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Contact to corresponding author: krulicky@mail.vstecb.cz; Institute of Technology and Business, School of Expertness and Valuation, Okruzni 517/10, 37001 Ceske Budejovice, Czech Republic

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### Pedro Pardal

*Polytechnic Institute of Setúbal, Portugal*

 [orcid.org/0000-0003-3187-3472](https://orcid.org/0000-0003-3187-3472)


### Rui Dias

*Polytechnic Institute of Setúbal, Portugal*

 [orcid.org/0000-0002-6138-3098](https://orcid.org/0000-0002-6138-3098)

### Petr Šuleř

*Institute of Technology and Business, Czech Republic*

 [orcid.org/0000-0001-7562-0659](https://orcid.org/0000-0001-7562-0659)


### Nuno Teixeira

*Polytechnic Institute of Setúbal, Portugal*

 [orcid.org/0000-0001-7906-7731](https://orcid.org/0000-0001-7906-7731)

### Tomáš Krulický

*Institute of Technology and Business, Czech Republic*

 [orcid.org/0000-0002-0378-2699](https://orcid.org/0000-0002-0378-2699)

## Integration in Central European capital markets in the context of the global COVID-19 pandemic

**JEL Classification:** C58; G10; G11; G12; G14; G15; F30

**Keywords:** COVID-19; capital market; financial integration; portfolio diversification; financial crisis

### Abstract

**Research background:** Covid-19 pandemic had a strong impact on the economy and capital market. In times of crisis, it is important for investors to be able to diversify their investment portfolio in order to mitigate risk. However, the growing trend towards capital market integration may make it ineffective. Research on financial integration, during the Covid-19 period, has start-

ed to develop, mainly in major global capital markets. It is, therefore, important to extend this research to other capital markets.

**The purpose of the article:** This contribution aims to analyze financial integration in the stock indexes of the capital markets of Austria (ATX), Slovenia (SBITOP), Hungary (BUDAPEST SE), Lithuania (OMX VILNIUS), Poland (WIG), the Czech Republic (PX PRAGUE), Russia (MOEX) and Serbia (BELEX 15), in the context of the global pandemic (COVID-19).

**Methods:** To measure the unit roots in the time series, we used ADF, PP, and KPSS tests, and Clemente *et al.* (1998) test to detect structural breaks. To analyze financial integration, we applied the Gregory and Hansen integration test, and to validate the robustness of results, we use the impulse-response function (IRF) methodology, with Monte Carlo simulations, as they provide a dynamic analysis generated from the VAR model estimates.

**Findings & Value added:** The results suggest very significant levels of integration, which decreases the chances of portfolio diversification in the long-term. Evidence shows 47 pairs of integrated stock market indexes (out of 56 possible). The stock indexes ATX, BUDAPESTE SE, BELEX 15 show financial integration with all other indexes. On the contrary, the index of OMX VILNIUS shows only 3 integrations. Results also show that most of the significant structural breaks occurred in March 2020. The analysis of the relationship between markets, in the short term, shows positive/negative co-movements, with statistical significance and with a persistence longer than one week.

## Introduction

The COVID-19 pandemic has caused global concerns and a period of great uncertainty for the economy and to population in general (Lăzăroiu *et al.*, 2020). It has affected global trade as well as social and cultural life, including tourism, trade in goods, production and sectors such as transport. Moreover,

Government restrictions had an effect in businesses downturns and changes in consumer behaviour (Sheth, 2020). This new reality brought also opportunities for some business, as for example, a significantly strengthened of the online sales channels (Williams, 2020; Hao *et al.*, 2020). However, in general, the economic activity has been disrupted.

The health crisis also had a strong impact on the capital markets and on the main stock indexes, bringing uncertainty and instability (Ali *et al.*, 2020; Liu *et al.*, 2020; Saadat *et al.*, 2020; Vochozka *et al.*, 2020). Therefore, the periods of crisis are challenging to investors, which want to mitigate risks using portfolio diversification strategies (Lee, 2017). It is of high relevance to detect international links between capital markets and to verify if they are financially integrated. A capital market is considered integrated when financial products with the same risk characteristics exhibit the same expected rate of return, regardless of where they are traded (Dias *et al.*, 2019). A closer or strong linkage between markets increases the levels of vulnerability to external shocks and, as a result, may jeopardize the efficiency of portfolio diversification (Dias *et al.*, 2019).

In this context, this essay aims to analyse financial integration in the stock indexes of the capital markets of Austria (ATX index), Slovenia (SBITOP index), Hungary (BUDAPEST SE index), Lithuania (OMX VILNIUS index), Poland (WIG index), the Czech Republic (PX PRAGUE index), Russia (MOEX index) and Serbia (BELEX 15 index), in the context of the global pandemic (COVID-19). To our knowledge, studying financial integration in these capital markets and under the pandemic crisis is an open field to research, being important to test financial integration within them and understand if they could serve as an alternative, in relation to the global main markets. Therefore, could they work as a refuge for international investors to diversify their portfolios?

The objective of the study follows two research questions: (i) the global pandemic has accentuated the interdependencies in the capital markets of Central Europe; if so, (ii) how could it influence the efficiency of portfolio diversification.

The results obtained suggest very significant levels of integration, which decreases the chances of portfolio diversification in the long run. In turn, the analysis of the relationship between markets, in the short term, through the impulse-response functions shows positive / negative movements, with statistical significance, with persistence longer than one week. In addition, there was no immediate adjustment in prices between markets, due to the high levels of shocks identified.

This investigation adds two main contributions to the literature. The first contribution refers to the study of risk diversification in the Central and Eastern European markets, in the context of the pandemic of the COVID-19 outbreak. As far as we know, this is the first study to analyse these capital markets in isolation. There are recent studies that have analysed the diversification of risk, in the context of the global pandemic namely the authors Liu *et al.* (2020) and Zeren and Hizarci (2020), but they follow quite different approaches and different samples.

The second contribution is of an econometric nature, as results are compared between econometric methods and mathematical models that have the possibility of evaluating correlations in the context of non-stationarity. In particular, the test by Clemente *et al.* (1998), which gains recognised relevance when the sample period presents significant structural breaks in the data series. In addition, the Gregory and Hansen test (1996), which demonstrates the presence of integration between capital markets with structural breakdowns and, in a complementary way, the VAR-IRF model with the purpose of verifying the links of these markets in the short term and assessing whether these markets provide international investors with a good diversification of their portfolios.

In terms of structure, this essay is organized in 5 sections. Section 1 is represented by the current introduction. Section 2 presents a Literature Review regarding articles on integration in the capital markets. Section 3 describes the used data and methods. Section 4 explains the results. Finally, section 5 presents the general conclusions of the work.

## **Literature review**

Grubel (1968) or Levy and Sarnat (1970) argue that investing in international stock markets is based on the fact that the correlation between assets is less than that examined in domestic assets. Therefore, the low correlation between international stock markets is a key circumstance for portfolio diversification. For this purpose, the understanding of international links between capital markets in periods of financial crisis is of higher relevance for investors, fund managers and academics (Lee, 2017). Thus, the occurrence of integration between capital markets can have significant implications for the international diversification of risk (Dias *et al.*, 2019), or even, the degree of integration could be directly correlates with economic growth (Hoffmann *et al.*, 2020).

Voronkova (2004) and Lucey and Voronkova (2008) analysed the level of integration in the Central European markets. Voronkova (2004) investigated the level of financial integration between Central European capital markets and developed markets, after accounting for structural changes. The results suggest that the stock market indexes in Central Europe show relevant levels of integration, jeopardizing portfolio diversification. Lucey and Voronkova (2008) analysed the integration of capital markets before and after the 1998 crisis, with co-integration tests with regime change. The authors propose that capital markets are partially integrated and suggest that there is a potential of portfolio diversification in some of those markets.

Syllignakis and Kouretas (2006), Horvath and Petrovski (2012), Stoica *et al.* (2015) analysed integration and co-movements in the stock markets of Central and Eastern Europe. Syllignakis and Kouretas (2006) show that the examined stock markets are partially integrated, and there is also evidence that the five stock markets in Central Europe (the Czech Republic, Slovakia, Hungary, Slovenia and Poland), together with the German and American stock markets, they have a significant common permanent component, that is, they are integrated. In contrast, the Estonian and Romanian markets are segmented.

Horvath and Petrovski (2012) argue that the degree of co-movement is much higher in Central Europe. The correlation between stock markets in South East Europe and developed markets is nil. The exception to this regularity is Croatia, with its stock market showing a greater degree of integration compared to Western Europe, but still below the typical levels of Central Europe. Stoica *et al.* (2015) argue that integration has intensified in these markets with the exception of Bulgaria. The results of the study can be used to formulate efficient diversification strategies.

Özer *et al.* (2016), Tong *et al.* (2018), Moagar-Poladian *et al.* (2019) analyzed the interconnections between capital markets. Özer *et al.* (2016) show hybrid results, failing to confirm the existence of interdependencies between the capital market of Germany, Austria, the Czech Republic, Croatia, Lithuania and Greece. These conclusions have important implications for international investors, portfolio managers and regulatory authorities. Tong *et al.* (2018) show that the results of centrality suggest that the US and Hong Kong markets have been the most dominant markets in their geographic region. For Europe, they find 3 dominant centres, France, the United Kingdom, and Germany, in contrast to the previous literature, which suggests that the United Kingdom was the dominant country. They also identified that Japan and Australia, instead of acting as dominant countries in their region, serve as countries that link this region to the rest of the world. Finally, they show that Africa does not form a cluster, and individual African countries tend to connect to other developed markets. Moagar-Poladian *et al.* (2019) show that the Central and Eastern European capital markets show a significant level of integration during the European financial crisis.

Caporale *et al.* (2020), Milos *et al.* (2020) analysed the stock markets of Central and Eastern Europe. Caporale *et al.* (2020) suggest the existence of structural breaks and significant financial integration. Milos *et al.* (2020) found that the returns on the stock indexes had long-term correlations, showing that the stock markets in question aren't efficient and haven't reached a mature stage of development.

For Krarup (2020), the case of European capital markets integration is an epistemic problem, where there is strong uncertainty about the interpretation of relevant standards and doctrines. Krarup (2020) and Bremus and Kliatskova (2020) also draw attention to this problem by analysing harmonization and convergence in the form of institutional quality to European capital market.

Liu *et al.* (2020) studied the impact of the coronavirus outbreak on 21 stock market indexes. The authors show significant structural breaks resulting from the COVID-19 outbreak. Zeren and Hizarci (2020) analysed the

effects of the Covid-19 pandemic on the stock markets, in the period from January 23, 2020 to March 13, 2020. The authors show levels of causality between the number of deaths resulting from the outbreak global economy and capital markets. It was understood that the global cases of the outbreak have co-integration relations with the SSE, KOSPI and IBEX35 indexes, but not with the FTSE MIB, CAC40, DAX30 indexes. Global pandemic has been examined also in the context of individual stock markets, such as the London Stock Exchange (Griffith *et al.*, 2020), or through qualitative research methods such as crisis management, at the company or industry level in Italy (Rapaccini *et al.*, 2020). Other authors, like Grigaliuniene *et al.* (2020) studied capital markets in a crisis period, namely the post-crisis effect of the recent financial crisis. Through the APARCH modelling methodology they show that the expansion of the euro within the monetary union has helped to dampen local market volatility in the post-crisis period in the Member States.

In addition, Central European capital markets have also, been studied on different perspectives and not only directly to financial integration. Zinecker *et al.* (2016) examine the interrelations between the capital markets of Poland, Czech Republic and Germany during the period 1997–2015. The results confirmed significant interdependencies and conditional correlations have been more noticeable, for all markets pairs, since 2004. The authors argued that this could be due to the accession of both countries to the European Union. Pietrzak *et al.* (2017) confirm the long-term interdependencies for these stock markets. In line with previous studies, Hašková and Vochozka (2018) refer to the little attention to the degree of synchronization with the cyclical position of Germany, which is perceived as an economic hegemon.

Baruník and Vácha (2013) applied wavelet techniques to study the relationship between stock markets of Central Eastern European (CEE) countries and German DAX. The results, contrary to previous studies, show a lower degree of contagion between CEE stock market indexes and German DAX, after the stock market crash of 2008. Carausu *et al.* (2017) also studied contagion between the CEE and the Western European and US capital markets, between 2000 and 2016. The authors found that, between 2005 and 2009, CEE stock markets show evidence of contagion, with the exception of the Slovakian and Estonian markets. In the period from 2010 and 2016, the stock markets of Bulgaria, Hungary, the Czech Republic and Poland, showed de-contagion, especially to the US stock market, while the Croatian stock market presented evidence of de-contagion to Western European stock markets.

Šuleř and Machová (2020) analysed the financial stability and development of companies in the V4 region (Visegrad four) and identifying it as a potential refuge for investors to diversify their portfolios. Vrbka and Rowland, (2017) and Horák *et al.* (2020) explore the use of neural networks and a number of contemporary models to predict bankruptcy and Horák and Krulický (2019) to predict stock price developments. Measures related to the pandemic itself, such as reduced border permeability or changes in customer behaviour affect the economy globally and are comparable to other extraordinary phenomena that have an impact on capital market participants (Vrbka *et al.*, 2019).

In summary, this work aims to contribute to the provision of information to investors and regulatory authorities of the stock markets of Central Europe, where individual and institutional investors seek diversification benefits, as well as helping to promote the implementation of policies that contribute to the efficiency of these markets. Therefore, the context of this work is to examine the long-term financial integration and the short-term shocks between these capital markets in the context of the global pandemic (COVID-19).

## **Research methodology**

Data refer to the quotations of stock exchange indexes of Austria (ATX), Slovenia (SBITOP), Hungary (BUDAPEST SE), Lithuania (OMX VILNIUS), Poland (WIG), the Czech Republic (PX PRAGUE), Russia (MOEX) and Serbia (BELEX 15), at the close of trading sessions and was obtained from the Thomson Reuters platform (Table 1). The daily quotations cover the period from July 1, 2019 to May 14, 2020, and are in local currency, to mitigate exchange rate distortions.

The sample period intends to comprehend the first effects of global pandemic COVID-19 and the choice is related with the study by Nsoesie *et al.* (2020). According to these researchers from Harvard Medical School, evidence has emerged that the virus appeared in the city of Wuhan, China, in a period prior to December 2019. The study was based on the observation of an increase in the number of vehicles in the car park of hospital centres and on the large number of searches in the Chinese search engine Baidu, related to symptoms of the virus at the end of the summer of 2019. Additionally, the sample includes the period of virus widespread in Europe during February / March 2020 (Liu *et al.*, 2020; Zeren & Hizarci, 2020).

To the econometric analysis Tsay (2010) proposes the use of the logarithmic rates of returns series rather than prices series. The series based on

the logarithmic rate of returns show statistical characteristics that simplify the analytical treatment, in particular the characteristic of stationarity, which usually is not observed in price series. The logarithmic rates of return are calculated by the following expression:

$$r_t = \ln\left(\frac{P_t}{P_{t-1}}\right) \quad (1)$$

Where  $r_t$  is the logarithmic rate of return, at day  $t$ , and  $P_t$  and  $P_{t-1}$  are the closing prices of the series, at the moments  $t$  and  $t - 1$ , respectively.

The development of the research took place over several stages, with statistics and econometric models being estimated through EViews 11 and Stata 15. The characterization of the sample used was carried out through descriptive statistics, the Jarque and Bera (1980) adherence test, and the quantile graphs. With the purpose of checking the stationarity of the time series, we will use the ADF (Dickey & Fuller, 1981), PP (Perron & Phillips, 1988) and KPSS (Kwiatkowski *et al.*, 1992) tests. In addition to the stationarity tests, we will use the test by Clemente *et al.* (1998) to detect structural breaks resulting from the global pandemic.

To verify the integration or segmentation of the stock indexes of the selected capital markets, we use the methodology of Gregory and Hansen (1996), which is more appropriated to examine capital markets in periods of high volatility with structural breaks. In addition, the reason why standard co-integration tests such as Engle and Granger (1987) and Johansen (1988) are not suitable for testing regime change co-integration is that such tests assume that the co-integration vector is invariant in time.

In order to measure and evaluate shocks (co-movements) between markets, in the short term, we will use the impulse-response function (IRF) methodology, with Monte Carlo simulations, in view of providing a dynamic analysis (variable over time), generated from the estimates of the VAR model, thus making it possible to study the causal relationships found, even when no causal relationships to Granger between the variables are previously detected (Lütkepohl & Saikkonen, 1997).

The impulse-response functions show how a given variable responds, over time, to an unexpected increase in that variable (stimulus or innovation) or another variable included in the VAR model. In other words, an innovation in a given variable produces a chain reaction, over time, in the remaining variables of the VAR, which the impulse-response function allows to monitor and interpret.

According to the authors, Lütkepohl and Saikkonen (1997) and Aziakpono (2006) if a process is white noise (with zero mean, constant variance),



in this case the *VAR*, evaluated can be transformed into a representation of moving average, whose coefficients are the responses to impulses in forecasting errors. Therefore, the moving average is expressed as follows:

$$Y_t = C + \sum_{s=0}^k B_s \varepsilon_{t-s} \quad (2)$$

Where  $Y_t$  is a column vector ( $m \times 1$ ) with  $m$  stationary dependent variables,  $C$  is a column vector ( $m \times 1$ ) of the deterministic component,  $B_s$  is the matrix of autoregressive parameters ( $m \times m$ ),  $m$  is the number of lags selected through the information criteria of Akaike (AIC) and Schwarz (SC).  $\varepsilon_t$  is the vector ( $m \times 1$ ) of the unanticipated disturbances or components, associated with the respective dependent variables, designated in *VAR* terminology by innovations, shocks, or impulses, and which are *i. i. d.*, with normal distribution, zero mean and variance-covariance  $\Omega$ . The disturbances of each of the equations of the *VAR* model may be contemporaneously correlated. The covariances are given by the non-diagonal elements of the  $E(\varepsilon_t \varepsilon_t') = \Omega$ .

In the present work, we chose to use generalized impulse-response functions, introduced by Koop *et al.* (1996) and Pesaran and Shin (1998), and by choosing the Monte Carlo simulation procedure, with 1000 times repetition. This analysis differs from the traditional orthogonal impulse-response analysis, as it does not depend on the ordering of variables in the *VAR* model. The traditional approach, such as that based on Cholesky's factorization, for the orthogonalization of *VAR* innovations, leads to different conclusions, depending on the ordering of variables.

## Results and discussion

Figure 1 shows the behaviour of the 8 stock market indexes based on the logarithmic rates of return. The analysis comprises the period between July 1, 2019 and May 14, 2020, which is a period of considerable complexity, due to understanding the outbreak of the global pandemic (COVID-19). The results show the instability experienced in these stock market indexes, especially in months of February and March, when the first strong effects of the global pandemic affected European countries.

Table 2 shows the main descriptive, as well as the Jarque-Bera adherence test for the stock indexes of the 8 capital markets. The analysis of descriptive statistics evidence that most return rates (logarithmic) have negative daily averages, except for the Lithuanian stock market index (OMX VILNIUS). Austria (ATX) is the stock market index with the most

significant standard deviation (risk), while Serbia (BELEX 15) has the lowest. The asymmetry characteristics are negative, with the Lithuanian stock market index (OMX VILNIUS) showing the more significant levels of asymmetry and kurtosis. On the other hand, all the logarithmic rates of return series showed signs of deviation from the hypothesis of normality, given their coefficients. In the case of a normal distribution, the asymmetry coefficient takes zero and the kurtosis coefficient takes three. The analysed series are leptokurtic and have asymmetric flaps. Additionally, all series of logarithmic rates of return showed signs of deviation from the normality hypothesis, since the Jarque-Bera test rejects the null hypothesis of normality ( $H_0$ ) for a level of significance of 1%.

The quantile plots show that distribution of the logarithmic rates of return is leptokurtic and asymmetric or skewed. The distribution is leptokurtic because the graph is shaped like an “S”, on the 45° line, and it is asymmetric because the “S” is not symmetrical on the line, showing the existence of non-linear relationships between the theoretical quantiles and the empirical quantiles. Especially in the distribution tabs, showing heavier tails in the empirical distribution, which allows us to reject the normality hypothesis (see Figure 2).

The results of the stationarity tests, described in Table 3, verified through the ADF tests (Dickey & Fuller, 1981), PP (Perron & Phillips, 1988) or also KPSS (Kwiatkowski *et al.*, 1992) show that the time series are non-stationary in prices (levels). However, when the models are estimated in prices' first differences, the results show the stationarity.

Table 4 shows the results of the test by Clemente *et al.* (1998), where the most significant structural breaks are identified. The stock market indexes of Austria (ATX), Serbia (BELEX 15) and Slovenia (SBITOP) show structural breaks in July 2019. The Hungarian (BUDAPESTE SE) and Polish (WIG) stock market indexes crashed in February 2020, while the Russian and Lithuanian markets had the strongest structural break in March 2020, which is evidence in line with the pandemic outbreak period. This evidence is in line with the studies of the authors Liu *et al.* (2020), Zeren and Hizarci (2020), which show significant structural breaks resulting from the global pandemic.

As for the financial integration analysis, results of the Gregory-Hansen tests (1996) are described in Table 5. Evidence shows 47 pairs of integrated stock market indexes, out of 56 possible. The stock market indexes of Austria (ATX), Hungary (BUDAPEST SE) and Serbia (BELEX 15) show 7 integrations (out of 7 possible). Meanwhile, the Polish (WIG), the Czech Republic (PX PRAGUE) and Russia stock market indexes exhibit 6 integrations with their peers. However, the stock indexes of Slovenia

(SBITOP) and Lithuania (OMX VILNIUS) have 5 and 3 integrations, respectively. Additionally, the econometric tests show that the structural breaks are mostly in March 2020. These results are in line with the articles by the authors Moagar-Poladian *et al.* (2019), Caporale *et al.* (2020), Milos *et al.* (2020), which show high levels of integration in the stock indexes of the capital markets in Central and Eastern Europe, compromising the hypothesis of an efficient portfolio management. This evidence has important implications for individual and international investors, portfolio managers and regulatory authorities.

The traditional tests ADF (Dickey & Fuller, 1981), PP (Perron & Phillips, 1988), or also KPSS (Kwiatkowski *et al.*, 1992) demonstrated that the prices in levels were non-stationary. Thus, in order to validate the robustness of VAR Granger Causality / Block Exogeneity Wald Tests, we used the logarithmic rates of return to analyse the significance of the causal relationships between the 8 stock market indexes. To determine the number of lags to include in the causality tests, we used the HQIC criteria (Hannan-Quinn information criterion), which suggests 6 lags. A smaller number of lags increases the degrees of freedom, while a larger number of lags decreases the problems of autocorrelation. As we previously performed a VAR with six lags, then we performed the VAR Residual Serial Correlation LM Tests at seven lags, and the null hypothesis was not rejected, which corroborates that the model presents a robust estimation (see Table 6).

The IRF methodology, with Monte Carlo simulations (see Figure 3), tested the degree of response of the variables in the stock market indexes of Austria (ATX), Slovenia (SBITOP), Hungary (BUDAPEST SE), Lithuania (OMX VILNIUS), Poland (WIG), the Czech Republic (PX PRAGUE), Russia (MOEX) and Serbia (BELEX 15), to changes (impulses) of a standard deviation for each of the referred variables. These results show the prompt response to market shocks, with a reflection on the following day, but also the speed in processing information. In all cases, own and other innovations generate, on the following day, statistically significant positive / negative responses, at a significance level of 5%. Taking into account the period of one day, the response of each stock market index to shocks in its own market, exceeds the dimension of the response to shocks in other places, in practically all of those involved. Therefore, we can infer that the assumption of the hypothesis of market efficiency is questionable, since the forecast of the market movement can be improved when considering the lagged movements of the other markets, which allows for the occurrence of arbitrage operations.

## Conclusions

This essay aims to analyse financial integration in the stock market indexes of the capital markets of Austria (ATX), Slovenia (SBITOP), Hungary (BUDAPEST SE), Lithuania (OMX VILNIUS), Poland (WIG), the Czech Republic (PX PRAGUE), Russia (MOEX) and Serbia (BELEX 15), in the context of the global pandemic (COVID-19). In order to carry out this analysis, different approaches were taken for the defined research questions: (i) the global pandemic has accentuated the interdependencies in the capital markets of Central Europe; if so, (ii) how could it influence the efficiency of portfolio diversification.

Thus, we carried out two statistical tests for this aim. The first test estimates whether the markets have expressive levels of financial integration, in the context of the global pandemic. The second assesses whether the price indexes show any co-movement, showing whether the hypothesis of arbitrage and abnormal returns would be feasible.

In relation to the first test, the results show 47 pairs of integrated stock market indexes (out of 56 possible). The stock indexes of the capital markets in Austria (ATX), Hungary (BUDAPEST SE) and Serbia (BELEX 15) show 7 integrations (out of 7 possible). Meanwhile, the Polish (WIG), the Czech Republic (PX PRAGUE) and Russia stock market indexes exhibit 6 integrations with their peers. However, the stock indexes of Slovenia (SBITOP) and Lithuania (OMX VILNIUS) have 5 and 3 integrations, respectively. Additionally, we found that the most significant structural breaks occurred, especially in March 2020.

The IRF tests show the prompt response to market shocks. Evidence suggest that the effect of those shocks was reflected on the following day. In all cases, there were statistically significant positive / negative responses, at a significance level of 5%. In a one-day period, the response of each stock market indexes, to shocks in its own market, exceeds the dimension of the response to shocks in other stock indexes, for almost, all analysed indexes. Therefore, results suggest that the prediction of the market movements could be improved, when it is considered the lagged movements of the other markets. This would allow for the occurrence of arbitrage operations and could have compromised the market efficiency hypothesis.

As a summary, and based on the results gained through tests carried out with econometric models, the global pandemic had an expressive impact on the memory properties of the stock indexes of the capital markets of Central Europe. We believe that the level of financial integration is very significant in these markets, which increases the problematic on the implementation of efficient portfolio diversification strategies. These capital markets

also prove to be inefficient, in their weak form, due to the high levels of arbitrage identified. In conclusion, we consider that this evidence is relevant for investors and regulatory authorities, in relation to regional development policies and portfolio diversification strategies in the capital markets of Central Europe.

With regard to suggestions for future research, this study used general indices, of daily frequency, to analyse the links between the capital markets. With further research, it could be considered the sectoral indices of the capital markets, instead of general indices, to understand their links in the international context. Similarly, it would also be interesting to use higher frequency data, intra-day basis, minute prices, as well as to incorporate macroeconomic and financial variables to simplify the analysis of the interactions established between the various international indices. In conclusion, new approaches on the subject could be explored to help clarify what is contagion or interdependence, as well as to delimit when contagion or interdependence exists.

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**Table 3.** Stationary tests to first differences of prices of the 8 stock indexes, between 01/07/2019 to 14/05/2020

Indexes	ADF			PP			KPSS *		
	Levels	1st Dif.	Results	Levels	1st Dif.	Results	Levels	1st Dif.	Results
ATX	-1.857 (0)	-29.069 (0)	I (1)	-2.040 (9)	-28.997 (9)	I (1)	0.960 (22)	0.091 (8)	I (1)
(p-value)	(0.353)	(0.000)		(0.270)	(0.000)				
BELEX 15	-1.806 (1)	-31.937 (0)	I (1)	-1.971 (2)	-31.516 (7)	I (1)	1.118 (22)	0.075 (1)	I (1)
(p-value)	(0.378)	(0.000)		(0.300)	(0.000)				
BUDAPEST SE	-0.204 (0)	-16.439 (1)	I (1)	-0.447 (8)	-25.549 (7)	I (1)	2.993 (22)	0.064 (8)	I (1)
(p-value)	(0.935)	(0.000)		(0.898)	(0.000)				
OMX VILNIUS	-1.627 (2)	-15.559 (1)	I (1)	1.769 (13)	-24.762 (11)	I (1)	0.843 (22)	0.105 (13)	I (1)
(p-value)	(0.468)	(0.000)		(0.396)	(0.000)				
SBITOP	-1.649 (0)	-25.448 (0)	I (1)	-1.725 (14)	-25.441 (17)	I (1)	2.294 (22)	0.033 (15)	I (1)
(p-value)	(0.457)	(0.000)		(0.418)	(0.000)				
PX PRAGUE	-1.013 (2)	-15.816 (1)	I (1)	-1.200 (13)	-25.18 (11)	I (1)	1.286 (22)	0.109 (12)	I (1)
(p-value)	(0.750)	(0.000)		(0.676)	(0.000)				
MOEX	-1.990 (9)	-7.579 (8)	I (1)	-1.827 (15)	-33.155 (7)	I (1)	1.731 (22)	0.055 (19)	I (1)
(p-value)	(0.292)	(0.000)		(0.368)	(0.000)				
WIG	-1.867 (0)	-28.732 (0)	I (1)	-2.074 (10)	-31.472 (8)	I (1)	1.138 (22)	0.104 (13)	I (1)
(p-value)	(0.352)	(0.000)		(0.280)	(0.000)				

Note: In the ADF test the criteria (Lag Length - Automatic - based on SIC), in PP (Bandwidth (Newey-West automatic) using Bartlett Kernel), in KPSS (Bandwidth (Newey-West automatic) using Bartlett Kernel). The lateral values in brackets refer to the lags.

\* KPSS is inferred through critical values. If LM statistic greater than the critical value the null hypothesis is rejected and the series is non-stationary. KPSS critical values: 1% level (0.739), 5% level (0.463), 10% level (0.347)

**Table 4.** Unit root tests with structural breaks by Clemente *et al.* (1998) of the logarithmic rates of return for the 8 stock indexes, between 01/07/2019 to 14/05/2020

Index	t-stat	Break Date	p-value
ATX	-12.834 (0)	23/07/2019	0.000
BELEX 15	-14.406 (0)	09/07/2019	0.000
BUDAPEST SE	-16.936 (0)	27/02/2020	0.000
SBITOP	-14.373 (0)	16/07/2019	0.000
OMX VILNIUS	-15.780 (0)	04/03/2020	0.000
WIG	-14.956 (0)	25/02/2020	0.000
PX PRAGUE	-13.636 (0)	09/03/2020	0.000
MOEX	-15.502 (0)	03/03/2020	0.000

**Table 5.** Integration tests of Gregory-Hansen, in stock indexes prices, for the 8 stock indexes, between 01/07/2019 to 14/05/2020

Indexes	t-statistic *	Method	Lags	Break Date	Results
ATX / BELEX 15	-4.86	Trend	5	20/01/2020	Cointegration
ATX / BUDAPEST SE	-7.07	Trend	3	17/03/2020	Cointegration
ATX / OMX VILNIUS	-5.53	Trend	3	16/03/2020	Cointegration
ATX / SBITOP	-6.04	Trend	3	16/03/2020	Cointegration
ATX / PX PRAGUE	-6.44	Trend	0	16/03/2020	Cointegration
ATX / MOEX	-5.65	Trend	3	16/03/2020	Cointegration
ATX / WIG	-7.22	Trend	3	17/03/2020	Cointegration
BELEX 15 / ATX	-5.30	Regime	5	16/03/2020	Cointegration
BELEX 15 / BUDAPEST SE	-5.74	Regime	5	15/01/2020	Cointegration
BELEX 15 / OMX VILNIUS	-5.72	Trend	0	17/03/2020	Cointegration
BELEX 15 / SBITOP	-6.28	Trend	0	18/03/2020	Cointegration
BELEX 15 / PX PRAGUE	-5.04	Trend	0	18/03/2020	Cointegration
BELEX 15 / MOEX	-5.18	Trend	2	20/03/2020	Cointegration
BELEX 15 / WIG	-5.33	Trend	3	17/03/2020	Cointegration
BUDAPEST SE / ATX	-6.32	Trend	3	19/03/2020	Cointegration
BUDAPEST SE / BELEX 15	-5.60	Trend	3	09/03/2020	Cointegration
BUDAPEST SE / OMX VILNIUS	-5.44	Trend	1	09/03/2020	Cointegration
BUDAPEST SE / SBITOP	-6.51	Trend	0	08/01/2020	Cointegration
BUDAPEST SE / PX PRAGUE	-6.44	Trend	0	09/03/2020	Cointegration
BUDAPEST SE / MOEX	-5.68	Trend	0	09/03/2020	Cointegration
BUDAPEST SE / WIG	-6.74	Trend	0	12/03/2020	Cointegration
OMX VILNIUS / ATX	-4.79	Regime	2	18/03/2020	Cointegration
OMX VILNIUS / SBITOP	-6.55	Regime	3	11/03/2020	Cointegration
OMX VILNIUS / PX PRAGUE	-4.96	Regime	5	11/03/2020	Cointegration
SBITOP / BELEX 15	-4.88	Regime	0	26/02/2020	Cointegration
SBITOP / BUDAPEST SE	-7.04	Regime	5	08/01/2020	Cointegration

**Table 5.** Continued

Indexes	t-statistic *	Method	Lags	Break Date	Results
SBITOP / OMX VILNIUS	-5.32	Regime	3	10/03/2020	Cointegration
SBITOP / PX PRAGUE	-5.87	Regime	0	07/01/2020	Cointegration
SBITOP / MOEX	-6.80	Regime	0	20/11/2019	Cointegration
PX PRAGUE / ATX	-5.55	Trend	0	20/03/2020	Cointegration
PX PRAGUE / BUDAPEST SE	-6.41	Regime	2	17/03/2020	Cointegration
PX PRAGUE / OMX VILNIUS	-4.88	Trend	0	13/03/2020	Cointegration
PX PRAGUE / SBITOP	-6.28	Regime	0	28/01/2020	Cointegration
PX PRAGUE / MOEX	-5.30	Regime	3	12/03/2020	Cointegration
PX PRAGUE / WIG	-6.53	Trend	4	17/03/2020	Cointegration
MOEX / BELEX 15	-5.36	Trend	4	20/02/2020	Cointegration
MOEX / BUDAPEST SE	-5.60	Trend	0	13/01/2020	Cointegration
MOEX / OMX VILNIUS	-4.80	Trend	1	09/03/2020	Cointegration
MOEX / SBITOP	-5.54	Trend	0	29/08/2019	Cointegration
MOEX / PX PRAGUE	-5.22	Trend	0	25/03/2020	Cointegration
MOEX / WIG	-6.49	Trend	3	17/03/2020	Cointegration
WIG / ATX	-6.06	Trend	2	19/03/2020	Cointegration
WIG / BELEX 15	-5.10	Trend	1	03/03/2020	Cointegration
WIG / BUDAPEST SE	-5.30	Trend	1	26/03/2020	Cointegration
WIG / OMX VILNIUS	-5.52	Trend	0	03/03/2020	Cointegration
WIG / SBITOP	-4.69	Regime	1	02/03/2020	Cointegration
WIG / PX PRAGUE	-5.21	Regime	3	03/03/2020	Cointegration

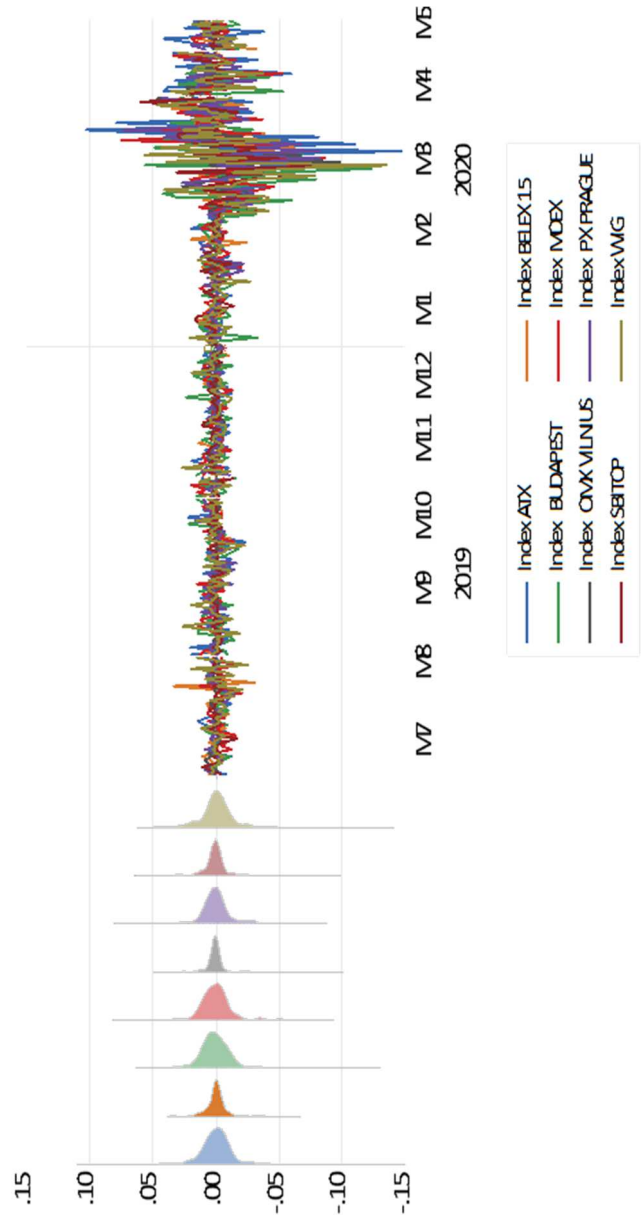
Note: \* Critical values for structural break (trend), maximum of 5 lags: ADF 1% level (-5.45), 5% level (-4.99), 10% level (-4.72);  $Z_t$  1% level (-5.46), 5% level (-4.99), 10% level (-4.72);  $Z_a$  1% level (-57.28), 5% level (-47.96), 10% level (-43.22). Critical values for structural break (regime), maximum of 5 lags: ADF 1% level (-5.47), 5% level (-4.95), 10% level (-4.68);  $Z_t$  1% level (-5.47), 5% level (-4.95), 10% level (-4.68);  $Z_a$  1% level (-57.17), 5% level (-47.04), 10% level (-41.85).

**Table 6.** VAR Residual Serial Correlation LM Tests, in logarithmic rates of return, for the 8 stock indexes, between 01/07/2019 to 14/05/2020

Lag	LRE* stat	df	p-value	Rao F-stat	df	p-value
1	125.368	64	0.000	2.036	(64, 842.8)	0.000
2	115.703	64	0.000	1.864	(64, 842.8)	0.000
3	87.114	64	0.029	1.381	(64, 842.8)	0.029
4	80.239	64	0.083	1.267	(64, 842.8)	0.083
5	112.517	64	0.000	1.810	(64, 842.8)	0.000
6	93.009	64	0.010	1.479	(64, 842.8)	0.011
7	<b>62.280</b>	<b>64</b>	<b>0.538</b>	<b>0.973</b>	<b>(64, 842.8)</b>	<b>0.539</b>

Note: \*Edgeworth expansion corrected likelihood ratio statistic.

Figure 1. Logarithmic rates of returns in the 8 stock indexes, between 01/07/2019 to 14/05/2020



**Figure 2.** Quantile graphs of the logarithmic rates of return for the 8 stock indexes, between 01/07/2019 to 14/05/2020

