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# Russian invasion 2022: analysis of persistent volatility and return spillovers among IMOEX, WTI and Russian OT (10Y)

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***Abstract:*** Russia's invasion of Ukraine is creating instability in the financial markets, with European stock markets falling, and the effects reflected in energy and food prices. A war scenario brings with it a humanitarian crisis and it is the most vulnerable who suffer the worst consequences. Based on these events it is intended in this paper to test the persistence of returns on the IMOEX capital market, Russian Sovereign OT (10 YR), and the WTI oil index over the period April 24th, 2017, to April 22nd, 2022. To perform this analysis different approaches were undertaken to analyse, if: (i) do the analysed markets exhibit persistence in their returns? The results suggest that the returns do not follow the i.i.d. hypothesis from dimension 2, reinforcing the idea that time series returns are nonlinear in nature or have a significant nonlinear component, except for the Russian capital market, which was expected considering the results of the Ljung-Box (with squares of the returns) and ARCH-LM tests.

***Keywords:*** Russian invasion of Ukraine; persistence; serial autocorrelation; arbitrage; portfolio diversification

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# Ruska invazija 2022: analiza nenehne (vztrajne) volatilnosti in prelivanja donosov med IMOEX, WTI in ruskim OT (10Y)

***Povzetek:*** Ruska invazija na Ukrajino ustvarja nestabilnost na finančnih trgih, pri čemer prihaja do padcev evropskih borz, učinki pa se odražajo v cenah energije in hrane. Vojni scenarij s seboj prinaša humanitarno krizo, pri čemer najhujše posledice trpijo najranljivejši. Na podlagi omenjenih dogodkov je zastavljen namen tega prispevka. Želeli smo preizkusiti vztrajnost donosov na kapitalskem trgu IMOEX, donosa desetletne ruske obveznice (ruski dolg OT (10 YR)) in indeksa surove nafte WTI v obdobju od 24. aprila 2017 do 22. aprila 2022. Za izvedbo te analize so bili uporabljeni različni pristopi, kot npr.: (i) ali analizirani trgi kažejo vztrajnost svojih donosov? Rezultati kažejo, da donosi ne sledijo i.i.d. hipotezo iz dimenzije 2, ki potrjuje idejo, da so donosi časovnih vrst po naravi nelinearni ali vsebujejo pomembno nelinearno komponento, razen za ruski kapitalski trg, kar je bilo pričakovano glede na rezultate Ljung-Box testa (s kvadrati donosnosti) in ARCH - LM testa.

***Ključne besede:*** Ruska invazija na Ukrajino, vztrajnost, serijska avtokorelacija, arbitraža, diverzifikacija portfelja

## 1. INTRODUCTION

The theme of the market efficiency hypothesis is that the current price of the asset reflects all available information at a given time, and the price adjusts fast as new and unpredicted information comes to the market. The mean reversion hypothesis, also called negative serial correlation, has been interpreted as an efficient correction mechanism in developed markets and a sign of a speculative bubble in emerging financial markets (Summers, 1986; Fama and French, 1988).

This investigation will test the persistence of returns on the IMOEX capital market, Russian Sovereign OT (10 YR), and the WTI oil index over the period April 24, 2017, to April 22, 2022. The results suggest that the returns do not follow the i.i.d. hypothesis, starting at dimension 2, reinforcing the idea that returns have a non-linear nature or have a significant non-linear component, which means, there is persistence in returns, except for the Russian capital market.

This research presents contributions to the existing literature. The first contribution is related with the study of persistence in the Russian capital market and sovereign OT yields, as well as the main oil index (WTI), in the context of the global pandemic (Covid-19), the oil price war between Russia and Saudi Arabia, as well as the Russian invasion of Ukraine in 2022. To our knowledge there are studies that have analysed the impact of the global pandemic on financial markets (Bagão et al., 2020; Dias and Pereira, 2021; Vasco et al., 2021), regarding the oil prices war in 2020 (Dias et al., 2021), but not on the Russian invasion of Ukraine in 2022. As a second contribution we can consider the dynamics of mathematical and econometric models employed, namely the unit root tests in panel by Breitung (2000) and by Levin, Lin, and Chu (2002), as well as, the Ljung and Box (1978) autocorrelation model (with squares of the returns), the conditional heteroscedasticity model (ARCH-LM by Engle, 1982), and finally, the model that estimates non-linear structures or components (BDS by Brock and De Lima, 1996).

In terms of structure, this paper is organized into 5 sections. Section 2 presents the literature review of articles on market efficiency, in its weak form. Section 3 describes the methodology and data. Section 4 contains the results. Section 5 concludes the present essay.

## 2. LITERATURE REVIEW

Different papers have addressed the issue of market efficiency by analysing the hypothesis of predictability of returns, through the analysis of mean reversion patterns of stock prices, inspired by the seminal papers of Poterba and Summers (1988) and Fama and French (1988), which documented mean reversion in stock markets over time horizons longer than one year.

Aggarwal (2018), Rehman, Chhapra, Kashif, and Rehan (2018), Karasiński (2020) tested the persistence of returns in various financial markets. Aggarwal (2018) analysed the market efficiency and persistence of the South Korean stock market (KOSPI) and suggests that the time series do not follow a random walk process. Rehman, Chhapra, Kashif, and Rehan (2018) show that the Pakistan, India, and Bangladesh stock market indices are not efficient in their weak form. Meanwhile, Karasiński (2020) examined weak efficiency in the European markets and found that the global efficiency tended to improve after the 2008 global financial crisis.

In more recent studies, Zebende et al. (2022), Dias et al. (2022) measured efficiency, in its weak form, and tested the persistence of the returns of several international markets. Zebende et al. (2022) used intraday data to measure market efficiency, in its weak form, in G20 capital markets. For this purpose,

the entire analysis was divided into two different time scales: Period I, a time scale of less than five

days, and Period II, with a time scale of more than ten days. The time-lapse, which includes the 2020 global pandemic, the authors show, and using the econophysical DFA model, for maturities less than 5 days, capital markets tend toward efficiency, while for maturities longer than 10 days, stock markets tend to be inefficient.

Authors Dias et al. (2022), on the other hand, measured the efficient market hypothesis in its weak form in the capital markets of Botswana, Egypt, Kenya, Morocco, Nigeria, South Africa, Japan, the UK, and the US over the period from September 2nd, 2019, to September 2nd, 2020. The authors show that returns are autocorrelated over time, that is, the random walk hypothesis is rejected in all the analysed markets, with no differences between mature and emerging markets.

In summary, this paper aims to contribute with information to investors and regulators where individual and institutional investors seek diversification benefits, as well as to help promote the implementation of policies that will contribute to the efficiency of these markets in this period of the Russia-Ukraine war 2022.

## 3. METHODOLOGY

### 3.1.Data

Data relative to the IMOEX closing capital market prices, the Russian Sovereign OT (10 YR) and the WTI oil index were obtained from the Thomson Reuters Eikon platform. The quotes are daily and cover the period from April 24th, 2017, to April 22nd, 2022, and are in local currency to mitigate exchange rate distortions.

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

| Index | Country |
|---|---|
| IMOEX | Russia |
| OT 10 YR | Russia |
| WTI | USA |

Source: Own elaboration

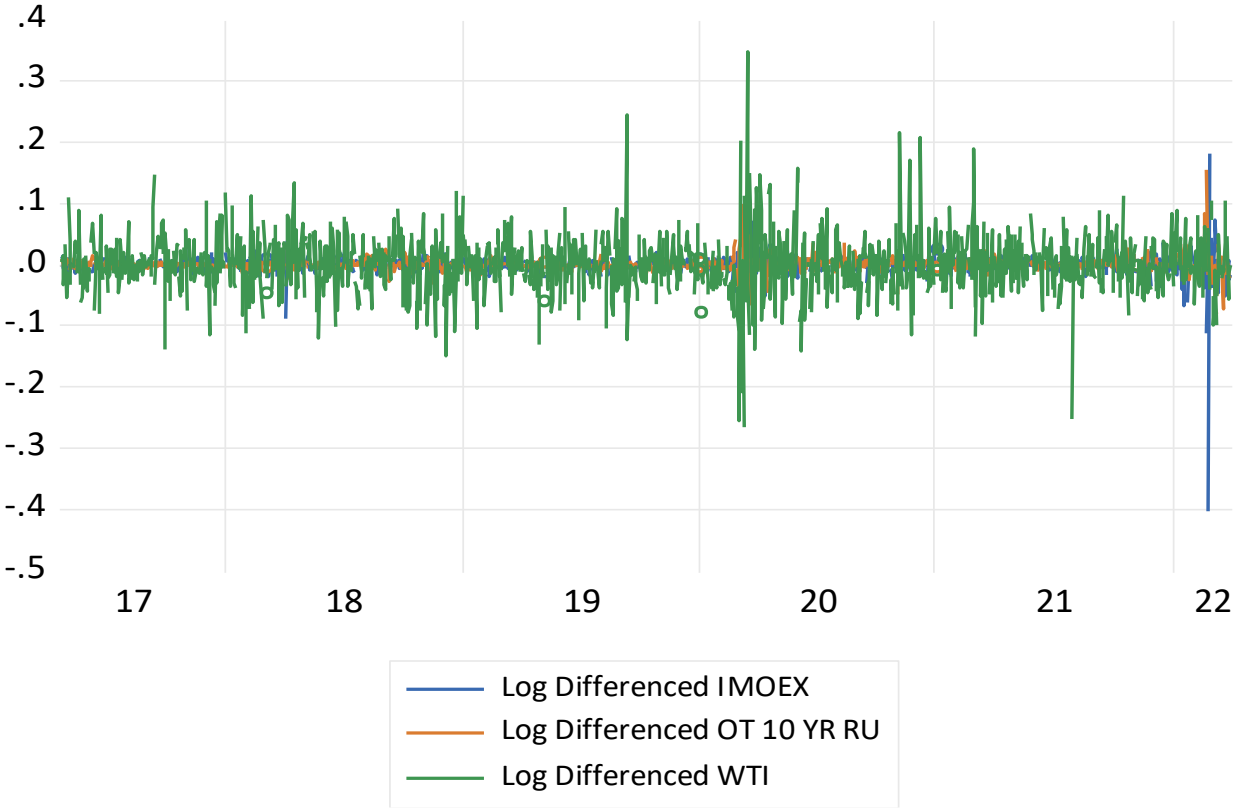
### 3.2. Methodology

The research was developed in several stages. The characterization of the sample used was done through descriptive statistics, the Jarque and Bera (1980) goodness of fit tests. To apply the econometric methods that will answer the research question, it was necessary to analyse the stationarity of the time series. In this way, we performed the panel unit root tests of Breitung (2000) and Levin, Lin, and Chu (2002). To answer the research question, we tested the persistence of the returns using the following tests: Ljung and Box (1978) (with the squares of the returns); ARCH-LM (Engle, 1982) and BDS (Brock and De Lima, 1996).

## 4. RESULTS

Figure 1 shows the evolution, return, on the IMOEX capital market, of the Russian Sovereign OT (10 YR), and the WTI oil index, over the period April 24th, 2017, to April 22nd, 2022. In a global way, a synchrony between all series and a generalized dispersion around the mean can be observed. However, in comparative terms, it is possible to observe that the WTI oil index shows high volatility in 2020, while the Russian capital market, as well as Russia's OT 10 YR shows extreme volatility in 2022, which is coincident with Russia's invasion of Ukraine, as well as, the instability experienced in the financial markets, with European stock markets falling, and the effects being reflected in energy and food prices. Figure 2. Evolution, of the returns, of the financial markets under analysis, for the period April 24th 2017 to April 22nd 2022.

Figure 1. Evolution, of the returns, of the financial markets under analysis, for the period April 24th 2017 to April 22nd 2022




Source: Own elaboration.
Note: Data worked by the author (1245 time data).

Table 2 shows the main descriptive statistics of the three financial markets, namely the Russian stock market (IMOEX), Russia's 10-year sovereign bonds (OT 10 YR RU), and the oil index (WTI), over the period April 24th, 2017, to April 22nd, 2022. Based on the results presented we find that the average returns are positive, while the WTI oil index has the highest standard deviation (0.048355). The results show that the return series propose departures from the normality hypothesis. This result emerges through the test of Jarque and Bera (1980), which allowed rejecting the null hypothesis of normality (H0) in favour of the alternative (H1 - non-normality), for a significance level of 1%. Additionally, the skewness and kurtosis coefficients are statistically different from those with a normal distribution, being leptokurtic and asymmetric.

Table 2. Descriptive statistics, returns, of the 3 financial markets for the period April 24th 2017, to April 22nd 2022.

| | IMOEX | OT 10 YR RU | WTI |
|---|---|---|---|
| Mean | 0.000275 | 9.65E-05 | 0.000695 |
| Std. Dev. | 0.012727 | 0.011374 | 0.048355 |
| Skewness | -1.323712 | 2.243910 | 0.279540 |
| Kurtosis | 16.43646 | 45.23607 | 8.540812 |
| Jarque-Bera | 9729.013 | 93583.86 | 1608.808 |
| Probability | 0.000000 | 0.000000 | 0.000000 |
| Observations | 1245 | 1245 | 1245 |

Source: Own elaboration

To apply the econometric methods that will answer the research question, it was necessary to analyse the stationarity of the time series. And so, a panel unit root tests of Breitung (2000) and Levin, Lin, and Chu (2002) were performed.

The results of the Breitung and LLC tests are shown in table 3 and 4 respectively, and suggest the rejection of the null hypothesis, for whatever significance level is considered (1%, 5% and 10%). In this sense, the null hypothesis of both tests that postulates the existence of a unit root (or unstable variance) was rejected for the time period under study, which shows that we are facing robustness in the estimation of the Ljung and Box (1978) autocorrelation models, of ARCH effects (Engle, 1982), and of BDS non-linear structures or components (Brock and De Lima, 1996).

Table 3. Breitung test performed on the 3 financial markets under analysis for the period April 24th 2017, to April 22nd 2022

| Method | | | Statistic | Prob.** |
|---|---|---|---|---|
| Breitung t-stat | | | -11.7816 | 0.0000 |
| ** Probabilities are computed assuming asympotic normality | | | | |
| Intermediate regression results on D(UNTITLED) | | | | |
| | S.E. of | | | |
| Series | Regression | Lag | Max Lag | Obs |
| D(IMOEX) | 72.0715 | 0 | 22 | 1245 |
| D(OT 10 YR RU) | 0.10950 | 2 | 22 | 1238 |
| D(WTI) | 0.27026 | 0 | 22 | 1245 |
| | Coefficient | t-Stat | SE Reg | Obs |
| Pooled | -0.08721 | -11.782 | 0.007 | 3725 |

Source: Own elaboration.
Note: Automatic lag length selection based on SIC: 0 to 2

Table 4. Levin et al. (2002) test performed on the 3 financial markets under analysis over the period April 24th 2017, to April 22nd 2022.

| Method | | | | Statistic | | Prob.** | |
|---|---|---|---|---|---|---|---|
| Levin, Lin & Chu t* | | | | -67.4381 | | 0.0000 | |
| ** Probabilities are computed assuming asympotic normality | | | | | | | |
| Intermediate results on D(UNTITLED) | | | | | | | |
| | 2nd Stage | Variance | HAC of | | Max | Band- | |
| Series | Coefficient | of Reg | Dep. | Lag | Lag | width | Obs |
| D(IMOEX) | -1.11869 | 2287.6 | 30.895 | 0 | 22 | 150.0 | 1245 |
| D(OT 10 YR RU) | -0.73958 | 0.0095 | 0.0007 | 2 | 22 | 27.0 | 1238 |
| D(WTI) | -0.96794 | 0.0377 | 0.0019 | 0 | 22 | 40.0 | 1245 |
| | Coefficient | t-Stat | SE Reg | mu* | sig* | | Obs |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pooled | -0.98581 | -54.456 | 1.008 | -0.500 | 0.707 | | 3728 |

Source: Own elaboration.
Note: Automatic lag length selection based on SIC: 0 to 2. Newey-West automatic bandwidth selection and Bartlett kernel

In order to verify the existence of persistence in the returns of the stock market (IMOEX), OT 10 YR, and the WTI oil index, we estimated the following models: Ljung-Box (with the squares of the returns); ARCH-LM (Engle, 1982) and BDS (Brock and De Lima, 1996). In Table 5 we can see the results of the Ljung-Box test, applied to time series returns as well as squared returns. We perform at a first stage, and for lags 4 and 12, the Ljung-Box test and verified that as we increase the lags the autocorrelation becomes more persistent, except for the IMOEX market. To validate the results, we use the same model, with squared returns, also for lags 4 and 12, and prove that the autocorrelation becomes more persistent, the exception being the Russian capital market that shows anti persistence, or the absence of long memories.

Table 5. Results of Ljung-Box tests applied to the residuals of the 3 time series for the period April 24th 2017 to April 22nd 2022.

| | **IMOEX** | **OT 10 YR RU** | **WTI** |
|---|---|---|---|
| LB(4) | 44.747*** | 118.48*** | 0.8654 |
| LB(12) | 57.443*** | 183.78*** | 25.997** |
| $LB^2(4)$ | 37.503*** | 159.57*** | 174.54*** |
| $LB^2(12)$ | 38.712*** | 325.61*** | 347.97*** |

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

To analyse the presence of the phenomenon of conditional heteroscedasticity in financial series, it is usual to use the Lagrange Multiplier test (ARCH-LM test) (Engle, 1982). The ARCH-LM tests were applied to the residuals of first order autoregressive processes and, for lag 10. In tables 6, 7 and 8 we can see that the residuals of the autoregressive processes of the financial markets under analysis exhibit conditional heteroscedasticity, bearing this characteristic often present in financial assets. The Ljung-Box tests, applied to the squared returns (table 5), for lags 4 and 12, confirm the evidence of the ARCH-LM test, reinforcing the evidence of the presence of ARCH effects in the time series. The IMOEX capital market shows less significant heteroscedasticity (3.905316), whereas Russia's OT 10 YR and the oil index show pronounced signs. In a complementary way, we verified that the IMOEX capital market presents conditioned heteroscedasticity, but does not present persistence in its returns, suggesting that investors operating in this market, eventually, will not be able to obtain returns above the market average without incurring in additional risk.

Table 6. ARCH-LM test applied to the IMOEX stock market residuals over the period April 24th 2017 to April 22nd 2022.

| **Heteroskedasticity Test: ARCH (IMOEX)** | | | |
|---|---|---|---|
| F-statistic | 3.905316 | Prob. F(10,1226) | 0.0000 |
| Obs*R-squared | 38.18713 | Prob. Chi-Square(10) | 0.0000 |

Source: Own elaboration
Note: The LM test was applied to the residuals of a first order autoregressive process of each series. The asteric ***, ** represent significance at 1% and 5%, respectively.

Table 7. ARCH-LM test applied to the residuals of Russia's 10YR Sovereign OT over the period April 24th 2017 to April 22nd 2022.

| **Heteroskedasticity Test: ARCH (OT 10 YR RU)** | | | |
|---|---|---|---|
| F-statistic | 21.18507 | Prob. F(10,1226) | 0.0000 |
| Obs*R-squared | 182.2577 | Prob. Chi-Square(10) | 0.0000 |

Source: Own elaboration

Note: The LM test was applied to the residuals of a first order autoregressive process of each series. The asteric ***, ** represent significance at 1% and 5%, respectively.

Table 8. ARCH-LM test applied to the residuals of the WTI oil index over the period April 24th 2017 to April 22nd 2022.

| **Heteroskedasticity Test: ARCH (WTI)** | | | |
|---|---|---|---|
| F-statistic | 19.38866 | Prob. F(10,1226) | 0.0000 |
| Obs*R-squared | 168.9133 | Prob. Chi-Square(10) | 0.0000 |

Source: Own elaboration

Note: The LM test was applied to the residuals of a first order autoregressive process of each series. The asteric ***, ** represent significance at 1% and 5%, respectively.

In table 9, 10 and 11 it is possible to check the results of the BDS test, and we can see that the hypothesis that the returns are i.i.d. is rejected, with statistical significance, from dimension 2 onwards, reinforcing the idea that the returns of the analysed markets have a non-linear nature or have a significant non-linear component, with the exception of the Russian capital market, which was expected in view of the results of the Ljung-Box (with squares of the returns) and ARCH-LM tests. According to Taylor (1986) the significant presence of higher autocorrelation between the squares of the returns than between the original values of the returns is also an indication of the presence of nonlinearity. Table 5 shows the results of the autocorrelation tests of squares of the returns, for lags 4 and 12, and all indices reject the null hypothesis, identifying serial autocorrelation, with the exception made to the Russian stock market. The results of the autocorrelation tests are completely coincident with those obtained by the BDS test. The rejection of the null hypothesis, i.i.d., may be explained, among other factors, by the existence of autocorrelation or the existence of heteroscedasticity in the time series, cases in which the rejection of the null hypothesis is explained by non-linear dependence of the data. These findings are in line with the studies of authors Vasco et al. (2021), Zebende et al. (2022), Dias et al. (2022), which show the existence of persistence in the returns of international financial markets.

Table 9. BDS test applied to IMOEX stock market residuals over the period April 24th 2017 to April 22nd 2022.

| **BDS Test for IMOEX** | | | | | |
|---|---|---|---|---|---|
| Dimension | BDS Statistic | Std. Error | z-Statistic | Prob. | |
| 2 | -1.29E-06 | 4.53E-05 | -0.028443 | 0.9773 | |
| 3 | -3.86E-06 | 0.000101 | -0.038224 | 0.9695 | |
| 4 | -7.73E-06 | 0.000169 | -0.045762 | 0.9635 | |
| 5 | -1.29E-05 | 0.000247 | -0.052187 | 0.9584 | |
| 6 | -1.93E-05 | 0.000334 | -0.057909 | 0.9538 | |
| Raw epsilon | | 0.293647 | | | |
| Pairs within epsilon | | 1552517. | V-Statistic | 0.998397 | |
| Triples within epsilon | | 1.93E+09 | V-Statistic | 0.997596 | |
| Dimension | C(m,n) | c(m,n) | C(1,n-(m-1)) | c(1,n-(m-1)) | c(1,n-(m-1))^k |
| 2 | 773146.0 | 0.996791 | 774390.0 | 0.998395 | 0.996792 |
| 3 | 770661.0 | 0.995185 | 773146.0 | 0.998394 | 0.995188 |
| 4 | 768180.0 | 0.993577 | 771903.0 | 0.998392 | 0.993585 |
| 5 | 765703.0 | 0.991968 | 770661.0 | 0.998391 | 0.991981 |
| 6 | 763230.0 | 0.990358 | 769420.0 | 0.998390 | 0.990377 |

Source: Own elaboration.

Notes: The method considered in the BDS test was the pair fraction, for a value of 0.7. The first column refers to the embedding dimension. The values presented in the table refer to the z-Statistic. ***, ** represent the significance at 1% and 5%, respectively.

Table 10. BDS test applied to the residuals to Russia's 10YR Sovereign OT for the period April 24th 2017 to April 22nd 2022.

| **BDS Test for OT 10 YR RU** | | | | | |
|---|---|---|---|---|---|
| Dimension | BDS Statistic | Std. Error | z-Statistic | Prob. | |
| 2 | 0.042875 | 0.003209 | 13.36260 | 0.0000 | |
| 3 | 0.081362 | 0.005110 | 15.92321 | 0.0000 | |
| 4 | 0.108718 | 0.006100 | 17.82319 | 0.0000 | |
| 5 | 0.124353 | 0.006375 | 19.50610 | 0.0000 | |
| 6 | 0.130746 | 0.006166 | 21.20522 | 0.0000 | |
| Raw epsilon | | 0.009994 | | | |
| Pairs within epsilon | | 1094557. | V-Statistic | 0.703891 | |
| Triples within epsilon | | 1.07E+09 | V-Statistic | 0.552093 | |
| Dimension | C(m,n) | c(m,n) | C(1,n-(m-1)) | c(1,n-(m-1)) | c(1,n-(m-1))^k |
| 2 | 418439.0 | 0.539479 | 546591.0 | 0.704701 | 0.496604 |
| 3 | 335160.0 | 0.432805 | 546485.0 | 0.705697 | 0.351444 |
| 4 | 275763.0 | 0.356676 | 545577.0 | 0.705658 | 0.247958 |
| 5 | 231038.0 | 0.299310 | 544689.0 | 0.705644 | 0.174956 |
| 6 | 196262.0 | 0.254667 | 544153.0 | 0.706086 | 0.123921 |

Source: Own elaboration.

Notes: The method considered in the BDS test was the pair fraction, for a value of 0.7. The first column refers to the embedding dimension. The values presented in the table refer to the z-Statistic. ***, ** represent the significance at 1% and 5%, respectively.

Table 11. BDS test applied to the residuals to the WTI oil index over the period April 24th 2017 to April 22nd 2022.

| **BDS Test for WTI** | | | | | |
|---|---|---|---|---|---|
| Dimension | BDS Statistic | Std. Error | z-Statistic | Prob. | |
| 2 | 0.012129 | 0.002409 | 5.033731 | 0.0000 | |
| 3 | 0.022377 | 0.003826 | 5.848642 | 0.0000 | |
| 4 | 0.026560 | 0.004552 | 5.834330 | 0.0000 | |
| 5 | 0.028702 | 0.004741 | 6.053815 | 0.0000 | |
| 6 | 0.027952 | 0.004569 | 6.118465 | 0.0000 | |
| Raw epsilon | | 0.062647 | | | |
| Pairs within epsilon | | 1094487. | V-Statistic | 0.703846 | |
| Triples within epsilon | | 1.04E+09 | V-Statistic | 0.537925 | |
| Dimension | C(m,n) | c(m,n) | C(1,n-(m-1)) | c(1,n-(m-1)) | c(1,n-(m-1))^k |
| 2 | 393132.0 | 0.506852 | 545555.0 | 0.703366 | 0.494723 |
| 3 | 286552.0 | 0.370036 | 544516.0 | 0.703155 | 0.347658 |
| 4 | 209788.0 | 0.271343 | 543822.0 | 0.703388 | 0.244783 |
| 5 | 155078.0 | 0.200903 | 542963.0 | 0.703408 | 0.172202 |
| 6 | 114981.0 | 0.149198 | 542177.0 | 0.703522 | 0.121246 |

Source: Own elaboration.

Notes: The method considered in the BDS test was the pair fraction, for a value of 0.7. The first column refers to the embedding dimension. The values presented in the table refer to the z-Statistic. ***, ** represent the significance at 1% and 5%, respectively.

## 5. CONCLUSIONS

The general conclusion to be retained and, supported by the results obtained, through the tests performed with mathematical models and econometrics show that the events that occurred in 2020, global pandemic and oil price war between Saudi Arabia and Russia, as well as, the current war in 2022 between Russia-Ukraine has a significant impact on the memory holdings of Russia's Sovereign OT (10-year) and the WTI oil index, however this impact is not seen on Russia's capital market (IMOEX). We found that the returns do not follow the i.i.d. hypotheses, starting at dimension 2, reinforcing the idea that the returns of the time series have a non-linear nature or have a significant non-linear component, except for the Russian market, which was expected in view of the results of the Ljung-Box (with the squares of the returns) and ARCH-LM tests, the latter with little significance. These findings are relevant for international investors looking to diversify their portfolios efficiently, these findings also open room for market regulators to take steps to ensure better information for investors.

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