrencies (red); European countries (blue), a group composed primarily of developed countries in Europe and Russia; Japan and South Korea, two Asian powers (yellow); and emerging and developed countries in North America and Oceania (green).

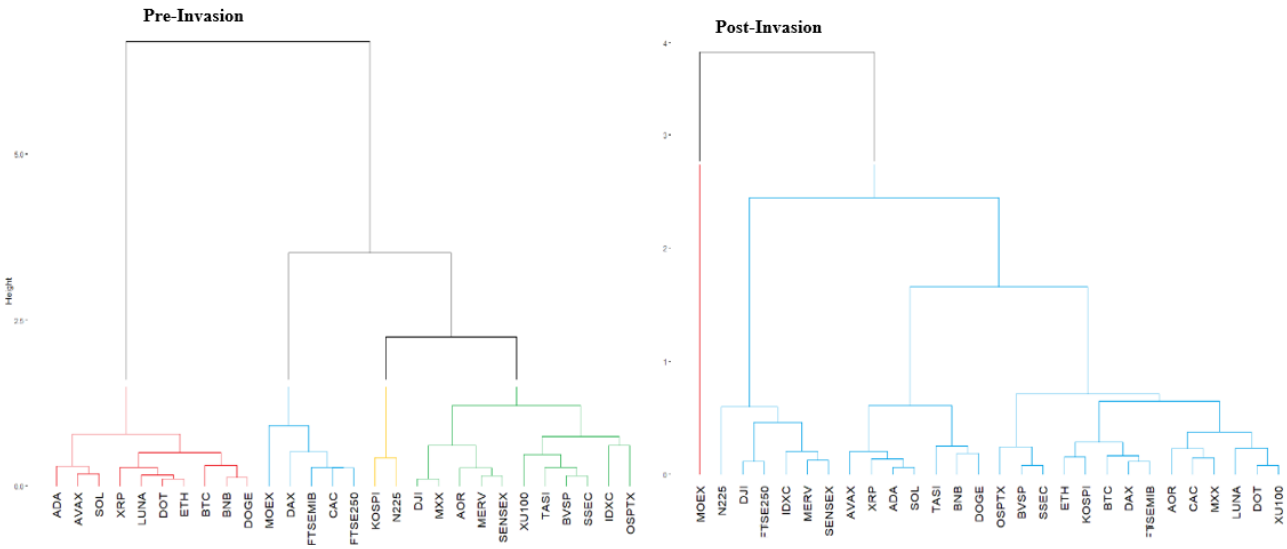

Figure 4

Hierarchical Cluster Analysis of Data Before and After Invasion.

Source: Elaborated by the author

This first grouping reflects four important points: first, the common behavior of market efficiency of cryptocurrencies before the invasion; the homogeneity of market efficiency in European countries; the uniqueness of the behavior of the Japanese and South Korean market, supporting the conclusion of Sohel Azad (2009) that these markets have similarities with each other, at the same time that they are distinguished from the Chinese market and other Asian countries; and, finally, the approximation of the market efficiency of the other developed countries (USA, Canada and Australia) with the emerging countries.

Still regarding the latter, it can be verified, firstly, that there is a previous sub-grouping of DJI, OSPTX and AOR, indicating similarity between these developed markets. Furthermore, the inclusion of Latin American and Asian countries may occur due to the cointegration and similarities in the market structure of these countries, as well as the strong relationship with the American market (Al Nasser & Hajilee, 2016; Chen et al., 2002); Humayun Kabir & Shakur, 2018).

In the post-invasion period, a curious fact occurred with the Russian market because it did not group with any of the others (red cluster). This fact corroborates the fact that this is the market of one of the countries that started the war, presenting, therefore, a different behavior from the others, reflecting the numerous sanctions that the international community imposed both on its economy and its financial system.

The second cluster (blue) encompasses all other analyzed markets. This division was made based on the silhouette chart. However, in order to deepen the analysis of the group's conclusions, it is observed that, from left to right, there is a proximity to the American, English and Japanese markets, three developed countries that took a stand against the Russian invasion of Ukraine. Further on, it is possible to verify a proximity with the Indian and Indonesian markets, which present a high co-integration with the Japanese market (Tiwari et al., 2013), and the Argentine market, which, as previously mentioned, has a strong relationship with the American market.

We can see, then, a subconglomerate formed primarily by cryptocurrencies, reflecting the similarities and integration of the members of this market, as highlighted by Ji et al. (2019). Furthermore, it is possible to observe a similarity between the behavior of the Brazilian and Chinese markets, both members of the BRICS, and local market leaders.

Finally, it can be seen that the European markets behaved in a way suchlike ETH and BTC. According to the study by Gama Silva et al. (2019), cryptocurrency investors have a characteristic of herding behavior and risk aversion, so that they are more affected by negative news. In this sense, this similar behavior can be justified between European markets, closer to the Ukraine war, with BTC and ETH, considered to be less inefficient for hedging by Yatie (2022). Furthermore, from an empirical point of view, the members of this subgroup presented results that indicated an increase in LTM.

Therefore, it can be concluded that the GPU effects are not something simple to capture and, although there are some patterns of similarity within groups, these are not significantly different from the effects between groups. Furthermore, it can be seen that this type of risk is likely to impact market behavior, even if not permanently. Therefore, it is necessary to reformulate investment strategies as well as earnings expectations.

In general, although the presence of GPU has apparently contributed for the markets to behave efficiently, so that arbitrage is a more difficult objective to achieve, none of the analyzed markets behaved in a fully efficient way, with deterministic elements in the series of returns, such as LTM. Nevertheless, the impact of this element has become milder, so that investors must recalibrate their models to more accurately capture the short-term effects in their forecasts.

Final Remarks

In early 2022, Russia carried out an invasion of Ukraine on the grounds of liberating and bringing peace to regions that were under the control of the Ukrainian government (Donetsk and Lugansk). This event has had great repercussion at a global level, affecting, among other sectors, the financial market.

Faced with the effects of risk arising from geopolitical issues, the present study aimed to analyze the effect of this conflict on the equity markets of emerging and developed countries, as well as on the cryptocurrency market. For this, three analyzes were carried out based on intraday data of market index returns from the G-20 countries and the 10 largest existing cryptocurrencies.

Initially, entropy analysis was performed, that is, the degree of randomness of returns. In general, the outbreak of the invasion had an effect of reducing deterministic factors in the variation of the analyzed assets, indicating an improvement from the point of view of market efficiency.

It can be seen that China was the most affected nation, from the entropy point of view, indicating an increase in the degree of uncertainty regarding the sector's assets. Furthermore, it can be seen that, although not so expressively, emerging countries showed greater efficiency gains than developed ones. However, the cryptocurrency market proved to be closer to a random walk model, which is expected of an efficient market from an EMH perspective.

After that, an MFDFA analysis was performed, which aimed to measure variations in the effect of LTM as a result of invasion. On this metric, one can, in summary, see that geographic segregation was more efficient than segregation based on the country's degree of development. With respect to this aspect, the countries of North America and Europe showed a trend of increasing LTM, while the Asian countries, a reduction of this effect.

Finally, the cluster analysis indicated that before the Russian invasion there was a clearer separation between the behavior of the cryptocurrency market, in European countries and in other countries. However, in the period after the incursion, this distinction became more subtle, thus indicating that the GPUs have the ability to change, even if only in the short and medium term, the behavior of markets in an isomorphic movement.

This finding is the empirical contribution of this study, in the perspective that investors should keep in mind the need to recalibrate their forecast models to adapt to the new market behavior, when implementing efficient arbitrage strategies.

Added to this, the increase in the randomness of returns indicates that the existence of arbitrage will be reduced, which also implies the need to reduce expectations of abnormal profitability.

As with any study, this one is not without limitations. Among the most relevant points is the limitation of data access as well as the short time that has elapsed since the beginning of the invasion. Added to this is the fact that the war between Russia and Ukraine did not come to an end until the work was completed, and new events can occur, whose effects can be even more impacting from the point of view of market efficiency.

In this regard, it is suggested, for future studies, firstly the expansion of the time horizon, especially to capture the status quo of the markets before the invasion. Furthermore, it is also suggested to expand the study to capture the after-effects resulting from the invasion.

It would be interesting to add to this analysis the effects of the invasion on the foreign exchange and commodities market, in order to identify their similarities and differences with the findings observed in the stock and cryptocurrency market, which were found in this study.

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