

Commonalities in Returns in the Stock Markets of the Visegrad Group: A Quantile Coherency Approach

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Abstract: *The aim of this paper is to investigate the dependence structure in the frequency domain for the joint distribution of returns from the stock markets in the countries belonging to the V4 countries. We analyze twenty-years of historical daily prices of four main stock indices from the Czech Republic, Hungary, Poland, and Slovakia. Using a quantile coherency measure we found, that linkages between Czech, Hungarian, and Polish stock markets are significantly positive for all considered quantiles and frequencies. These three markets are more strongly dependent during the long downturns and the effect is permanent after the European Union accession. The Slovak stock market is the least connected with other countries in the group. Results of the paper revealed, that Czech, Hungarian and Polish stock market is subject to similar trends in terms of returns for different investment horizons. International market participants should incorporate interdependencies between these markets during the portfolio building process.*

Keywords: *quantile coherency, frequency domain, Visegrad Group, stock market*

JEL codes: *C40, G01, G15*

Introduction

According to the information from the Visegrad Declaration on Cooperation (Visegrad Group, 1991), one of the practical aspects of their partnership is to “develop economic cooperation, based on the principles of the free market, and mutually beneficial trade in goods and services, (...) to create favorable conditions for direct cooperation of enterprises and foreign capital investments, aimed at improving economic effectiveness”. Cooperation between countries can be initiated in many ways, causing capital flows and strengthening links in the real economy. However, one of the important parts of a market economic system and a financial market is a capital market, whose performance one can track using selected stock market indices. A relevant strand of the literature looks at financial market integration in terms of correlations and connectedness between major indices that serve as benchmarks representing a broad market picture.

In this paper, we extend previous works devoted to the dependencies between the stock markets in the V4 countries. The main contribution to the existing literature is to investigate differences in the strength of linkages related to the investment horizon and to consider returns from different parts of the distribution. To this end, we employ the quantile coherency approach to analyze the frequency-dependent

structure of correlations in different quantiles of the joint distribution of a two-dimensional process of returns. We set the following research questions:

RQ1: Are the coherencies between market returns in all V4 countries at a similar level?

RQ2: Are the coherencies stronger for some frequencies or quantiles related to the specific part of the distribution?

Answers to these research questions are crucial to achieve the main goal of the paper, which is to describe the dependence structure in the frequency domain between returns from the stock markets in the countries belonging to the V4 countries. Revealed features are important to the international investors in the portfolio building process, if their funds are invested in shares of companies from markets in Central and Eastern Europe.

The remainder of the paper is organized as follows. First section contains literature review, where we present the previous works related with our study. Next, we present the methodology employed in this study. The next sections contain a description of the data and the quantile coherency estimates related to the full sample. Then, we extend the analysis considering four specific subsamples related to the period before and after the European Union's accession, Global Financial Crisis - European debt crisis period, and post-crisis period. Finally, we compare the results of this paper with earlier works and discuss the economic interpretation of revealed commonalities in returns in the stock markets of the Visegrad Group. The last section contains the concluding remarks.

1 Literature Review

Previous studies related to dynamics and linkages between the stock markets of the Visegrad Group have mainly focused on the interrelationships, the level of integration and contagion effects with the developed stock markets (Wang and Moore, 2008; Syllignakis and Kouretas, 2011; Gjika and Horváth, 2013; Baumöhl, 2013; Boţoc, 2017; Horváth et al., 2018; Živkov et al., 2019; Boţoc and Anton, 2020; Tilfani et al., 2020). For example, Wang and Moore (2008) used DCC-GARCH model and found, that correlation between CEE stock markets and aggregate Eurozone market increased during the financial crises and after EU accession. Gjika and Horváth (2013) made similar conclusions using asymmetric DCC model. Moreover, Živkov et al. (2019) found, that Slovak index has the least synchronized movements with the German and US stock markets.

Another part of the literature is devoted to the issue of the integration and linkages between the countries in the V4 group. For example, Gjika and Horváth (2013) analyzed asymmetric dynamic conditional correlations (ADCC) between Polish, Czech, and Hungarian stock markets. They found an asymmetry in the correlation structure between Polish and Hungarian stock markets. According to their study, the correlations increase more when both Polish and Hungarian stock markets are declining. Baumöhl (2013) used the ADCC model and reported that the correlations

among the CEE-4 markets are high (except for the Slovak market) and increased due to the Global Financial Crisis. Reboredo et. al (2015) used static and dynamic copula functions to describe the dependence structure between Central and Eastern European stock markets (Czech Republic, Hungary, Poland, and Romania). Their results show that there is positive dependence between all analyzed countries and symmetric tail dependence for almost all stock indices. Hungarian and Polish markets exhibit no tail dependence. Their results, however, are based on the daily data only. Vychytilova (2018) used Spearman's rank correlation to estimate dependencies between the four stock markets of the Visegrad group after World Financial Crisis and found that correlation between the Slovak stock market and other markets is the weakest. Similarly, Hung (2019) found a strong correlation and volatility transmission across markets in CEE countries and that these stock markets are more integrated after the global financial crisis. Moreover, the results of the study of Moagăr-Poladian et al. (2019) show, that EU enlargement in 2004 and the European sovereign debt crisis were crucial factors affecting the stock market comovements in the CEE countries.

2 Methodology: Quantile Coherency

Let $(X_t)_{t \in \mathbb{Z}}$ denotes a two-variate strictly stationary process $X_t = (X_{t,1}, X_{t,2})'$, F_j is the marginal distribution function of $X_{t,j}$ for $j = 1, 2$ and $q_j(\tau) = F_j^{-1}(\tau) = \inf\{q \in \mathbb{R}: \tau \leq F_j(q)\}$, where $\tau \in [0,1]$ denotes the quantile function of $X_{t,j}$. As a measure for the dependency structure of $(X_t)_{t \in \mathbb{Z}}$ Baruník and Kley (2019) proposed a matrix $\Gamma_k(\tau_1, \tau_2) = (\gamma_k^{j_1, j_2}(\tau_1, \tau_2))_{j_1, j_2=1,2}$ of quantile cross-covariance kernels, where

$$\gamma_k^{j_1, j_2}(\tau_1, \tau_2) = Cov(I\{X_{t+k, j_1} \leq q_{j_1}(\tau_1)\}, I\{X_{t, j_2} \leq q_{j_2}(\tau_2)\}), \quad (1)$$

$k \in \mathbb{Z}$, $I\{A\}$ denotes the indicator function of the event A and $\tau_1, \tau_2 \in [0,1]$. The quantile cross-covariance kernels provide information about serial and cross-section dependence between the time series $X_{t,1}$ and $X_{t,2}$.

Next, they define a matrix $\mathfrak{f}(\omega; \tau_1, \tau_2) = (\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2))_{j_1, j_2=1,2}$ of quantile cross-spectral density kernel, where $\omega \in \mathbb{R}$ and

$$\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2) = \frac{1}{2\pi} \sum_{k=-\infty}^{\infty} \gamma_k^{j_1, j_2}(\tau_1, \tau_2) e^{-ik\omega}. \quad (2)$$

A quantile coherency kernel provides information about the joint dynamics of the time series $X_{t,1}$ and $X_{t,2}$. It is defined as

$$\mathfrak{R}^{j_1, j_2}(\omega; \tau_1, \tau_2) = \frac{\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2)}{(\mathfrak{f}^{j_1, j_1}(\omega; \tau_1, \tau_2) \mathfrak{f}^{j_2, j_2}(\omega; \tau_1, \tau_2))^{\frac{1}{2}}} \quad (3)$$

for $(\tau_1, \tau_2) \in (0,1)^2$. A quantile coherency (frequency-dependent correlation) is a complex-valued function of ω . The range of possible complex values of $\mathfrak{R}^{j_1, j_2}(\omega; \tau_1, \tau_2)$ is limited to the set $\{z \in \mathbb{C}: |z| \leq 1\}$. Estimation of $\mathfrak{R}^{j_1, j_2}(\omega; \tau_1, \tau_2)$ is carried out using

the smoothed copula cross-periodograms. For a detailed description of the estimation procedure, see Baruník and Kley (2019).

In this paper we consider three frequencies to measure quantile coherency between returns that correspond to a weekly, monthly, and quarterly period (short-, medium-, and long-term investing horizon), a broad range of quantile levels: $\tau_i \in (0.05, 0.95)$ and we assume that $\tau_1 = \tau_2$. For example, when $(\tau_1, \tau_2) = (0.05, 0.05)$, a quantile coherency relates to extreme negative returns. If the real part of the quantile coherency is significantly positive for selected frequency, there is a coincidence between the events, when both returns are equal or lower than their quantiles of the order 0.05.

3 Data

The data consists of daily prices of four main stock indices from the Czech Republic (PX), Hungary (BUX), Poland (WIG20), and Slovakia (SAX)². The data cover the period from 2 January 2000, until 26 June 2020. There are also four subsamples related to the period before (2.01.2000-30.04.2004) and after (4.05.2004-31.07.2008) the European Union's accession, Global Financial Crisis - European debt crisis period (1.08.2008-30.12.2012), and the post-crisis period (2.01.2012-30.12.2020). We intentionally omit in the fourth subsample the latest data from the year 2020 to avoid the impact made by the COVID-19 pandemic in this period. In all calculations we use daily logarithmic returns for stock i on the day t as $r_{i,t} = 100 \cdot \ln\left(\frac{P_{i,t}}{P_{i,t-1}}\right)$, where $P_{i,t}$ is the price of the stock i on day t .

Table 1 gives calculated basic descriptive statistics of daily logarithmic returns. The mean value in all cases is close to zero. Volatility, measured by standard deviation, is on a similar level for all indices and is quite moderate. In all cases, skewness and excess kurtosis values indicate the non-normal distribution of returns, which is confirmed by the results of the Jarque-Bera (JB) test. Next, as a preliminary assessment of the dependencies between the returns, we measured the correlation between considered stock indices. Since the simple Pearson correlation coefficient has many drawbacks, i.e. its measure only linear dependence and is sensitive to outliers and violation of normality assumption, we decided to calculate Spearman's rho rank correlation coefficient, which measures a monotonic dependence. Table 2 gives estimates of Spearman's rho coefficients. There is positive and quite strong monotonic dependence between BUX, PX, and WIG20 index. However, Spearman's rank correlations between the index from the Slovak stock market and other indices are close to zero and insignificant. Nevertheless, these measures don't show a whole picture and characteristics of the dependence structure between considered indices. It is possible, that there is dependence in different parts of the joint

² Historical data for all indices were obtained from the database available on the website www.stooq.pl

distribution, and/or at different frequencies even between uncorrelated variables (Baruník and Kley, 2019).

Table 1 Descriptive Statistics of Daily Returns and Jarque-Bera Test Results – Full Sample

	Min	Mean	Max	Std. Dev.	Skewness	Excess kurtosis	JB test (p-val.)
BUX	-12.65	0.03	22.02	1.56	0.15	22.02	<0.01
PX	-19.90	0.01	12.36	1.42	-1.00	12.36	<0.01
SAX	-14.81	0.03	11.88	1.20	-0.65	11.88	<0.01
WIG20	-14.25	0.00	12.43	1.58	-0.11	12.43	<0.01

Source: Author's own calculations

Table 2 Estimates of the Spearman's rank correlation coefficient between daily returns – full sample, p-values of significance test in parentheses

	BUX	PX	SAX
PX	0.50 (<0.01)		
SAX	0.01 (0.53)	0.02 (0.10)	
WIG20	0.51 (<0.01)	0.52 (<0.01)	0.01 (0.73)

Source: Author's own calculations

4 Empirical Results

4.1 Quantile Coherency Estimates

This part of the study is based on the quantile coherency estimates for the full sample. We consider three frequencies to measure quantile coherency for returns that correspond to weekly, monthly, and quarterly periods ($\omega \in 2\pi\{1/5, 1/22, 1/66\}$, respectively), a broad range of quantile levels: $\tau_i = 0.05, 0.10, \dots, 0.95$, and we assume that $\tau_1 = \tau_2$.

Figures 1-6 presents the quantile coherency estimates for all pairs of indices in the study. Generally speaking, obtained results show that there is a relatively strong, positive coherency between returns in the Hungarian, Czech, and Polish stock markets and that the Slovak stock market is the least connected with other markets. However, there are differences in the quantile coherency estimates depending on the quantile level and selected frequency.

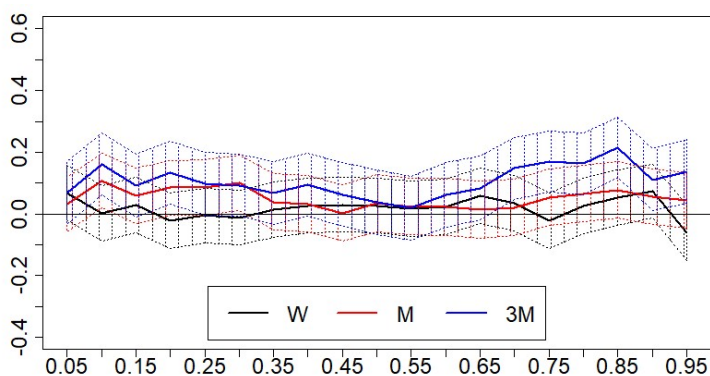
The quantile coherency between Hungarian and Slovak stock market returns, presented in Figure 1, is insignificant in most cases. Nevertheless, in the case of the long investment horizon represented by the quarterly period, all estimates for

quantile levels higher than 0.65 are weakly positive and significant. It means, that there is some (but rather low) coincidence between Hungarian and Slovak stock markets upturns in the long term.

Figure 2 presents the quantile coherency estimates between Czech and Slovak stock market returns. The estimated values are rather low. In the case of a weekly period, significant coherency estimates appeared only for the lowest quantile. Similarly, for the monthly and quarterly periods, there is a low, significant coherency in the case of the left tail of the distribution. It indicates that there is a low coincidence of the Czech and Slovak stock returns in the longer-term bad market situation. Moreover, there is a positive coherency in the quarterly period for the highest quantile, i.e. only for the strongest stock market upturns in the long-term.

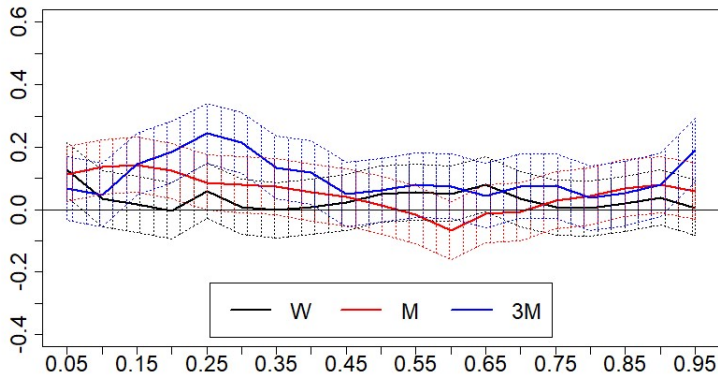
The quantile coherency between the Polish and Slovak stock market returns, depicted in Figure 3 indicates, that there is a low coincidence mainly for returns close to the median (normal market condition), in the left tail (negative returns) and for extremely positive returns in the long-term. For higher frequencies, estimates are insignificant.

Figure 1 BUX-SAX. The real part of quantile coherency estimates and 95% confidence intervals in the case of weekly (W), monthly (M) and quarterly (3M) period



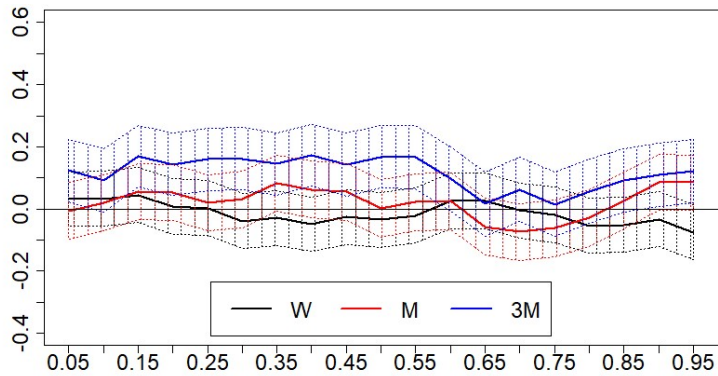
Source: Author's own elaboration

Figure 2 PX-SAX. The real part of quantile coherency estimates and 95% confidence intervals in the case of weekly (W), monthly (M) and quarterly (3M) period



Source: Author's own elaboration

Figure 3 WIG20-SAX. The real part of quantile coherency estimates and 95% confidence intervals in the case of weekly (W), monthly (M) and quarterly (3M) period

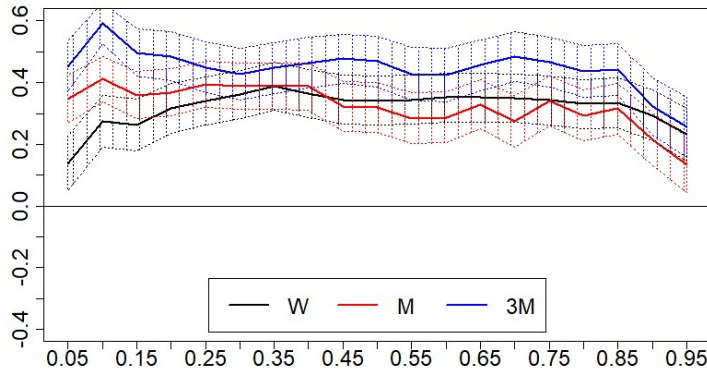


Source: Author's own elaboration

There are much larger synchronization effects between the stock markets in the Czech Republic, Poland, and Hungary. In the case of the Hungarian and Czech stock indices (see Figure 4), there is significantly positive coherency for all quantiles and analyzed frequencies. Moreover, returns are more strongly related in the long-term in comparison to shorter periods. In the left tail of the distribution, i.e. for extremely negative returns, the difference is the most pronounced. Furthermore, for monthly and quarterly periods one can observe that negative returns are more dependent than positive returns. A similar pattern applies to the Hungarian-Polish and Czech-Polish dependencies in returns, depicted in Figures 5 and 6. A coherency between extremely negative returns is stronger in the long-term in comparison to shorter periods and in comparison to the quantile levels related to the center and the right

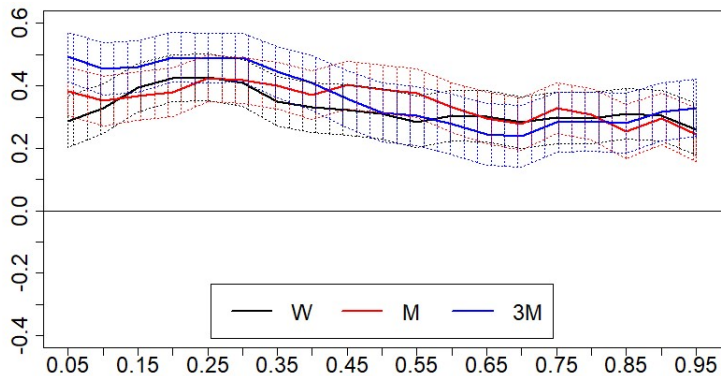
tail of the distribution. There are asymmetric tail dependencies between Polish, Hungarian, and Czech stock markets in monthly and quarterly periods. It means, that Hungarian, Czech, and Polish stock markets are strongly dependent during the long downturns.

Figure 4 BUX-PX. The real part of quantile coherency estimates and 95% confidence intervals in the case of weekly (W), monthly (M) and quarterly (3M) period



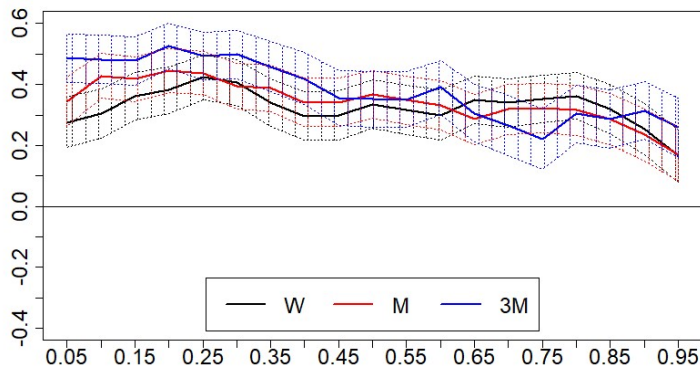
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Figure 5 BUX-WIG20. The real part of quantile coherency estimates and 95% confidence intervals in the case of weekly (W), monthly (M) and quarterly (3M) period



Source: Author's own elaboration

Figure 6 PX-WIG20. The real part of quantile coherency estimates and 95% confidence intervals in the case of weekly (W), monthly (M) and quarterly (3M) period



Source: Author's own elaboration

4.1.2 Subsample Analysis

The patterns detected in the previous section refer to the properties of returns in a quite long period. However, there are periods, when an integration among stock markets may be stronger. There are many studies showing that during a Global Financial Crisis of 2007-2008 dependencies in the financial market were above average. Moreover, all countries analyzed in this study joined the European Union in May 2004 and this event could also be a trigger for stronger dependencies. It would be worth checking, whether a coherency between considered markets changed for some quantiles and frequencies due to the global market downturns and European Union accession. To this end, we divided data into four subsamples:

1. 2.01.2000-30.04.2004 – the period before the European Union's accession,
2. 4.05.2004-31.07.2008 – the period after the European Union's accession,
3. 1.08.2008-30.12.2012 – the global financial crisis and European debt crisis period,
4. 2.01.2012-30.12.2020 – the post-crisis period.

The estimated values of Spearman's rank correlation in these four subsamples are presented in Table 3. BUX, PX, and WIG20 indices were positively correlated in all subperiods. The correlation level slightly increased after the European Union's accession and during the global financial crisis and European debt crisis, but in the post-crisis period, linkages were weaker. The Slovak stock market was significantly correlated only with the Czech stock market in the post-accession period, but the monotonic dependence was weak.

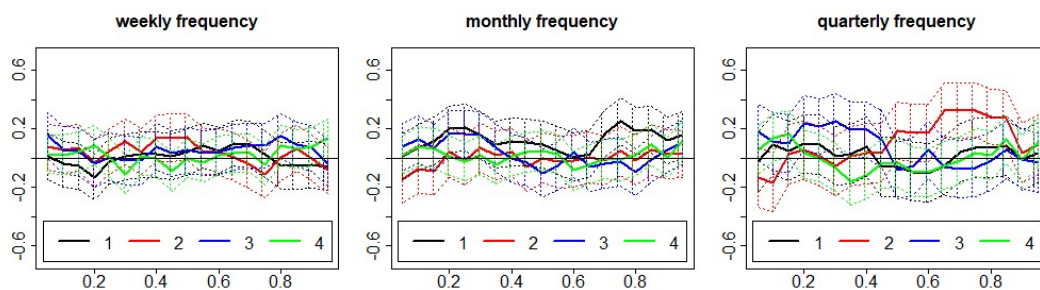
Table 3 Estimates of the Spearman's rank correlation coefficient between daily returns – subsample analysis, p-values of significance test in parentheses

2.01.2000-30.04.2004			
	BUX	PX	SAX
PX	0.46 (<0.01)		
SAX	-0.01 (0.68)	0.01 (0.82)	
WIG20	0.44 (<0.01)	0.49 (<0.01)	0.03 (0.37)
4.05.2004-31.07.2008			
	BUX	PX	SAX
PX	0.54 (<0.01)		
SAX	0.05 (0.18)	0.06 (0.05)	
WIG20	0.61 (<0.01)	0.54 (<0.01)	0.00 (1.00)
1.08.2008-30.12.2012			
	BUX	PX	SAX
PX	0.56 (<0.01)		
SAX	0.02 (0.52)	0.03 (0.37)	
WIG20	0.61 (<0.01)	0.65 (<0.01)	0.00 (0.89)
2.01.2012-30.12.2020			
	BUX	PX	SAX
PX	0.41 (<0.01)		
SAX	0.03 (0.31)	0.01 (0.57)	
WIG20	0.41 (<0.01)	0.41 (<0.01)	0.01 (0.75)

Source: Author's own calculations

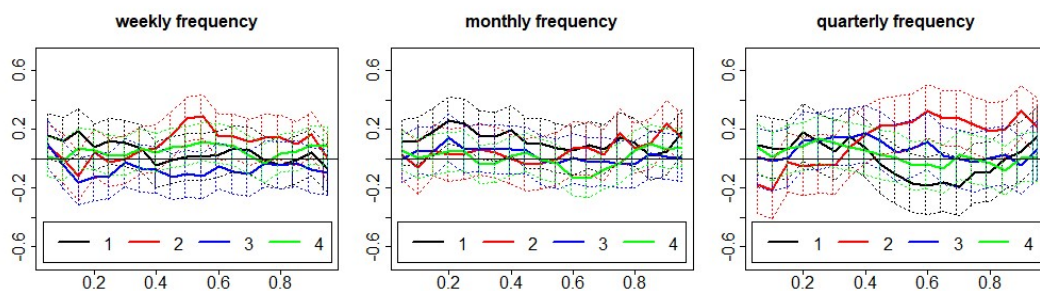
Figures 7-12 presents estimates of the quantile coherency in the subperiods for the same frequencies and quantile levels as in the previous section. In most cases the coherency between the Slovak stock market and other markets was insignificant (see Figure 7-9). However, there are specific features that can be observed based on these estimates. A coherency between Hungarian and Slovak stock markets for the quarterly investing horizon in the second subperiod was positive and significant in the right tail of the distribution, i.e. after the EU accession, there was a weak coincidence of stock market upturns. On the other hand, in the crisis period, there was a weak coherency for the quarterly periods and extreme negative returns. Similarly, after the EU accession, one can observe significant linkages in the right tail of the distribution in the case of Czech-Slovak returns. Nevertheless, all these effects are rather weak and there were no intensive changes of the quantile coherencies between the Slovak stock market and other markets in the considered subperiods.

Figure 7 BUX-SAX. The real part of quantile coherency estimates and 95% confidence intervals in the subperiods



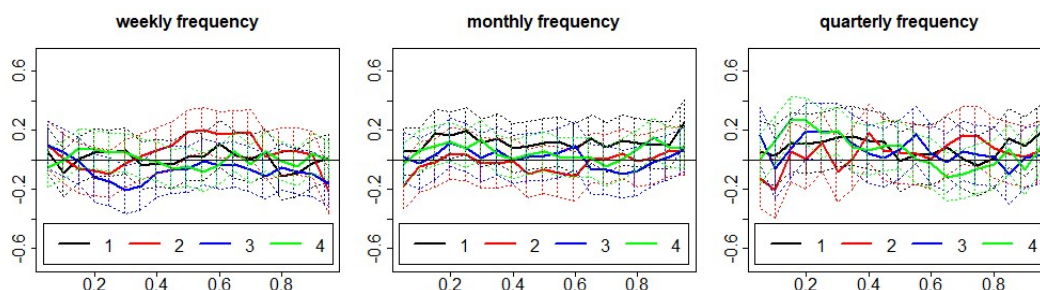
Source: Author's own elaboration

Figure 8 PX-SAX. The real part of quantile coherency estimates and 95% confidence intervals in the subperiods



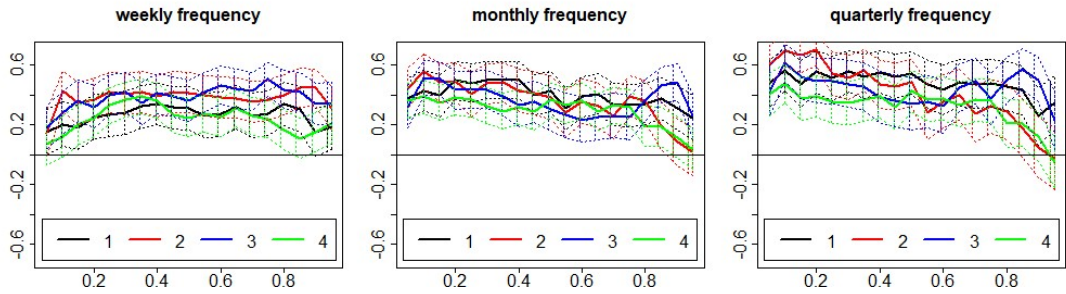
Source: Author's own elaboration

Figure 9 WIG20-SAX. The real part of quantile coherency estimates and 95% confidence intervals in the subperiods



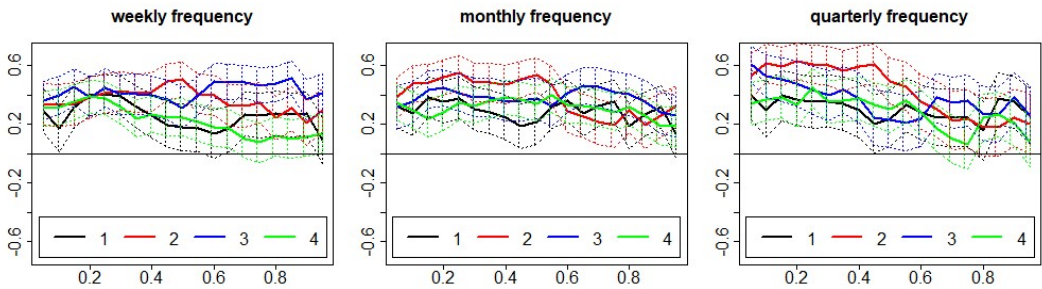
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Figure 10 BUX-PX. The real part of quantile coherency estimates and 95% confidence intervals in the subperiods



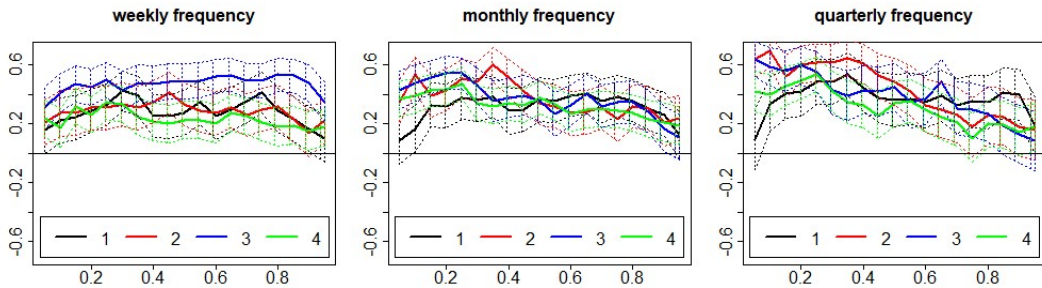
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Figure 11 BUX-WIG20. The real part of quantile coherency estimates and 95% confidence intervals in the subperiods



Source: Author's own elaboration

Figure 12 PX-WIG20. The real part of quantile coherency estimates and 95% confidence intervals in the subperiods



Source: Author's own elaboration

Figures 10-12, showing quantile coherency between Hungarian, Czech, and Polish stock exchange, are quite similar in the subperiods. A coherency for pairs BUX-PX and BUX-WIG20 for extremely negative returns is stronger in the medium- and long-term in comparison to the quantile levels related to the center and the right tail of the distribution. There is a similar effect in the case of the coherency between PX and WIG20 in the monthly and quarterly periods for all subperiods after joining the European Union. The feature, that Hungarian, Czech and Polish stock markets are strongly dependent during the long downturns, is permanent since EU accession. The difference between estimates in the pre- and post-accession period is related mainly to the coherencies with the Polish stock market in the longer-term bad market situation. A comparison between linkages in the crisis and in the post-crisis period shows, that dependencies during global turmoil were generally stronger compared to more tranquil times in the years after the global recession and European debt crisis. The difference is most pronounced in the case of a short-term period.

5 Discussion of Results

Detailed results in the previous section show complex and non-obvious aspects of the comovements and the commonalities of the CEE stock markets. Moreover, we found the answers to the following research questions:

RQ1: Are the coherencies between market returns in all V4 countries at a similar level?

We found, that coherencies between Czech, Hungarian, and Polish stock markets are significantly positive for all considered quantiles and investing horizons. Obtained results indicate, that there is a strong co-movement between the returns in these three markets in the short-, medium- and long-term, as well as in the market upturns and downturns. The Slovak stock market is the least connected with other countries in the group. This is in line with the conclusions from the previous studies. For example, Vychytilova (2018) showed, that the Slovak stock market was uncorrelated with other markets in the V4 group almost in all years in the post-GFC period and this was explained by the low liquidity, depth, and market capitalization of the Bratislava Stock Exchange. Baumöhl (2013) makes similar arguments and points out that the Slovak stock market may be inefficient, which is related to market capitalization and the shareholder structure. This result could also be related to the fact, that the Slovak stock market is the least connected with the developed countries (Živkov et al., 2019).

RQ2: Are the coherencies stronger for some frequencies or quantiles related to the specific part of the distribution?

There are differences in the quantile coherency estimates depending on the quantile level and selected frequency. The quantile coherency between Hungarian and Slovak stock market returns is significant only in the case of the right tail for the long investment horizon represented by the quarterly period. In the case of Czech and Slovak stock market returns, significant coherency estimates appeared mainly

for the lower quantiles. There is a positive coherency for the highest quantile, i.e. only for the strongest stock market upturns, only in the long-term. The quantile coherency between the Polish and Slovak stock market returns indicates, that there is a low coincidence mainly for returns close to the median, in the left tail, and for extremely positive returns in the long-term. Moreover, returns in the Polish, Hungarian, and Slovak stock markets are more strongly related in the long-term in comparison to shorter periods. In the left tail of the distribution, i.e. for extremely negative returns, the difference is the most pronounced. We found, that the Warsaw, Budapest, and Prague Stock Exchanges are more strongly dependent during the long downturns. It relates to one of a well-known feature of financial markets, that correlations increase in bear markets (Longin and Solnik, 2002). Our results are in line with the previous studies showing that the stock markets in the CEE countries are more integrated after the crisis (Gjika and Horváth, 2013; Baumöhl, 2013; Vychytilova, 2018; Hung, 2019; Moagăr-Poladian et al., 2019). The coherencies between the markets behave differently in different quantiles and subperiods due to the fact, that negative extreme returns attract investors' attention stronger than moderate or positive ones. This phenomenon can therefore be explained in terms of behavioral finance.

Conclusions

In this paper, we analyzed the linkages between stock markets in the countries belonging to the Visegrad Group. We employed a quantile coherency approach to analyze the dependence structure in the frequency domain for the joint distribution of returns. Results from a quantile coherency approach revealed an important feature of linkages between Polish, Slovak, Czech, and Hungarian Stock Exchanges, which would be imperceptible if other methods, such as correlation analysis or copula functions for one selected data frequency, were used. Linkages between Czech, Hungarian, and Polish stock markets are significantly positive for all considered quantiles and frequencies. These three markets are more strongly dependent during the long downturns and the effect is permanent after the European Union accession. The Slovak stock market is the least connected with other countries in the group in all subperiods.

Obtained results could be important for international market participants with different trading horizons to better evaluate interdependencies between the countries in Central Eastern Europe. We analyzed these features in terms of frequency-dependent correlations between main indices that serve as a benchmarks representing a broad market. In conclusion, our results are interesting in the context of the financial market integration between CEE countries.

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