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Testing the Causal Relationship between Central and Eastern European Capital Markets: Evidence in Periods of Uncertainty in the Global Economy

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Abstract: *The purpose of this study is to examine the movements of capital markets in Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), the Czech Republic (PRAGUE PX), Slovenia (SBI TOP), and Poland (WIG) from September 18th, 2017 to September 15th, 2022. To obtain more robust results, we divide the sample into two sub-periods: the Quiet period, from September 18th, 2017, to December 31st, 2019; and the Stress Period, from January 1st, 2020, to September 15th, 2022, marked by the global pandemic (COVID-19), the oil price war in 2020, and the Russian invasion in 2022. The time series exhibit non-normal distributions due to the presence of fat tails, a characteristic that is common in periods of extreme volatility. The results of the VAR Granger Causality/Block Exogeneity Wald Tests model verified the existence of 16 pairs of markets showing co-movements between them during the quiet subperiod. The market that causes more co-movements is the Austrian stock market (ATX), while the Russian stock index (IMOEX) does not cause shocks in the markets under analysis. In the Stress subperiod, we verify the presence of 42 pairs of markets causing (each other in the Grangerian sense. The stock indexes ATX, BUX, CROBEX, and PRAGUE PX show 6 causal relations in 7 possible, while the capital markets of Russia (IMOEX) and Poland are the ones that cause less (4 in 7 possible). In conclusion, we verify that the events that occurred in 2020 and 2022 have significantly increased the movements in these regional markets. Such findings could put into question the implementation of efficient portfolio diversification strategies and eventually some gains above the market average due to arbitrage levels. The authors consider this evidence to be relevant for supervisors, regulators, and investors operating in these regional markets.*

1. INTRODUCTION

The economic literature related to capital markets has paid much attention to identifying the mechanisms through which an exogenous shock propagates between two capital markets. Thus, many studies focus on detecting the interactions between international financial markets, while identifying determinants of contagion and the phenomenon of co-movement between capital markets (Dias, da Silva, et al., 2019; Dias, Heliodoro, et al., 2019).

Several studies have examined the effect of exogenous shocks on a financial market to understand the synchronizations between markets, as well as the diversification of portfolios in

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international markets. In general, investors, risk managers, national regulators, and international financial institutions have shown interest in understanding how the phenomenon of contagion and interdependence develops due to the adverse implications of exogenous shocks on national financial markets (Dias et al., 2020; Dias et al., 2021; Pardal et al., 2020; Silva et al., 2020).

This study aims to investigate the shocks and causal relationships between the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG) over the period from September 18th, 2017 to September 15th, 2022. There is considerable literature on financial market interconnectedness, notably by writers Jawadi et al. (2019), Dias et al. (2020), and Dias and Carvalho (2021a), however many of these studies have mainly examined Western European markets. The choice of these emerging economies is motivated by the fact that their financial markets are entirely congruent with the major global financial markets, with substantial possibilities of interdependence.

In conducting this study, we are interested in answering the following research question: (1) Did the global economic instability caused by the events of 2020 and 2022 increase the com-movements between Western European and Eastern European capital markets? During the Quiet subperiod, the results indicate the existence of 16 of 56 possible causal relationships, whereas the number of causal relationships between pairs of markets under analysis increased significantly during the Stress subperiod, which included the events of 2020 and 2022, inferring 42 of 56 possible causal relationships. These findings may call into question portfolio diversification in these regional markets.

This research paper is divided into 5 sections. In addition to the current introduction, section 2 presents a Literature Review regarding articles on the movements and causal links between international capital markets, section 3 describes the methodology and data, section 4 contains the results. Section 5 presents the general discussions of the paper.

2. LITERATURE REVIEW

From the investor's point of view, knowledge of the form and intensity of interdependence between different financial markets is vital for efficient hedging decisions, to minimize the adverse effect of uncertainty on the expected return on investments. In the same way, understanding the interdependence relations between international stock markets facilitates the identification of diversification opportunities (Guedes et al., 2022; Teixeira et al., 2022; Zebende et al., 2022).

The authors Horvath and Petrovski (2012) examined the movements of Western European capital markets relative to Central Europe (Czech Republic, Hungary and Poland) and Southeast Europe (Croatia, Macedonia and Serbia) in the period 2006-2011.

The authors show that the co-movements in Central Europe are more significant when compared to the capital markets of Western Europe and Southeast Europe. Moreover, the results show that the correlation of Southeast European equity markets with developed markets is essentially zero, opening doors for investors operating in these markets to diversify their portfolios efficiently.

The authors Koseoglu and Cevik (2013) investigated the causality relationships between stock markets and foreign exchange markets in the Czech Republic, Hungary, Poland and Turkey.

Moreover, they show that stock markets cause in a Grangerian sense the exchange markets in all countries, both in mean and variance, suggesting that the stock market plays an important role in the price discovery process for the exchange market of the countries analyzed.

Özer et al. (2016) analyzed the co-movement between the markets of Germany, Austria, Czech Republic, Croatia, Lithuania and Greece, the authors show mixed results by failing to highlight co-movement. These findings have relevant implications for international investors, portfolio managers and policymakers.

In a complementary manner, the authors Cevik et al. (2017) analyzed the presence of a causal link between the financial markets of Central and Eastern European (CEE) countries adopting an asymmetric causality test. The authors evidence of a causal relationship running from the Czech Republic to Poland; moreover, Poland's stock market causes Turkey's stock market. Complementarily the results of the asymmetric causality test indicate only one causal link running from the Czech Republic to Hungary and Poland.

While the authors Jawadi et al. (2019) studied the movements between the US market and the G-6, BRIC and MENA markets. The authors show that the MENA and BRIC markets are segmented with the US market, while the G-6 markets show integration with the US.

In more recent studies, the author Shi (2022) investigated the co-movements between China's stock market and 12 capital markets in the Asia-Pacific region after the global financial crisis. The author uses weekly conditional correlations to detect contagion and explores the transmission mechanisms by regressing monthly economic and financial variables. The empirical results show that events (specifically, the Shanghai stock market crash, the US-China tariff war, and the COVID-19 pandemic) significantly increased the co-movements between China and Asia-Pacific markets.

While the authors Karamti and Belhassine (2022) analyzed the connection between the COVID-19 outbreak and major financial markets within a time and frequency framework. Wavelet coherence analysis reveals perceptive differences between short-term and long-term market reactions. In the short term, the authors evidence strong co-movement during the first and second wave of the 2020 pandemic. Furthermore, the authors explain that the panic caused by the pandemic spread in the United States contaminates international markets, and they suggest that the gold market and cryptocurrencies are safer investments.

In summary, this paper aims to contribute to providing information to investors and regulators in Central and Eastern European capital markets, where individual and institutional investors seek diversification benefits. Therefore, this paper aims to examine the synchronizations between European capital markets and to understand whether the hypothesis of portfolio diversification is challenged due to uncertainty in the global economy.

3. METHODOLOGY AND DATA

3.1. DATA

Price index data for the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG), were sourced from the *Thomson Reuters Eikon* platform. The quotes are daily and cover the period from September 18th, 2017, to September 15th, 2022, which is a period marked by the global pandemic of 2020 and the Russian invasion of Ukraine in 2022; to keep the time series as reliable as possible we have kept the prices in local currency to mitigate exchange rate distortions.

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

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

Source: Own elaboration

3.2. METHODOLOGY

To answer the research question, we will start by characterizing the sample through statistical measures, such as mean, standard deviation, skewness and kurtosis. To validate the result regarding the time series distribution we will estimate Jarque and Bera (1980). To check white noise we will estimate the unit root tests of Breitung (2000) and Hadri (2000).

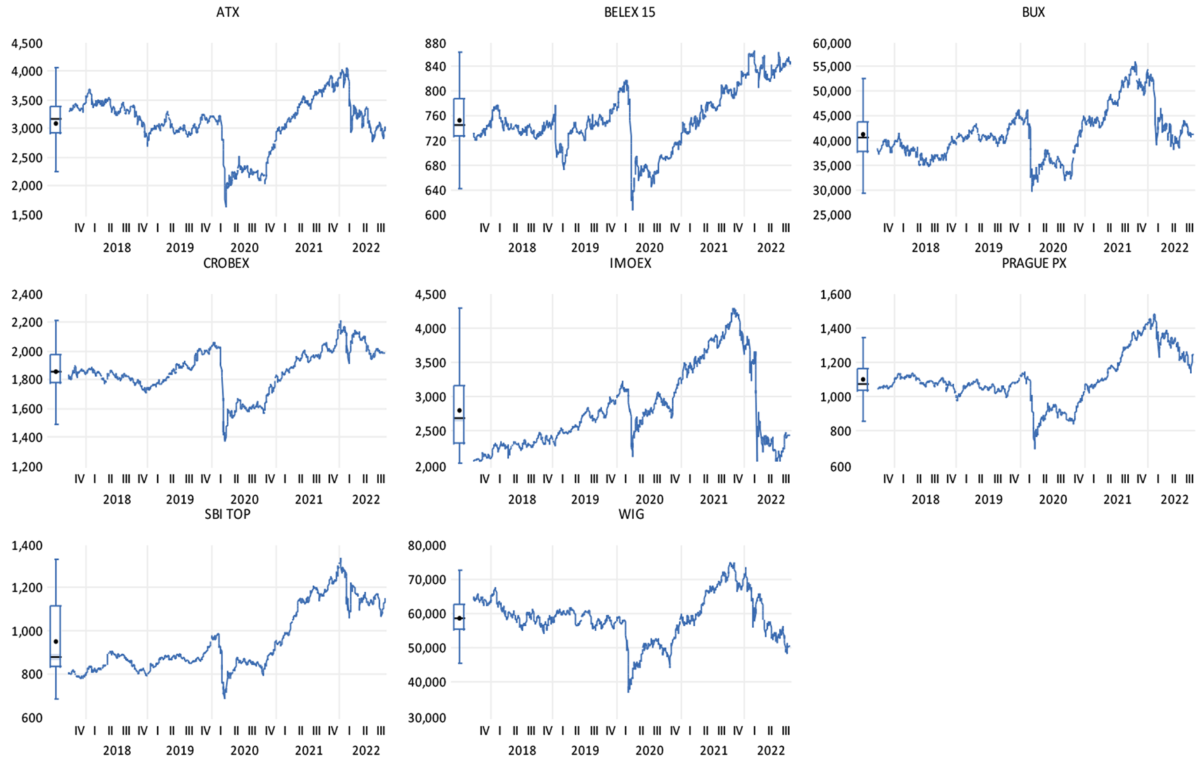
The VAR Granger Causality/Block Exogeneity Wald Tests methodology will be used to answer the research question. It employs the Wald statistic, which validates whether the coefficients of the endogenous variables lagged from the "cause" variable are null or does not "cause" the dependent variable in the Grangerian sense. It should, however, be noted that the result of this test is highly sensitive to the number of lags considered in the model, so the first concern is to properly estimate this value, to obtain robust evidence (Gujarati, 2004).

As a complement, and to determine the optimal number of lags, we used the LR criteria: sequential modified. LR test statistic (each test at 5% level). FPE: Final prediction error. AIC: Akaike information criterion. SC: Schwarz information criterion. HQ: Hannan-Quinn information criterion.

4. RESULTS

Figure 1 illustrates the evolution, in levels, of the price indexes of the European capital markets, namely Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG), over the period from September 18th, 2017 to September 15th, 2022, to analyze the reaction of financial markets to events such as the COVID-19 crisis in 2020 and Russia's invasion of Ukraine in 2022. The price indexes under study reveal the instability experienced in these markets, especially with the outbreak of the pandemic crisis.

With a subsequent upward trend in 2021, the markets again registered significant drops in 2022, especially in the Russian market due to its political decision to operate militarily in Ukraine. These findings are validated by the authors Bagão et al. (2020), Dias and Santos (2020), Dias and Carvalho (2021a), Teixeira et al. (2022), which show that the global pandemic of 2020 (Covid-19) caused very sharp turbulence in international financial markets.

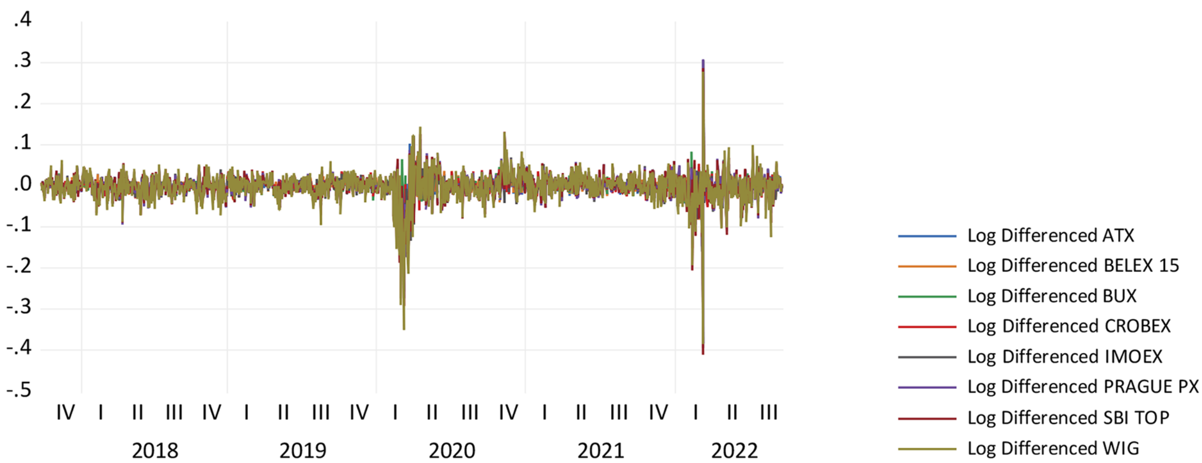


Note: Data processed by the authors (software: Eviews12)

Figure 1. Evolution, in levels, of the financial market under analysis, for the period from September 18th, 2017, to September 15th, 2022

Source: Own elaboration

Figure 2 shows the evolution of the price indexes in the first annual differences of the capital markets under analysis. In all the series, there is a relatively high dispersion around the average, as well as a relatively synchronized behavior between the time series. Through graphical analysis, we observe the existence of high volatility during the first and second quarters of 2020 and 2022, periods of high complexity marked by the COVID-19 pandemic and the Russian political decision to operate militarily in Ukrainian territory.



Note: Data processed by the authors (software: Eviews12)

Figure 2. Evolution of the returns, of the financial market under analysis, in the period from September 18th, 2017, to September 15th, 2022

Source: Own elaboration

Table 2a presents the values of the descriptive statistics of the price indexes of four stock markets, namely Austria (ATX), Serbia (BELEX 15), Hungary (BUX) and Croatia (CROBEX) and Table 2b presents the values of the descriptive statistics of the price indexes of Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG).

Regarding returns, according to classical financial theory, these would be close to zero, since it postulates that the longer the time interval of the time series, its return will tend towards zero. As can be seen, all indexes show returns close to zero and positive, except for the ATX, CROBEX and WIG price indexes, which showed negative returns for the period under study.

The results obtained show that the time series suggest departures from the normality hypothesis. This result emerges from the Jarque and Bera (1980) test, which allowed rejecting the null hypothesis of normality (H_0) in favor of the alternative ((H_1) - non-normality), for a significance level of 1%. Additionally, the skewness and kurtosis coefficients are statistically different from those of a normal distribution. These results are confirmed by the authors Guedes et al. (2022), Teixeira et al. (2022), Dias et al. (2022), Zebende et al. (2022) which show that the price series of capital markets present distributions that depart from normality.

Table 2a. Descriptive statistics, in returns, of the financial markets under analysis for the period from September 18th, 2017, to September 15th, 2022

	ATX	BELEX_15	BUX	CROBEX
Mean	-8.49E-05	0.000117	5.49E-05	7.80E-05
Std. Dev.	0.014819	0.006947	0.014134	0.008240
Skewness	-1.231871	-1.068310	-1.477502	-3.907048
Kurtosis	18.69780	15.33660	15.46578	53.60873
Jarque-Bera	13224.21	8210.143	8596.194	137343.2
Probability	0.000000	0.000000	0.000000	0.000000
Observations	1257	1257	1257	1257

Note: Data processed by the authors (software: Eviews12)

Source: Own elaboration

Table 2b. Descriptive statistics, in returns, of the financial markets under analysis for the period from September 18th, 2017, to September 15th, 2022

	IMOEX	PRAGUE PX	SBI TOP	WIG
Mean	0.000137	0.000137	0.000291	-0.000195
Std. Dev.	0.018450	0.010112	0.009027	0.013147
Skewness	-8.081235	-1.194789	-1.980833	-1.403024
Kurtosis	196.4023	15.81751	23.65061	18.53894
Jarque-Bera	1972739.	8903.676	23157.21	13058.80
Probability	0.000000	0.000000	0.000000	0.000000
Observations	1257	1257	1257	1257

Note: Data processed by the authors (software: Eviews12)

Source: Own elaboration

As we are estimating price indexes instead of returns, we should analyze the (non-) stationary nature of the time series of the capital markets under study. For identifying the presence of unit roots in the time series, there are individual or panel tests. However, in the present study, we will opt for the use of panel unit root tests because they have higher statistical power and allow obtaining more robust results, as they can increase considerably the sample size of the tests by considering not only the information of the time series dimension but also the cross-section dimension (Hadri, 2000; Maddala & Wu, 1999).

Specifically, the panel unit root tests postulated by Breitung (2000) and Hadri (2000). The Breitung test is considered a derived and improved test of the unit root test developed by Dickey and Fuller (1981) and has as a null hypothesis that all panels contain a unit root (or unstable variance). In turn, the test of Hadri (2000) will be used to validate the presence or absence of unit roots in panel data and to corroborate the results obtained from the previous test since its null hypothesis is contrary to the Breitung test.

According to the results obtained in Table 3 and 4, both tests suggest stationarity in first differences, that is, the data series are integrated of the first order, and these results allow us to assess that the time series present the necessary characteristics to show robust results.

Table 3. Breitung stationarity test (2000), applied to the financial markets under analysis, in the period from September 18th, 2017, to September 15th, 2022

Method			**Statistic**	**Prob.****
Breitung t-stat			-67.8685	0.0000
** Probabilities are computed assuming asymptotic normality				
Intermediate regression results on D(UNTITLED)				
Series	**S.E. of Regression**	**Lag**	**Max Lag**	**Obs**
D(ATX)	56.5883	0	22	1255
D(BELEX 15)	6.09273	1	22	1254
D(BUX)	640.726	2	22	1253
D(CROBEX)	15.3580	2	22	1253
D(IMOEX)	73.2703	0	22	1255
D(PRAGUE PX)	14.7590	0	22	1255
D(SBI TOP)	10.1143	1	22	1254
D(WIG)	1009.51	0	22	1255
	Coefficient	t-Stat	SE Reg	Obs
Pooled	-0.81482	-67.868	0.012	10026

Note: Data processed by the authors (software: Eviews12)

Source: Own elaboration

Table 4. Hadri Stationarity test (2002), applied to the financial markets under analysis, in the period from September 18th, 2017, to September 15th, 2022

Method			**Statistic**	**Prob.****
Hadri Z-stat			0.56682	0.2854
Heteroscedastic Consistent Z-stat			-0.43374	0.6678
* Note: High autocorrelation leads to severe size distortion in Hadri test, leading to over-rejection of the null.				
** Probabilities are computed assuming asymptotic normality				
Intermediate results on D(UNTITLED)				
		Variance		
Series	**LM**	**HAC**	**Bandwidth**	**Obs**
D(ATX)	0.0691	2476.260	13.0	1256
D(BELEX 15)	0.0292	34.98975	14.0	1256
D(BUX)	0.0566	345744.5	5.0	1256
D(CROBEX)	0.0408	350.3203	17.0	1256
D(IMOEX)	0.0822	2303.098	7.0	1256
D(PRAGUE_PX)	0.0699	155.0696	14.0	1256
D(SBI TOP)	0.0483	119.1608	14.0	1256
D(WIG)	0.0858	591143.9	9.0	1256

Note: Data processed by the authors (software: Eviews12)

Source: Own elaboration

In this paper, to analyze the structures of causal relations of time series, namely from Austria (ATX), Serbia (BELEX 15), Budapest (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Warsaw (WIG) during two periods, the Granger Causality approach was used. This approach, through the estimation of an Autoregressive Vector (VAR), allows us to identify the direction of causality, that is, using the F-statistic test it allows us to calculate for which values a given time series provides statistically significant information (predictive ability) on the evolution of the future values of another time series. For example, if one considers two stationary time series (X and Y; H0: If Y did not cause X, then we would be facing a unidirectional causal relationship). Nevertheless, if time series both cause and are caused by their pair, this leads us to conclude that we are facing a bidirectional causal relationship.

Note that to estimate the autoregressive vector, the first step is to estimate the optimal number of lags (observable values of the lagged time series) in the VAR model.

To determine the optimal number of lags for the estimation of the VAR model for the quiet period, the criteria presented in Table 5 was used. Based on the LR criterion, the results point to a model with 4 lags. In Table 6 we can observe the results of the test, which for the number of lags equal to 4; it leads us not to reject the null hypothesis, which postulates the non-existence of autocorrelation of residuals. Thus, rejecting the hypothesis of autocorrelation of serial residuals, it is determined that the model estimated considering a lag equal to 4 days is robust.

Table 5. Information Criteria to determining the optimal number of lags in VAR model for the Tranquil Period

Lag	LogL	LR	FPE	AIC	SC	HQ
0	15749.15	NA	4.80e-35	-56.31895	-56.25704*	-56.29477*
1	15837.40	173.6700	4.40e-35	-56.40573	-55.84852	-56.18814
2	15912.06	144.7786	4.24e-35*	-56.44387*	-55.39136	-56.03286
3	15972.28	115.0513	4.30e-35	-56.43035	-54.88253	-55.82591
4	16018.37	**86.72698***	4.58e-35	-56.36625	-54.32313	-55.56840
5	16057.41	72.35749	5.02e-35	-56.27695	-53.73853	-55.28568
6	16090.43	60.25008	5.61e-35	-56.16611	-53.13239	-54.98142
7	16135.20	80.41410	6.02e-35	-56.09732	-52.56829	-54.71921
8	16164.28	51.39540	6.85e-35	-55.97237	-51.94805	-54.40085
9	16205.56	71.78266	7.45e-35	-55.89109	-51.37147	-54.12616
10	16248.84	74.01328	8.06e-35	-55.81695	-50.80203	-53.85860

Note: Data processed by the authors (software: Eviews 12). * Indicates lag order selected by the criterion. LR: sequential modified. LR test statistic (each test at 5% level). FPE: Final prediction error. AIC: Akaike information criterion. SC: Schwarz information criterion. HQ: Hannan-Quinn information criterion.

Source: Own elaboration

Table 6. VAR Residual Serial Correlation LM Tests

Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	66.94431	64	0.3763	1.046828	(64, 2988.5)	0.3764
2	61.12963	64	0.5786	0.954978	(64, 2988.5)	0.5787
3	81.13419	64	0.0728	1.271716	(64, 2988.5)	0.0729
4	71.20053	64	0.2506	1.114171	(64, 2988.5)	0.2507
5	65.86011	64	0.4123	1.029688	(64, 2988.5)	0.4124

Note: Data processed by the authors (software: Eviews 12)

Source: Own elaboration

Table 7 shows the shocks in the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG), for the Quiet subperiod. When we apply 4 lags to the Granger Causality Tests model, we find 16 pairs of markets showing comovement between them, as follows: The Austrian stock market (ATX) causes shocks on BUX, CROBEX, IMOEX, PRAGUE PX and WIG, ATX is the market that causes the most (5 out of 7 possible); The Czech Republic stock index (PRAGUE PX) causes shocks in Serbia (BELEX 15), Hungary (BUX), Russia (IMOEX) (3 out of 7 possible); Hungary (BUX) market shocks Austria (ATX) and Poland (WIG) (2 out of 7 possible); Slovenia (SBI TOP) causes in a Grangerian sense the stock indexes in Hungary (BUX), Poland (WIG) (2 out of 7 possible); Stock market index Poland (WIG) causes stock market shocks in Russia (IMOEX), Czech Republic (PRAGUE PX) (2 out of 7 possible); The stock market Czech Republic (PRAGUE PX) causes movements on the stock market in Slovenia (SBI TOP), while the stock market Russia (IMOEX) does not cause shocks on the markets in the analysis.

Table 7. Granger Causality Tests applied to the financial markets under analysis, in the period from September 18th, 2017, to December 30th, 2022 (Tranquil Period)

	F-Statistic	**Prob.**
BELEX 15 does not Granger Cause ATX	1.05078	0,3803
ATX does not Granger Cause BELEX 15	0.67370	0,6104
BUX does not Granger Cause ATX	**4.56488*** **	0,0012
ATX does not Granger Cause BUX	**2.54162** **	0,0389
CROBEX does not Granger Cause ATX	0.36066	0,8366
ATX does not Granger Cause CROBEX	**3.64626*** **	0,0061
IMOEX does not Granger Cause ATX	1.24910	0,289
ATX does not Granger Cause IMOEX	**3.76539*** **	0,0049
PRAGUE PX does not Granger Cause ATX	1.61824	0,1682
ATX does not Granger Cause PRAGUE PX	**42.4698*** **	4,00E-31
SBI TOP does not Granger Cause ATX	1.45053	0,216
ATX does not Granger Cause SBI TOP	1.16741	0,3242
WIG does not Granger Cause ATX	0.90762	0,4591
ATX does not Granger Cause WIG	**13.1769*** **	3,00E-10
BUX does not Granger Cause BELEX 15	0.66281	0,618
BELEX_15 does not Granger Cause BUX	0.27883	0,8917
CROBEX does not Granger Cause BELEX 15	0.66464	0,6168
BELEX 15 does not Granger Cause CROBEX	0.70160	0,5911
IMOEX does not Granger Cause BELEX 15	0.49629	0,7385
BELEX 15 does not Granger Cause IMOEX	0.68176	0,6048
PRAGUE PX does not Granger Cause BELEX 15	**2.67354** **	0,0313
BELEX 15 does not Granger Cause PRAGUEPX	1.23831	0,2935
SBI TOP does not Granger Cause BELEX_15	1.01169	0,4007
BELEX 15 does not Granger Cause SBI TOP	0.78973	0,5321
WIG does not Granger Cause BELEX 15	1.44270	0,2185
BELEX 15 does not Granger Cause WIG	0.11123	0,9786
CROBEX does not Granger Cause BUX	1.28111	0,2762
BUX does not Granger Cause CROBEX	1.09616	0,3576
IMOEX does not Granger Cause BUX	1.62878	0,1655
BUX does not Granger Cause IMOEX	1.55066	0,1861
PRAGUE PX does not Granger Cause BUX	**3.84096*** **	0,0043

BUX does not Granger Cause PRAGUE PX	1.58294	0,1773
SBI TOP does not Granger Cause BUX	**3.49666*** **	0,0078
BUX does not Granger Cause SBI TOP	1.92676	0,1045
WIG does not Granger Cause BUX	0.72687	0,5738
BUX does not Granger Cause WIG	**4.43825*** **	0,0015
IMOEX does not Granger Cause CROBEX	0.44291	0,7776
CROBEX does not Granger Cause IMOEX	0.97459	0,4209
PRAGUE PX does not Granger Cause CROBEX	0.54811	0,7005
CROBEX does not Granger Cause PRAGUE PX	**2.23718***	0,0638
SBI TOP does not Granger Cause CROBEX	0.99070	0,412
CROBEX does not Granger Cause SBI TOP	1.12725	0,3427
WIG does not Granger Cause CROBEX	1.29738	0,2698
CROBEX does not Granger Cause WIG	0.54908	0,6998
PRAGUE_PX does not Granger Cause IMOEX	**2.28470***	0,0591
IMOEX does not Granger Cause PRAGUE PX	0.59557	0,666
SBI TOP does not Granger Cause IMOEX	0.81857	0,5136
IMOEX does not Granger Cause SBI TOP	0.68341	0,6037
WIG does not Granger Cause IMOEX	**4.07004*** **	0,0029
IMOEX does not Granger Cause WIG	1.48464	0,2054
SBI TOP does not Granger Cause PRAGUE PX	0.83193	0,5052
PRAGUE PX does not Granger Cause SBI TOP	**2.30572***	0,0571
WIG does not Granger Cause PRAGUE PX	**6.51376*** **	4,00E-05
PRAGUE PX does not Granger Cause WIG	1.44431	0,218
WIG does not Granger Cause SBI TOP	0.56089	0,6911
SBI TOP does not Granger Cause WIG	**3.91589***	0,0038

Note: Data processed by the authors (software: Eviews 12).
The asterisks ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively

Source: Own elaboration

For the Stress subperiod and to estimate the VAR model for this time lag, it was also necessary to determine the ideal number of lag days to include. For that purpose, the criteria presented in Table 8 were used. Based on the FPE and AIC criteria, the results point to a model that considers 9 days of lag.

Table 8. Information Criteria to determining the optimal number of lags in VAR model for the Stress Period

Lag	LogL	LR	FPE	AIC	SC	HQ
0	15617.80	NA	1.39e-30	-46.04660	-45.99328	-46.02596
1	15918.13	592.6910	6.91e-31	-46.74375	-46.26384*	-46.55796
2	16042.77	243.0275	5.78e-31	-46.92262	-46.01613	-46.57169
3	16179.01	262.4397	4.67e-31	-47.13573	-45.80265	-46.61966
4	16394.81	410.5795	2.99e-31	-47.58350	-45.82383	-46.90228*
5	16490.95	180.6579	2.72e-31	-47.67831	-45.49206	-46.83195
6	16614.54	229.3243	2.28e-31	-47.85411	-45.24127	-46.84261
7	16706.47	168.4017	2.10e-31	-47.93650	-44.89707	-46.75985
8	16804.47	177.2003	1.91e-31	-48.03678	-44.57076	-46.69499
9	16876.23	128.0781	**1.87e-31***	-48.05969*	-44.16709	-46.55275
10	16936.21	105.6297*	1.89e-31	-48.04783	-43.72864	-46.37575

Note: Data processed by the authors (software: Eviews 12).
* Indicates lag order selected by the criterion. LR: sequential modified. LR test statistic (each test at 5% level). FPE: Final prediction error. AIC: Akaike information criterion. SC: Schwarz information criterion. HQ: Hannan-Quinn information criterion.

Source: Own elaboration.

Table 9. VAR Residual Serial Correlation LM Tests

Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	98.45723	64	0.0037	1.546542	(64, 3415.3)	0.0037
2	94.81279	64	0.0074	1.488506	(64, 3415.3)	0.0074
3	110.9086	64	0.0003	1.745291	(64, 3415.3)	0.0003
4	106.7975	64	0.0006	1.679590	(64, 3415.3)	0.0006
5	124.8360	64	0.0000	1.968454	(64, 3415.3)	0.0000
6	129.9772	64	0.0000	2.051061	(64, 3415.3)	0.0000
7	121.9031	64	0.0000	1.921384	(64, 3415.3)	0.0000
8	70.11506	64	0.2800	1.096813	(64, 3415.3)	0.2801
9	97.53325	64	0.0044	1.531823	(64, 3415.3)	0.0044
10	73.24462	64	0.2007	1.146291	(64, 3415.3)	0.2008

Note: Data processed by the authors (software: Eviews 12)

Source: Own elaboration

Table 9 presents the results of the test, which allows rejecting H_0 for the number of lags equal to 9, which postulates the non-existence of autocorrelation of serial residuals, a crucial requirement for the estimation of a robust model.

Table 10 shows the shocks between the stock indexes of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG), for the Stress subperiod. When we apply 9 lags to the Granger Causality Tests, we find that 42 (out of 56 possible) pairs of markets show co-movements between each other.

In this subperiod of uncertainty in the global economy, the markets that had more influence on the remaining markets were the markets represented by the ATX, BUX, CROBEX and PRAGUE PX indexes, which showed 6 causal relations in 7 possible ones. The ATX index during this period showed predictive capacity over the behavior of indexes such as the BELEX 15, the CROBEX, the IMOEX, the PRAGUE PX, the SBI-TOP and the WIG. The BUX index influenced the ATX, the BELEX 15, the CROBEX, the PRAGUE PX, the SBI-TOP and the WIG stock markets. The Croatian stock index influenced the ATX, BELEX 15, BUX, PRAGUE PX, SBI-TOP and WIG indexes. PRAGUE PX is also considered, for the sample period under study, as a market with a strong influence on the remaining markets, specifically on ATX, BELEX 15, CROBEX, IMOEX, SBI-TOP and WIG.

Still with a relative influence, the indexes BELEX 15 and SBI-TOP present 5 causal relations out of 7 possible ones. In the case of BELEX 15, it caused the indexes ATX, IMOEX, PRAGUE PX, SBI TOP and WIG. The SBI-TOP caused the ATX, the BUX, the CROBEX, the PRAGUE PX and the WIG.

Finally, with 4 causal relations out of 7 possible ones, the IMOEX index appeared, which showed influence on ATX, BELEX 15, BUX and SBI-TOP. Also, the WIG showed 4 out of 7 causal relations, namely with the ATX, the BELEX 15, the IMOEX and the PRAGUE PXn general, during the quiet period, 16 causal relations were found in 56 possible ones. During the Stress period, on the other hand, there was a very significant increase in the number of causal relations between pairs of markets under analysis, inferring 42 causal relations out of a possible 56. These findings are in line with the results evidenced by the authors Pardal et al. (2021), Dias and Carvalho (2021b) which show that financial markets in periods of stress tend to increase their comovement among themselves.

Table 10. Granger Causality Tests applied to the financial markets under analysis, in the period from 1st January 2020 to September 15th, 2022 (Stress Period)

Null Hypothesis	F-Statistic	Prob.
BELEX 15 does not Granger Cause ATX	**2.41026****	0,0108
ATX does not Granger Cause BELEX 15	**10.2502*****	7,00E-15
BUX does not Granger Cause ATX	**14.4464*****	2,00E-21
ATX does not Granger Cause BUX	1.41261	0,1786
CROBEX does not Granger Cause ATX	**17.2922*****	8,00E-26
ATX does not Granger Cause CROBEX	**2.05753****	0,0312
IMOEX does not Granger Cause ATX	**2.42010****	0,0104
ATX does not Granger Cause IMOEX	**11.5216*****	7,00E-17
PRAGUE PX does not Granger Cause ATX	**4.99444*****	2,00E-06
ATX does not Granger Cause PRAGUE PX	**15.8923*****	1,00E-23
SBI TOP does not Granger Cause ATX	**15.1678*****	1,00E-22
ATX does not Granger Cause SBI TOP	**2.94479*****	0,002
WIG does not Granger Cause ATX	**23.9718*****	1,00E-35
ATX does not Granger Cause WIG	**1.87121***	0,0533
BUX does not Granger Cause BELEX 15	**2.91111*****	0,0022
BELEX 15 does not Granger Cause BUX	0.88284	0,5402
CROBEX does not Granger Cause BELEX 15	**6.90212*****	2,00E-09
BELEX 15 does not Granger Cause CROBEX	1.58932	0,1145
IMOEX does not Granger Cause BELEX 15	**1.85790***	0,0554
BELEX 15 does not Granger Cause IMOEX	**2.64553*****	0,0051
PRAGUE PX does not Granger Cause BELEX 15	**9.89020*****	3,00E-14
BELEX 15 does not Granger Cause PRAGUEPX	**2.54922*****	0,007
SBI TOP does not Granger Cause BELEX_15	0.91580	0,5107
BELEX 15 does not Granger Cause SBI TOP	**2.17349****	0,0222
WIG does not Granger Cause BELEX 15	**2.56960*****	0,0065
BELEX 15 does not Granger Cause WIG	**1.90468****	0,0485
CROBEX does not Granger Cause BUX	**2.05818****	0,0312
BUX does not Granger Cause CROBEX	**21.4591*****	5,00E-32
IMOEX does not Granger Cause BUX	**2.82029*****	0,0029
BUX does not Granger Cause IMOEX	0.74824	0,6646
PRAGUE_PX does not Granger Cause BUX	1.56872	0,1208
BUX does not Granger Cause PRAGUE PX	**17.1802*****	1,00E-25
SBI TOP does not Granger Cause BUX	**4.63684*****	6,00E-06
BUX does not Granger Cause SBI TOP	**6.51677*****	6,00E-09
WIG does not Granger Cause BUX	0.75113	0,6619
BUX does not Granger Cause WIG	**24.4322*****	3,00E-36
IMOEX does not Granger Cause CROBEX	1.20222	0,2905
CROBEX does not Granger Cause IMOEX	1.60669	0,1094
PRAGUE PX does not Granger Cause CROBEX	**2.46770*****	0,009
CROBEX does not Granger Cause PRAGUE PX	**19.6664*****	2,00E-29
SBI TOP does not Granger Cause CROBEX	**20.2739*****	3,00E-30
CROBEX does not Granger Cause SBI TOP	**2.22192****	0,0192
WIG does not Granger Cause CROBEX	1.11535	0,3493
CROBEX does not Granger Cause WIG	**29.2575*****	6,00E-43
PRAGUE PX does not Granger Cause IMOEX	**10.1195*****	1,00E-14
IMOEX does not Granger Cause PRAGUE PX	0.96218	0,4703

SBI TOP does not Granger Cause IMOEX	1.53859	0,1305
IMOEX does not Granger Cause SBI TOP	**1.97262****	0,04
WIG does not Granger Cause IMOEX	**4.29346*****	2,00E-05
IMOEX does not Granger Cause WIG	0.49442	0,8787
SBI TOP does not Granger Cause PRAGUE PX	**12.3335*****	4,00E-18
PRAGUE PX does not Granger Cause SBI TOP	**1.90168****	0,0489
WIG does not Granger Cause PRAGUE PX	**19.4386*****	5,00E-29
PRAGUE PX does not Granger Cause WIG	**2.94111*****	0,002
WIG does not Granger Cause SBI TOP	1.07866	0,3763
SBI TOP does not Granger Cause WIG	**20.0243*****	7,00E-30

Note: Data processed by the authors (software: Eviews 12).
The asterisks ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively

Source: Own elaboration

Overall, during the Tranquil period, ATX was the market that most influenced the behavior of the other capital markets under analysis, showing 5 causal relations out of 7 possible (BUX, CROBEZ, IMOEX, PRAGUE PX and WIG), followed by PRAGUE PX with 4 causal relations out of 7 possible (BELEX, BUX, IMOEX and SBI TOP). In turn, causing 2 markets, in the Granger sense, out of the 7 possible, are followed by the BUX (ATX and WIG), the SBI TOP (BUX and WIG) and the WIG (IMOEX, PRAGUE PX) price indexes. The CROBEX only showed 1 causal relation with the remaining pairs of capital markets under analysis (PRAGUE PX). Finally, BELEX and IMOEX, during the Tranquil period, did not cause any market.

5. CONCLUSION

This paper aimed to investigate the movements between the capital markets of Austria (ATX), Serbia (BELEX 15), Hungary (BUX), Croatia (CROBEX), Russia (IMOEX), Czech Republic (PRAGUE PX), Slovenia (SBI TOP) and Poland (WIG), in the period from September 18th, 2017, to September 15th, 2022. To achieve more robust results, we divide the sample into two sub-periods: the quiet period from September 18th, 2017, to December 31st, 2019; the period from January 1st, 2020, to September 15th, 2022, marked by the global pandemic (Covid-19), the oil price war in 2020 and the Russian invasion in 2022, we call Stress Period.

The time series show non-normal distributions due to the presence of fat tails, a characteristic that is usual in periods of extreme volatility. The results of the VAR Granger Causality/Block Exogeneity Wald Tests model verified the existence of 16 pairs of markets showing co-movements between them, during the quiet subperiod, the market that causes more co-movements is the Austria stock market (ATX), while the Russia stock index (IMOEX) does not cause shocks in the markets under analysis. In the Stress subperiod, we verify the presence of 42 pairs of markets causing each other in the Grangerian sense, the stock indexes ATX, BUX, CROBEX and PRAGUE PX present 6 causal relations in 7 possible, while the Russian capital market (IMOEX) and the Polish capital market are the ones that cause less (4 in 7 possible).

Specifically, we find consistent movements in the daily returns of Central and Eastern European stock indexes during the period of financial market stress. This convergence could be a sign of development from countries that are in the process of virtual integration, but such findings could jeopardize the implementation of efficient portfolio diversification strategies and possibly some above-market gains due to arbitrage levels.

References

Bagão, M., Dias, R., Heliodoro, P., & Alexandre, P. (2020). The Impact of Covid-19 on European Financial Markets: an Empirical Analysis. *6th LIMEN Conference Proceedings (Part of LIMEN Conference Collection)*, *6*(July), 1–11. https://doi.org/10.31410/limen.2020.1

Breitung, J. (2000). The local power of some unit root tests for panel data. *Advances in Econometrics*. https://doi.org/10.1016/S0731-9053(00)15006-6

Cevik, E. I., Korkmaz, T., & Cevik, E. (2017). Testing causal relation among central and eastern European equity markets: Evidence from asymmetric causality test. *Economic Research-Ekonomska Istrazivanja*, 30(1). 381-393. https://doi.org/10.1080/1331677X.2017.1305774

Dias, R., da Silva, J. V., & Dionísio, A. (2019). Financial markets of the LAC region: Does the crisis influence the financial integration? *International Review of Financial Analysis*, *63(January)*, 160–173. https://doi.org/10.1016/j.irfa.2019.02.008

Dias, R., Heliodoro, P., & Alexandre, P. (2019). Risk transmission among stock markets in LAC Region: financial crises impact. 5th International Scientific-Business Conference – *LIMEN 2019 – Leadership, Innovation, Management and Economics: Integrated Politics of Research – SELECTED PAPERS*. 91–97. https://doi.org/10.31410/LIMEN.S.P.2019.91

Dias, R., Heliodoro, P., Alexandre, P., & Vasco, C. (2020). *The shocks between oil market to the BRIC stock markets: A generalized VAR approach*. 4th EMAN Conference Proceedings (part of EMAN conference collection). 25–31. https://doi.org/10.31410/eman.2020.25

Dias, R., Pereira, J. M., & Carvalho, L. C. (2022). Are African Stock Markets Efficient? A Comparative Analysis Between Six African Markets, the UK, Japan and the USA in the Period of the Pandemic. *Naše Gospodarstvo/Our Economy*, *68(1)*, 35–51. https://doi.org/10.2478/ngoe-2022-0004

Dias, R., & Santos, H. (2020). Stock Market Efficiency in Africa: Evidence from Random Walk Hypothesis. *6th LIMEN Conference Proceedings (Part of LIMEN Conference Collection)*, *6*(July), 25–37. https://doi.org/10.31410/limen.2020.25

Dias, R., Santos, H., Heliodoro, P., Vasco, C., & Alexandre, P. (2021). WTI Oil Shocks in Eastern European Stock Markets: A Var Approach. *5th EMAN Conference Proceedings (Part of EMAN Conference Collection)*, October, 71–84. https://doi.org/10.31410/eman.2021.71

Dias, R. T., & Carvalho, L. (2021a). Foreign Exchange Market Shocks in the Context of the Global Pandemic (COVID-19). *Handbook of Research on Financial Management During Economic Downturn and Recovery*, 359-373. https://doi.org/10.4018/978-1-7998-6643-5.ch020

Dias, R. T., & Carvalho, L. (2021b). The Relationship Between Gold and Stock Markets During the COVID-19 Pandemic: An Econophysical Approach. *Handbook of Research on Financial Management During Economic Downturn and Recovery*, 462-475. https://doi.org/10.4018/978-1-7998-6643-5.ch026

Dias, R. T., Pardal, P., Santos, H., & Vasco, C. (2021). COVID-19 Pandemic and Its Influence on Safe Havens: An Examination of Gold, Silver, and Platinum. *Handbook of Research on Reinventing Economies and Organizations Following a Global Health Crisis*, 289-303. https://doi.org/10.4018/978-1-7998-6926-9.ch016

Dickey, D., & Fuller, W. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica, 49(4)*, 1057–1072. https://doi.org/10.2307/1912517

Guedes, E. F., Santos, R. P. C., Figueredo, L. H. R., Da Silva, P. A., Dias, R. M. T. S., & Zebende, G. F. (2022). Efficiency and Long-Range Correlation in G-20 Stock Indexes: A Sliding Windows Approach. *Fluctuation and Noise Letters*. 21(04). https://doi.org/10.1142/S021947752250033X

Gujarati, D. N. (2004). *Basic Econometrics*. 4th Edition, McGraw-Hill Companies.

Hadri, K. (2000). Testing for stationarity in heterogeneous panel data. *The Econometrics Journal, 3(2)*, 148-161. https://doi.org/10.1111/1368-423x.00043

Horvath, R., & Petrovski, D. (2012). International Stock Market Integration: Central and South Eastern Europe Compared. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2078238

Jarque, C. M., & Bera, A. K. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters*, *6*(3), 255–259. https://doi.org/10.1016/0165-1765(80)90024-5

Jawadi, F., Chlibi, S., & Cheffou, A. I. (2019). Computing stock price comovements with a three-regime panel smooth transition error correction model. *Annals of Operations Research, 274(1-2)*, 331-345. https://doi.org/10.1007/s10479-018-2805-3

Karamti, C., & Belhassine, O. (2022). COVID-19 pandemic waves and global financial markets: Evidence from wavelet coherence analysis. *Finance Research Letters*, *45*. https://doi.org/10.1016/j.frl.2021.102136

Koseoglu, S. D., & Cevik, E. I. (2013). Testing for causality in mean and variance between the stock market and the foreign exchange market: An application to the major central and Eastern European Countries. *Finance a Uver - Czech Journal of Economics and Finance*, *63(1)*.

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, *61*(SUPPL.), 631–652. https://doi.org/10.1111/1468-0084.0610s1631

Özer, M., Kamışlı, M., & Kamışlı, S. (2016). The Analysis of Volatility Spillovers between the German and Central and Eastern European (CEE) Stock Markets by Using Frequency Domain Causality Test. In *Europe and Asia: Economic Integration Prospects*.

Pardal, P., Dias, R., Šuleř, P., Teixeira, N., & Krulický, T. (2020). Integration in Central European capital markets in the context of the global COVID-19 pandemic. *Equilibrium, 15(4)*, 627-650. https://doi.org/10.24136/eq.2020.027

Pardal, P., Dias, R. T., Santos, H., & Vasco, C. (2021). Central European Banking Sector Integration and Shocks During the Global Pandemic (COVID-19). *Handbook of Research on Reinventing Economies and Organizations Following a Global Health Crisis*, 272-288. https://doi.org/10.4018/978-1-7998-6926-9.ch015

Shi, Y. (2022). What influences stock market co-movements between China and its Asia-Pacific trading partners after the Global Financial Crisis? *Pacific Basin Finance Journal*, *72*. https://doi.org/10.1016/j.pacfin.2022.101722

Silva, R., Dias, R., Heliodoro, P., & Alexandre, P. (2020). Risk Diversification in ASEAN-5 Financial Markets: An Empirical Analysis in the Context of the Global Pandemic (Covid-19). *6th LIMEN Selected Papers (Part of LIMEN Conference Collection)*, *6*(July), 15–26. https://doi.org/10.31410/limen.s.p.2020.15

Teixeira, N., Dias, R., Pardal, P., & Styles, L. (2022). The gold market as a safe haven when stock markets exhibit pronounced levels of risk: evidence during the China crisis and the COVID-19 pandemic. *Revista Gestão & Tecnologia, 21(1)*, 27–42. https://doi.org/10.12660/rgplp.v21n1.2022.82032

Zebende, G. F., Santos Dias, R. M. T., & de Aguiar, L. C. (2022). Stock market efficiency: An intraday case of study about the G-20 group. *Heliyon*, *8*(1), e08808. https://doi.org/10.1016/j.heliyon.2022.e08808