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Linear and nonlinear intraday causalities in response to U.S. macroeconomic news announcements: Evidence from Central Europe**

1. Introduction

The main goal of this paper is to analyze the information flow on and between the three stock markets in Frankfurt, Vienna, and Warsaw. These markets are rather different, since the capitalization of the Frankfurt Stock Exchange (FSE) is about ten times greater than that of the Warsaw Stock Exchange (WSE) and the Vienna Stock Exchange (VSE)¹. There are, however, many facts that suggest that the FSE, VSE, and WSE may be strongly interrelated. First, the VSE and WSE are similar in some aspects, since the main indices of these markets have been quoted for a similar period of time and are among the largest stock markets in Central and Eastern Europe². Second, the VSE and WSE have been competing markets in recent years. On the other hand, the FSE and VSE are developed markets, while the WSE is still an emerging market. Last but not least, Germany is the most important trading partner for both the Austrian and Polish economies.

The **Sequential Information Arrival Hypothesis** (SIAH), introduced by Copeland (1976), assumes that not all traders receive new information at exactly the same time (they receive it sequentially), while the **Mixture of Distribution Hypothesis** (MDH) from Clark (1973), in turn, assumes that new public information is received by

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¹ For more details, see Federation of European Securities Exchanges: www.fese.eu.

² The ATX20 index (VSE) is quoted from January 2, 1991, and the WIG20 index (WSE) is used from April 16, 1994.

all investors contemporaneously; these are the two main conjectures about the way that new information impacts the dynamic relationships between the variables that describe stock prices. Usually, the purpose of an analysis of the linear and nonlinear causal relationships between returns, volatility, and trading volume on a given stock market and between different markets in the presence of public news and without them is to judge which of the above-mentioned hypotheses is supported by empirical evidence. Such an analysis also reflects the behavior of investors and allows for an analysis of cross-country dependencies. This, in turn, can help to describe information flows between different stock markets and answer the question of which market is the one that primarily generates signals to investors on the other stock markets.

Besides examining linear and nonlinear causalities between returns, volatility, and trading volume on the three markets, we also analyze the reaction time to news releases as well as the changes in the duration of all of the causal relationships uncovered. The latter may help to answer the question of whether news announcements have an impact on the number of significant causal links and their profile.

This paper extends the current literature in several ways. First of all, we do not restrict the empirical study solely to the analysis of linear causal links, but we also examine nonlinear causalities on and between the three markets under study. Moreover, we try to estimate the time of reaction to a news release and changes in the duration of causal interference by using different lags in respective multidimensional time-series models³.

The rest of the paper is organized as follows. In the next section, we provide an overview of the economic literature on the relationships between returns, volatility, and trading volume and about the impact of U.S. macroeconomic news on CEE markets. In Section 3, we present the data used in this study and give a brief description of the methodology applied. The empirical findings as well as discussion are presented in Section 4. The final section concludes the paper and provides some suggestions for future research.

2. Literature overview

2.1. Links between financial variables on stock markets

Establishing the nature, direction, and strength of dynamic interrelations between stock prices, volatility, and trading volume improves our understanding of information flows on financial markets and helps reveal their structure. In

³ Recently, Gurgul and Lach (2015) have also focused of causalities on and between the stock markets operating in Frankfurt, Warsaw, and Vienna. They also divided the sample into periods with and without announcements of macroeconomic news from the U.S. economy. However, the authors did not discuss the issue of time of reaction to a news release and changes in the duration of causal interference and did not analyze the structure of nonlinear causal links.

this context, the detecting the channels of the transmission of this information between different groups of investors and between particular stock markets becomes a very important issue.

The investigation of return-volatility-trading volume links is often based on the notion of *Granger causality* (Granger, 1969). The concept of causality developed by Granger relates the concept of conditional dependency. There are numerous contributions conducted in the framework of Granger causality and its various extensions. Some results obtained via this approach are contradictory; e.g., the linear and nonlinear Granger causality tests applied by Hiemstra and Jones (1994) to daily Dow Jones returns and relative changes in NYSE trading volume detected bi-directional nonlinear causality between returns and volume, while Gallant et al. (1992) report a one-way strong nonlinear impact of lagged stock returns on current trading volume based on the daily S&P 500 index returns and NYSE trading volume. The causality in the opposite direction (from lagged trading volume to current stock returns) is weak.

Lee and Rui (2002) used daily data to test the dynamic relationships between the three largest stock markets; namely, those operating in the US, UK, and Japan. The main result was that U.S. financial market variables (trading volume in particular) have predictive power for price, trading volume, and volatility movement in the UK and Japan.

Gurgul and Majdosz (2005) took into account calendar effects and repeated the causal analysis in various sub-samples. They detected robust and significant bi-directional linear causality between daily stock returns and trading volume on the Warsaw Stock Exchange (WSE). Gurgul and Majdosz (2005) found that the U.S. and German returns (volatility) have predictive power in describing fluctuations in Polish trading volume. However, they did not find a similar connection on the Austrian stock market.

More recent contributions dedicated to interrelations between financial variables better reveal the characteristics of information flow because they are based on intraday data. Rossi and de Magistris (2010) focus on the link between the realized volatility and trading volume of four stocks listed on the NYSE. The authors find that trading volume and volatility exhibit long memory. However, these variables are not fractionally cointegrated. In this way, the results contradict the MDH in the version of Bollerslev and Jubinski (1999). The fractionally integrated VAR models supply evidence that a filtered log-volume probably has a positive impact on the current filtered log-volatility.

Darrat et al. (2003) used intraday data on 30 selected stocks from the DJIA. Based on the empirical results, they claim that high trading volume causes high return volatility, which is in accordance with the SIAH but not the MDH.

This direction of research was continued in the contribution by Gurgul and Wójtowicz (2008). In the framework of event-study methodology, the authors defined events as appearances of extreme high trading volume. They examined high volume premium hypothesis for companies listed on the WSE. The results were in line with the high volume premium conjecture, since the occurrences of high trading volume implied high returns (especially in the case of small companies) on the following days, especially one day afterwards. The results were not only in favor of the high trading volume premium hypothesis but also suggested the construction of profitable investment strategies. In the case of small trading volume, the mean abnormal returns were not statistically significant.

Darrat et al. (2003) were not able to distinguish between the SIAH and other plausible explanations of the observed causal relationships (e.g., the overconfidence hypothesis). To make such a distinction, it is important to know whether causality is implied by an announcement of public news. The contributors take for granted that, in the absence of public signals, rational investors do not change their positions. Therefore, under the rationality assumption, no causal link between volume and volatility is predicted. However, in the behavioral approach, it is assumed that investors trade even without the presence of public signals. Quasi-rational investors can ignore the absence of public signals and may still overreact to their own (private) signals, causing them to trade.

In a more-recent contribution, Darrat et al. (2007) reexamined lead-lag relations between the trading volume and volatility of large and small stocks from the NYSE. Causality was tested in two subperiods, with and without identifiable public news. The study by Darrat et al. (2007) was based on an idea of Fama (1998). They suggested a similar procedure, although in different contexts⁴. Darrat et al. (2007) supplied evidence in favor of the SIAH during periods with public news. However, they also detected causality running from trading volume to return volatility, even during periods without public news. In addition, return volatility was found to rise during periods with public news, while trading volume was higher during periods without public information announcements. The contributors stressed that the results are invariant with respect to different times of day. Some of the results of Darrat et al. are in favor of the self-attribution model of Daniel et al. (1998), which suggests overconfidence of the investors.

In a more-recent contribution, Bouezmarni et al. (2012) suggested a nonparametric test based on the Bernstein copula. Using high-frequency data, the authors

⁴ Based on a subset of stocks from the time period of 1990–1992, Pritamani and Singal (2001) checked the predictability of returns following announcements and large price changes. Chan (2003) collected news headlines for a subset of Center for Research in Security Prices (CRSP) stocks from 1980 to 2000. He addressed monthly returns following public news and returns after similar price movements in the absence of public news.

tested for causality between stock returns and trading volume. The contributors have found that, at a 5% significance level, the nonparametric test clearly rejected the null hypothesis of no-causality running from returns to volume. This was in line with the conclusion that followed from the outcomes of the linear causality test. In addition, their nonparametric test detected a non-linear feedback effect between trading volume and returns at a 5% significance level.

A widely accepted point of view in the economic literature is that macroeconomic data announcements can be seen as important news for stock market participants. In the next section, we review some contributions devoted to the analysis of the impact of macroeconomic data announcements on the performance of certain stock markets.

2.2. U.S. macroeconomic news announcements and their impact on causalities between European stock markets

Several contributors have focused on an examination of the impact of U.S. macroeconomic news on European stock markets (see: e.g., Nikkinen and Sahlström, 2004; Nikkinen et al., 2006; Hanousek et al., 2009; Harju and Hussain, 2011; Gurgul and Wójtowicz, 2014, 2015). In general, the results are somewhat contradictory.

Nikkinen and Sahlström (2004) provided evidence that volatility on the German and Finnish stock markets is affected only by U.S. announcements about the unemployment rate and PPI. In addition, domestic macroeconomic data does not influence either of the markets.

Nikkinen et al. (2006) demonstrated that announcements of some U.S. macroeconomic news are the sources of a rise in volatility on developed European stock markets. However, the reaction of CEE economies in transition (including the Czech Republic, Hungary, Poland, Russia, and Slovakia) seems to be negligible. Nikkinen et al. (2006) suggested the possibility of significant differences in the reaction to U.S. macroeconomic news between developed and emerging markets in Europe.

Singh et al. (2013) found that U.S. macroeconomic news has a more-frequent effect on volatility than on returns on European developed markets. According to this study, unexpected macroeconomic news impacts volatility on the stock markets in the UK, France, Germany, and Italy. However, in these cases, returns are influenced only on the German stock market. Cakan et al. (2015) suggested that there is a strong impact of U.S. news on volatility in emerging markets (including Poland, Russia, and Turkey). However, Gümüş et al. (2011) are convinced that U.S. data announcements have no effect on stocks listed on the Istanbul Stock Exchange.

Harju and Hussain (2011) used high-frequency data and reported that U.S. macroeconomic news announcements cause an immediate and statistically significant response of intraday volatility and the returns of the CAC40, DAX30, FTSE100, and SMI.

The reaction of stocks listed on the Frankfurt Stock Exchange on macroeconomic news was tested by Dimpfl (2011). The author found that 1-minute returns of the DAX30 react immediately after a news release. This significant reaction was observed in the first ten minutes.

Hanousek et al. (2009) checked the reaction of emerging markets in the Czech Republic, Hungary, and Poland to various macroeconomic announcements. The contributors detected that the strongest reaction of 5-minute returns takes place on the stock market in Prague. Stocks listed in Budapest respond significantly only to negative news. However, the Warsaw Stock Exchange does not react significantly to U.S. macroeconomic news. Hanousek et al. (2009) detected significant spillover effects on the emerging markets under study, as their main indices influence each other. They are also significantly influenced by preceding returns of the DAX30. The authors claim that the impact of the Frankfurt Stock Exchange (via the DAX30) is stronger than the impact of any of the emerging markets.

Significant causality from the FSE to stock markets in Prague and Warsaw was also reported by Černý and Koblas (2005). An important role of developed European markets for CEE emerging markets in Budapest, Prague, and Warsaw was also indicated by Égert and Kočenda (2007). They showed significant causalities between the returns of CEE markets and from developed to emerging European stock markets. Opposite causalities running from stocks listed on Eastern European stock markets to stocks on Western European stock markets were insignificant. Similar links could be observed for volatilities with two exceptions. According to Égert and Kočenda (2007), volatility in Budapest and Warsaw is a significant cause of volatilities on stock markets in Frankfurt and London.

The thorough analysis of intraday relationships between CEE markets conducted by Égert and Kočenda (2011) shows very little positive time-varying correlations among the returns of the BUX, PX50, and WIG20. The contributors stress that correlations between these indices and Western European stock markets are not pronounced.

The response of the Polish stock market to U.S. announcements was checked in detail by Gurgul and Wójtowicz (2014). Based on intraday data for the WIG20, a significant response to unexpected news from the U.S. economy in the first minute after a news announcement was detected. The cause of significant reactions are announcements regarding industrial production, durable goods orders, retail sales, and nonfarm payrolls. The last type of announcement incurs the strongest reaction.

3. Methodology and dataset

3.1. Testing for linear Granger causality using big data

The concept of Granger causality (Granger, 1969) is one of the most-common approaches in research concerning returns, return volatility, and trading volume interrelations. This concept can be understood as a special kind of conditional dependency. There is no need to explain it in detail, since this idea is rather well-known nowadays and has been widely used in previous studies. By and large, this concept is used to investigate whether knowledge of the past values of one (stationary) variable is helpful in predicting the future values of another one or not. In practical applications, one should test the statistical significance of the coefficient estimators of the potentially causal (explanatory) variable in respective Vector AutoRegression (VAR). A statistically significant test outcome implies the existence of linear causality running from an explanatory variable to the endogenous variable. As underlined by Granger and Newbold (1974) and Phillips (1986), when dealing with nonstationary time series, the results of the traditional (VAR-based) test for linear Granger causality can be spurious (which implies the need for an alternative approach). The modified approach depends on whether the time series under study are cointegrated (when it is recommended to test for causality using Vector Error Correction Models) or not (differencing the data and using the Toda-Yamamoto (1995) approach).

Among the special problems that arise when using traditional asymptotic-based tools for linear causality testing in the case of large data, one should list the issue of overrejection (Darrat et al. 2007). It is clear that the larger the sample, the more significant the size distortion, although one may ask an interesting question about the critical sample size above which the overrejection issue becomes a serious problem. By means of Monte Carlo simulations, Gurgul and Lach (2015) proved that increasing sample size and lag length leads to more-significant size distortion in the asymptotic variant of the Granger causality test. It is important to underline that the authors showed that size distortion becomes a serious problem even for around 400–600 observations⁵. Taking these outcomes into account, we followed the suggestions of Darrat et al. (2007); but instead of asymptotic critical values, we applied Bayesian critical values. Using critical values is recommended in order to avoid the problem of overrejection implied by the large size of the data in the causality tests.

⁵ Gurgul and Lach (2015) ran Monte Carlo simulations in order to shed some light on the issue of overrejection. They designed the simulation scheme in a way that would ensure comparability of their results with previous papers dealing with the size performance of a linear Granger causality test (e.g., Dolado and Lütkepohl, 1996; Hacker and Hatemi, 2006; Mantalos, 2000; Lach, 2010, among others).

3.2. Nonlinear Granger causality

Let us now shed some light on the concept of testing nonlinear Granger causality used in this paper. In recent years, the well-known nonlinear test proposed by Baek and Brock (1992) has been modified several times. In this paper, we use the approach proposed by Diks and Panchenko (2006). We will focus on the problem of investigating whether one time series (denote it as $\{Y_t\}$) nonlinearly Granger causes another time series (denote it as $\{Y_t\}$). For the present purposes, let us define for $t = 1, 2, \dots$ the $L_X + L_Y + 1$ dimensional vector $W_t = (X_{t-L_X}^{L_X}, Y_{t-L_Y}^{L_Y}, Y_t)^6$. The null hypothesis that $\{Y_t\}$ does not Granger cause $\{Y_t\}$ may be written in terms of density functions in the following way:

$$f_{X,Y,Z}(x, y, z) = f_{X,Z}(x, z) f_{Z|X,Y}(z | x, y) = f_{X,Z}(x, z) f_{Z|Y}(z | y) \quad (1)$$

where $f_X(z)$ stands for the probability density function of random vector X at point z , $X = X_{t-L_X}^{L_X}$, $Y = Y_{t-L_Y}^{L_Y}$, $Z = Y_t$, for $t = 1, 2, \dots$. The last equation may be rewritten in more convenient forms:

$$\frac{f_{X,Y,Z}(x, y, z)}{f_{X,Y}(x, y)} = \frac{f_{Y,Z}(y, z)}{f_Y(y)} \quad (2)$$

and

$$\frac{f_{X,Y,Z}(x, y, z)}{f_Y(y)} = \frac{f_{X,Y}(x, y)}{f_Y(y)} \frac{f_{Y,Z}(y, z)}{f_Y(y)} \quad (3)$$

Next, for the multivariate random vector W , let us define correlation integral $C_W(\varepsilon)$ by the following expression:

$$C_W(\varepsilon) = P[\|W_1 - W_2\| \leq \varepsilon] = \iint I(\|s_1 - s_2\| \leq \varepsilon) f_W(s_1) f_W(s_2) ds_2 ds_1 \quad (4)$$

where W_1, W_2 are independent with distributions in the equivalence class of distribution of W , letter I denotes the indicator function (equal to one if the condition in brackets holds true; otherwise, equal to zero), $\|x\| = \sup\{|x_i| : i = 1, \dots, d_W\}$ denotes the supremum norm (d_W is the dimension of sample space W), and $\varepsilon > 0$.

Hiemstra and Jones (1994) claimed that testing the null hypothesis in Granger's causality tests implies for every $\varepsilon > 0$:

⁶ Symbol $X_{t-L_X}^{L_X}$ denotes L_X -lagged vector of X_t ; i.e., $X_{t-L_X}^{L_X} = (X_{t-L_X}, X_{t-L_X+1}, \dots, X_{t-1})$.

$$\frac{C_{X,Y,Z}(\varepsilon)}{C_{X,Y}(\varepsilon)} = \frac{C_{Y,Z}(\varepsilon)}{C_Y(\varepsilon)} \quad (5)$$

or equivalently:

$$\frac{C_{X,Y,Z}(\varepsilon)}{C_Y(\varepsilon)} = \frac{C_{X,Y}(\varepsilon)}{C_Y(\varepsilon)} \frac{C_{Y,Z}(\varepsilon)}{C_Y(\varepsilon)} \quad (6)$$

The authors put pressure on calculating sample versions of correlation integrals and then tested whether left-hand- and right-hand-side ratios differ significantly or not. They proposed the use of the following formula as a correlation integral estimator:

$$C_{w,n}(\varepsilon) = \frac{2}{n(n-1)} \sum_{i < j} I_{ij}^w \quad (7)$$

where $I_{ij}^w = I(\|W_i - W_j\| < \varepsilon)$. As shown by Diks and Panchenko (2006), testing relations (5) or (6) is not equivalent, in general, to testing the null hypothesis of Granger causality. The authors found exact conditions⁷ under which the HJ test is useful in investigations concentrated on causality and provided a modified tool for testing nonlinear causal links.

3.3. Empirical applications

In order to describe information flow on the stock markets under study and between them, it is necessary to examine causal relationships in the presence of important public information and during periods without such information. Ongoing globalization leads to a continuous inflow of new information, which implies difficulties in indicating periods without inflow of important information (understood here as news essential to investors) on all three stock markets. The previous literature (see: e.g., Gurgul and Wójtowicz, 2015; Gurgul and Lach, 2015) suggests that, among many possible candidates, macroeconomic news announcements from the U.S. economy seem to be a suitable choice. This prediction follows from previous contributions that supplied evidence that macroeconomic news announcements significantly impact stock markets. Macroeconomic news from the U.S. economy is often thought the most influential, since this economy plays a predominant role over the whole world. Henceforward, we define **trading**

⁷ Since this property is not the main point of our research, we refer to Diks and Panchenko (2006) for more details on this issue.

session with information when at least one of the following U.S. macroeconomic indicators was announced: Consumer Price Index, Producer Price Index, Industrial Production, Retail Sales, Durable Goods Orders, Nonfarm Payrolls, Existing Home Sales, Housing Starts, New Home Sales, and Consumer Confidence⁸. In this paper, we apply intraday data covering the period of May 2013 – August 2013⁹. We consider 1-minute log-returns of the main index of each of the markets; namely, the DAX30 (FSE), ATX20 (VSE), and WIG20 (WSE)¹⁰. In order to obtain conditional variances (used as proxies of return volatility in causality analysis), we use the ARMA(1,1)-EGARCH-M(1,1) model (as in Darrat et al., 2007).

There are several measures of investor trading activity in the economic literature. These include trading volume (the number of shares traded) and turnover (the total value of shares traded), which are used quite often in practical applications. In order to allow comparability with the outcomes of previous studies in the empirical part of our study, we use intraday trading volume¹¹. More precisely, we compute the difference between the total trading volume index at the end and beginning of each 1-minute interval. Such a quantity describes the number of shares from a given index traded during a given 1-minute interval. This 1-minute trading volume, however, is highly skewed. To deal with this issue in further analysis, we apply natural logarithms of 1-minute trading volume.

One cannot forget that the stock markets under study are open at different hours and that there are intraday auctions at different times during the day¹². On the other hand, the causal relationships must be analyzed only during the periods when all three markets are open and, thus, may influence each other. Taking these facts into account, as well as the increased return volatility observed at the beginning and at the end of trading session, we study relationships between intraday returns, return volatility, and trading volume of the DAX30, ATX20, and WIG20 during two periods during trading days. The first period ranges from 9:20 to 11:45, and the second lasts from 14:35 to 16:45. These periods start at least 15 minutes after the beginning of continuous trading on each of the markets and end

⁸ These macroeconomic indicators are released monthly on different days of the month between 14.00 and 16.00 CET. The latter ensures that the impact of these announcements can be directly observed in stock prices, particularly in the values of all indices.

⁹ The data comes from the Vienna Stock Exchange, Warsaw Stock Exchange, and Bloomberg databases.

¹⁰ We apply 1-minute returns (instead of, for example, 5-minute returns) because, as indicated by the literature (Dimpfl, 2011; Gurgul and Wójtowicz, 2014), new public information on efficient stock markets implies investor reaction as soon as it is announced (often even in the first minute after the release of news).

¹¹ See: e.g. Bollerslev and Jubinski (1999); Lobato and Velasco (2000); Darrat et al. (2007); Rossi and de Magistris (2010).

¹² On the FSE, there was the intraday auction from 13:00 to 13:02. On the VSE, the intraday auction lasts from 12:00 to 12:07:30 on settlement days and from 12:00 to 12:04 on non-settlement days of the derivatives market.

at least 30 minutes before the end of trading sessions. We also apply 15-minute gaps before and after the intraday auctions in order to avoid potential problems with modeling the increased volatility just before or just after intraday auctions on the Frankfurt or Vienna Stock Exchanges

In order to test changes in the duration of causal interference, we proceeded with four different lag lengths in the underlying VAR models; for each pair of variables, we examined four windows of possible causal interference of lengths of 1, 5, 10, and 20 minutes, respectively.

4. Empirical results

Henceforward, we will refer to the first period (9:20–11:45) as the **morning period**. In this period, there are no available U.S. news announcements; whereas, during the second period (14:35–16:45, henceforward referred to as the **afternoon period**), U.S. stock markets are open and U.S. macroeconomic news is announced. In order to describe causality in the presence of public information and without it (which is particularly important in the context of the SIAH and the overconfidence hypothesis), one should analyze the domestic and cross-country relationships between returns, volatility, and trading volume on each market during these two periods on days when U.S. macroeconomic news is announced and on days without such announcements.

4.1. Linear causality analysis

4.1.1. Morning session

In the first step, we analyzed linear causalities during the morning sessions on days without important U.S. macroeconomic news announcements. During that time, trading is based on private information only. As a consequence, it is possible to examine the rationality of investors. In the next step, we focused on days with U.S. news announcements (so that we could test the effects of public news announcements on the structure of causal links on and between the markets under study).

Figure 1 presents the results of linear Granger causality tests during the morning period on days without news announcements¹³. The empirical results indicate the dominant role of the Frankfurt Stock Exchange among the stock

¹³ In this paper, we present the results of causality analysis in the form of directed graphs. Since the sample size exceeds 600 by far in this paper, we rely only on the Bayesian critical values in order to avoid the overrejection.

markets under study, especially when it comes to the number of linear causal links running from DAX30 returns. If stock exchanges in the U.S. are closed and no important news from the U.S. economy is expected, traders in Vienna and Warsaw make their investment decisions by observing price movements on the larger and more-liquid stock exchange in Frankfurt. Hence, prices on the VSE and WSE simply follow the prices on the FSE.

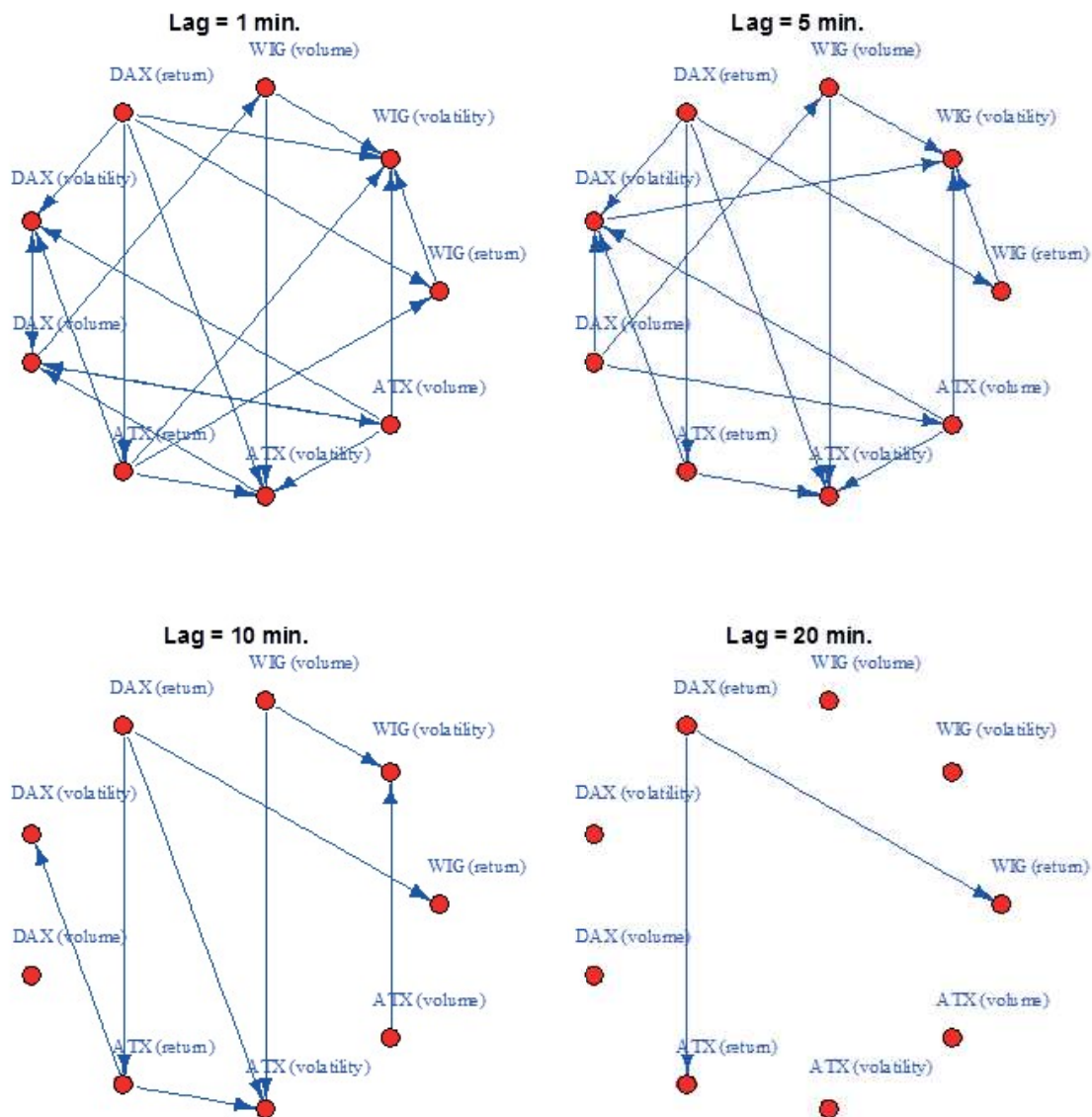


Figure 1. The results of linear Granger causality tests (morning session, days without news announcements)

When important macroeconomic data from the U.S. economy is expected to be announced (Fig. 2), linear causalities on the FSE, VSE, and WSE do not change significantly during the morning period from 9:20 to 11:45. As in the previous case, significant linear Granger causality from DAX30 returns to the returns of the ATX20 and WIG20 is observed regardless of the lag length considered; one may claim this is the main way that information from the FSE is transmitted to the CEE stock markets under study.

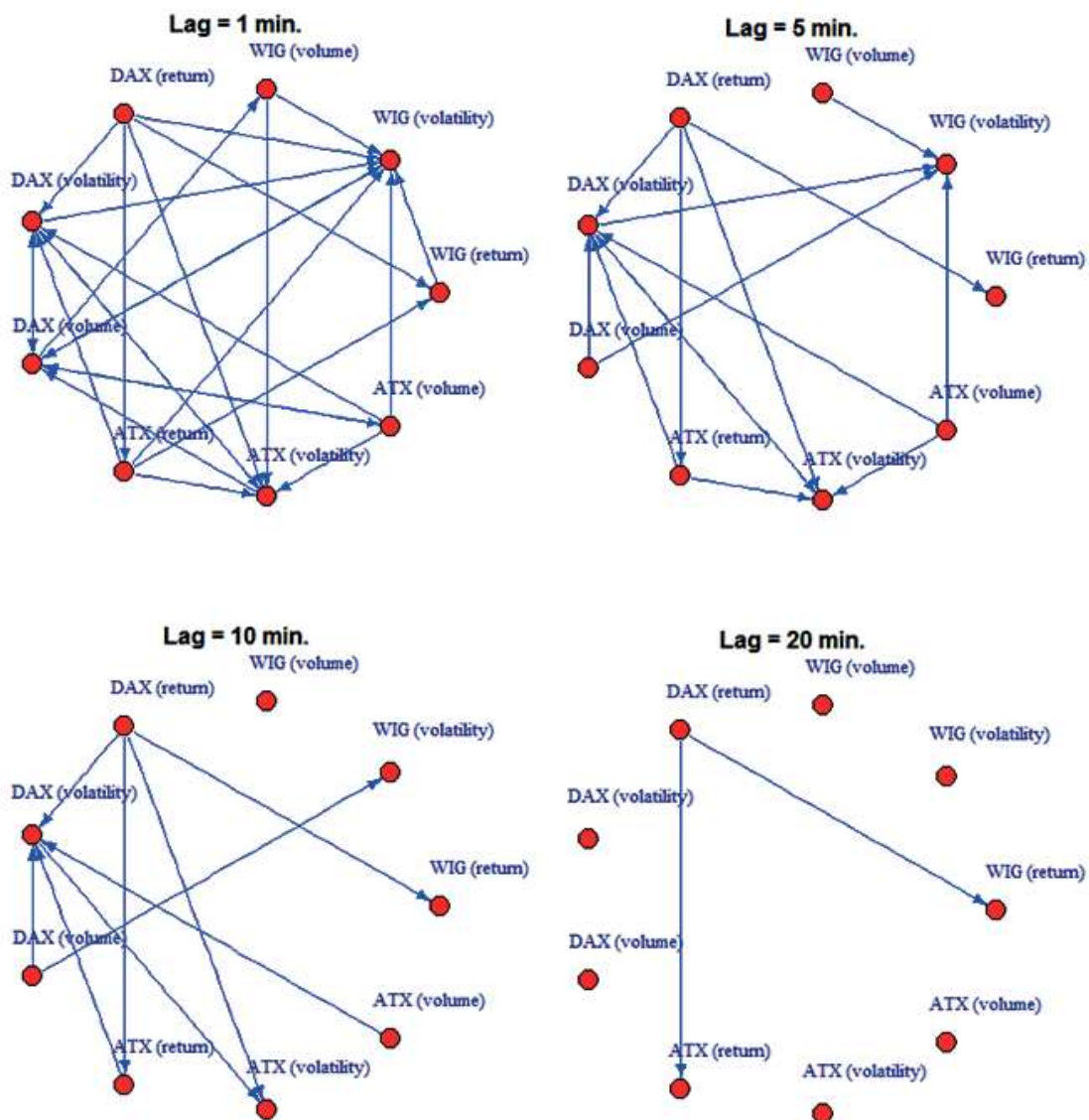


Figure 2. The results of linear Granger causality tests (morning session, days with news announcements)

To summarize, one may claim that only a few new significant linear causal links occur on days with U.S. macroeconomic news announcements. There are additional causal links that turned out to be significant only on days with U.S. macroeconomic news announcements (i.e., feedback between DAX volatility and ATX volatility as well as between DAX volume and WIG volatility)¹⁴. Moreover, a comparison of Figures 1 and 2 supports the claim that, on days with news announcements, the duration of significant causal interferences decreases¹⁵. The latter follows from the fact that, in the case of linear causal links identified for both types of days, the arrival of new information means that significant results are confirmed only in models with smaller lags. In other words, the linear causal impact represented in higher lags in the underlying VARs is too weak to lead to statistically significant results of the overall causality test (taking the form of the joint significance test). Therefore, evidence of intensive linear causality is observed only for relatively small lags of the potentially causal factor.

4.1.2. Afternoon session

Analyzing the results presented in Figure 3 (linear causalities during the afternoon period without important U.S. macroeconomic news announcements), one can notice one important fact. In general, during the afternoon sessions on days without important U.S. macroeconomic announcements, one may notice more-significant linear causal links as compared to the morning period (Fig. 1 and Fig. 2). First of all, regardless of the lag length assumed, significant causalities from DAX30 the returns to returns of the ATX20 and WIG20 are always observed. When important macroeconomic data from the U.S. economy is announced (Fig. 4), linear causalities on the FSE, VSE, and WSE change significantly during the afternoon period. First of all, regardless of the lag length assumed, we can see an increased causal impact running from DAX30-related variables to the variables describing the stock markets in Warsaw and Vienna. For example, for a lag length of ten minutes, there are only three causalities from the FSE to other markets during afternoon sessions without news. On the other hand, the number of these increases to seven in afternoon sessions with news announcements. On days with new information announcements, one can also notice that causal links between WIG20- and ATX20-related variables become significant with a stronger impact (occurring in more causal links) of the Warsaw Stock Exchange on the Vienna Stock Exchange. For example, on days without announcements, the models with lag lengths equal to 20 minutes

¹⁴ The significance refers to the outcomes obtained for at least one of the four lags considered.

¹⁵ This was confirmed in the case of causal links running from DAX volume to WIG volume, DAX volume to ATX volume, ATX returns to ATX volatility, ATX volume to WIG volatility, WIG volume to ATX volatility, WIG volume to WIG volatility, and WIG returns to WIG volatility.

allow the claim that there is one causal relation from WSE variables to VSE and one running in the opposite direction, while on days with announcements, the number of causal links running from the WSE is twice as large (but there are no causal links from the VSE to WSE).

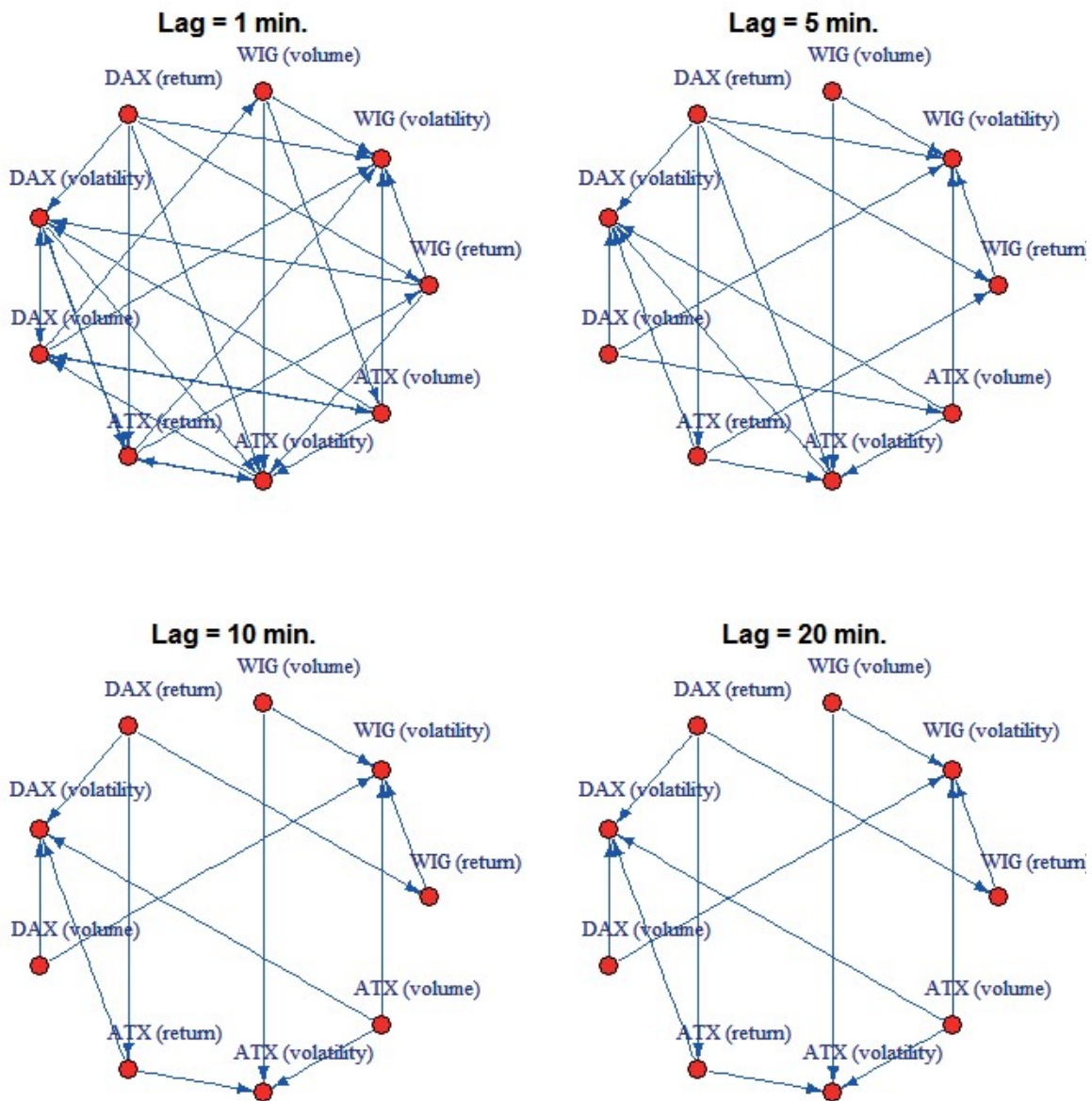


Figure 3. The results of linear Granger causality tests (afternoon session, days without news announcements)

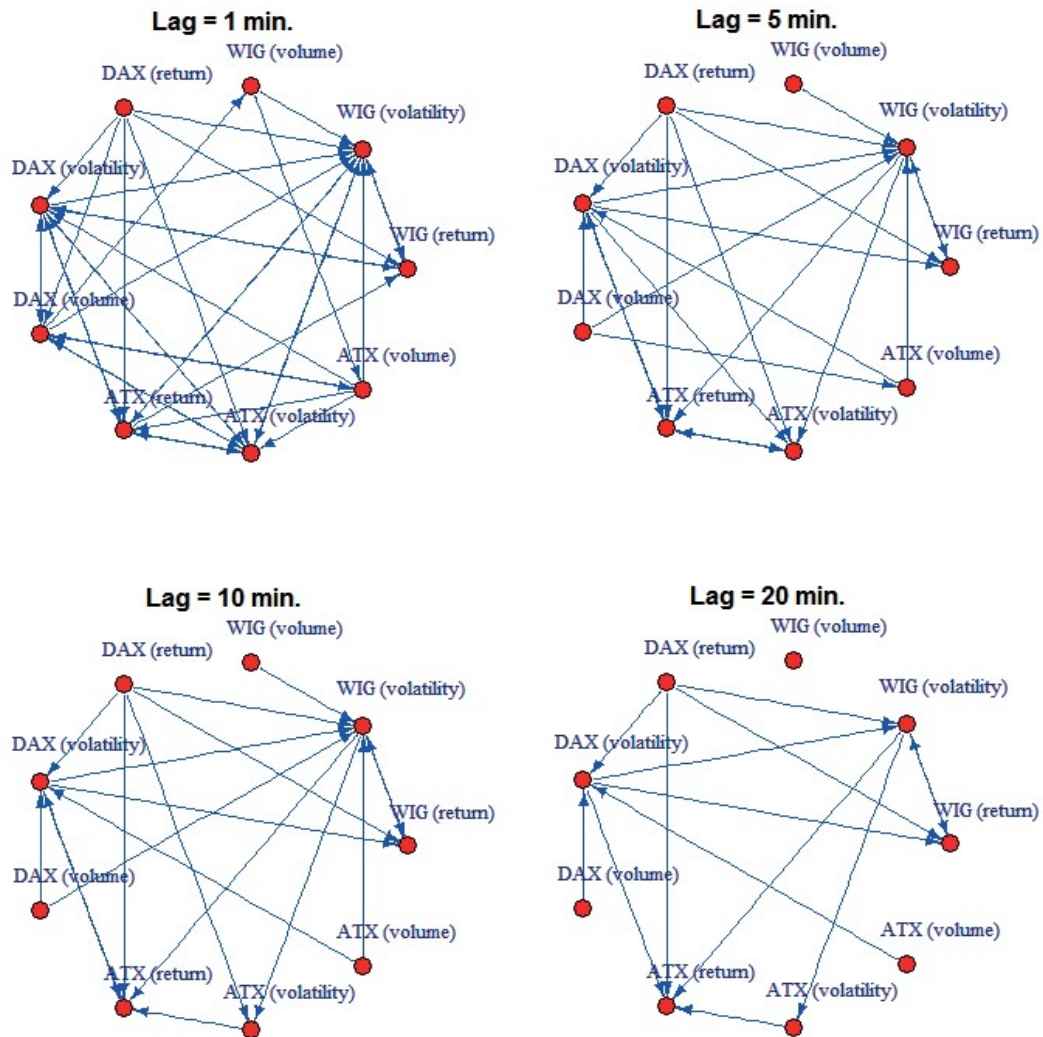


Figure 4. The results of linear Granger causality tests (afternoon session, days with news announcements)

To summarize, one may claim that, as compared to the morning period, there are many more new significant linear causal links that occur during the afternoon period with U.S. macroeconomic news announcements¹⁶. These additional links are presented in Figure 5 (left panel). Moreover, a comparison of Figures 3–4 (afternoon session) with Figures 1–2 (morning session) supports the claim that, on days with news announcements, the duration of linear causal interference during the afternoon session decreases in many more cases than during the morning session (Fig. 5, right panel).

¹⁶ In general, the number of significant causal links during the afternoon period is much higher than during the morning period.

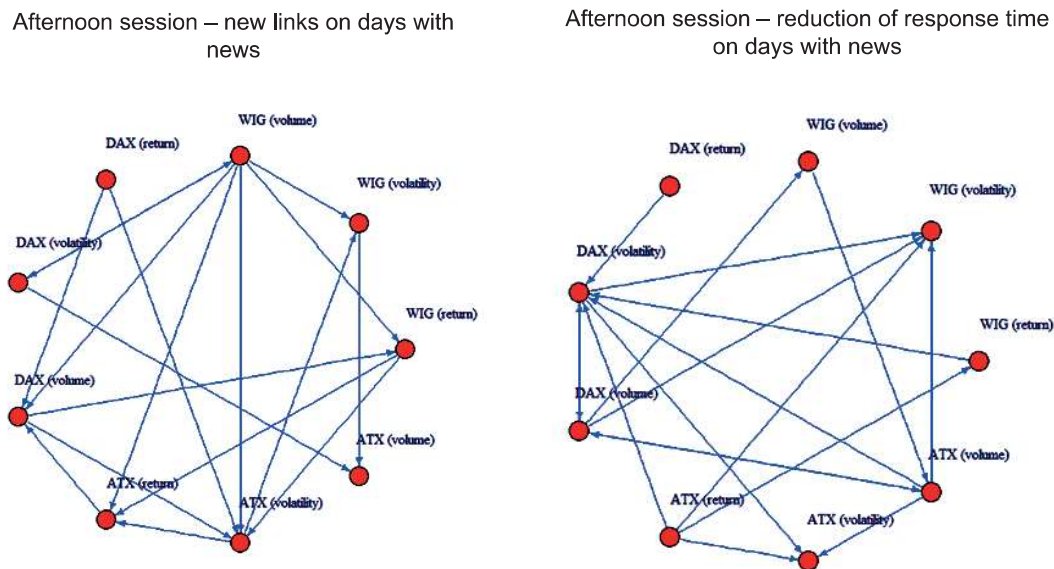


Figure 5. Afternoon session: linear causal links significant only on days with news announcements (left plot) and causal links with decreasing duration on days with news announcements (right plot)

The results for the afternoon session confirm the dominant role of the Frankfurt Stock Exchange. On days with the arrival of new information, both returns and return volatility on smaller markets are strongly influenced by the corresponding variables on the FSE.

4.1.3. Robustness analysis

In order to test the stability of the linear causalities established in the previous subsection, we conducted a number of additional computations. Taking into account the dominant role of the German stock exchange, we first re-estimated all of the VAR models describing FSE-related variables, adding lagged DAX30 returns, volatility, and turnover. The results proved that most of the cross-country causal links presented in Figures 2–4 running to DAX30-related indicators become insignificant on both types of days examined. In the next step of the stability analysis, we re-estimated all of the VAR models for the two subsamples covering the periods of May 2013 – June 2013 and July 2013 – August 2013, respectively. We once again focused on the benchmark case (non-augmented VAR models) and augmented models (with DAX30-related variables). In general, the results confirmed the previous findings; i.e., a lack of solid evidence supporting the impact of the VSE and WSE on the German stock market on both days with and without U.S. macroeconomic news announcements.

4.2. Nonlinear causality analysis

In addition to the analysis of linear causal links, we also conducted an analysis of nonlinear causal links using the procedure of Diks and Panchenko (2006). Figures 6–9 contain the results of the nonlinear test¹⁷. In order to test for nonlinear Granger causality, we conducted our calculations on the basis of residual time series resulting from the respective VAR models. Residual time series reflect strict nonlinear dependencies, since the linear causality has been filtered out by VAR estimation. We set up the common lag parameter (denoted as l_{DP}) at levels of 1 and 5¹⁸ while the bandwidth (denoted as b_{DP}) was set at levels of 0.5, 1, and 1.5¹⁹. The nonlinear causality is said to be significant if it is found statistically significant for at least one combination of parameters b_{DP} and l_{DP} . The detailed description of the role of these technical parameters and formula for the test statistic may be found in Diks and Panchenko (2006)²⁰.

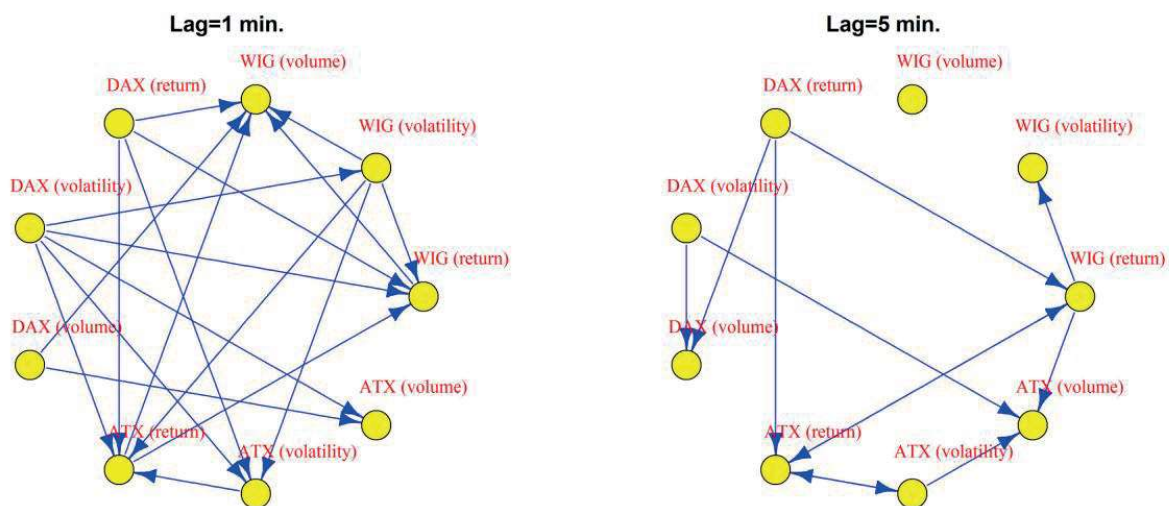


Figure 6. The results of nonlinear Granger causality tests (morning session, days without news announcements)

¹⁷ As in the previous case, we use graphs to visualize the structure of statistically significant causal links. Each arrow represents a significant nonlinear causal link established at a 1% significance level.

¹⁸ Since we did not report any significant nonlinear causal links for common lags higher than 5, we restrict the presentation of results of nonlinear causality for $l_{DP} = 1$ or $l_{DP} = 5$.

¹⁹ These values of b_{DP} have been commonly used in previous papers (see: e.g., Diks and Panchenko, 2006; Gurgul and Lach, 2010).

²⁰ In practical applications of the discussed nonlinear test, heteroscedasticity is also a problem, which may lead to over-rejection (Diks and Panchenko, 2006). Therefore, before conducting nonlinear tests, we additionally tested all examined time series for the presence of various heteroscedastic structures (using, among others, White's test and a Breusch–Pagan test).

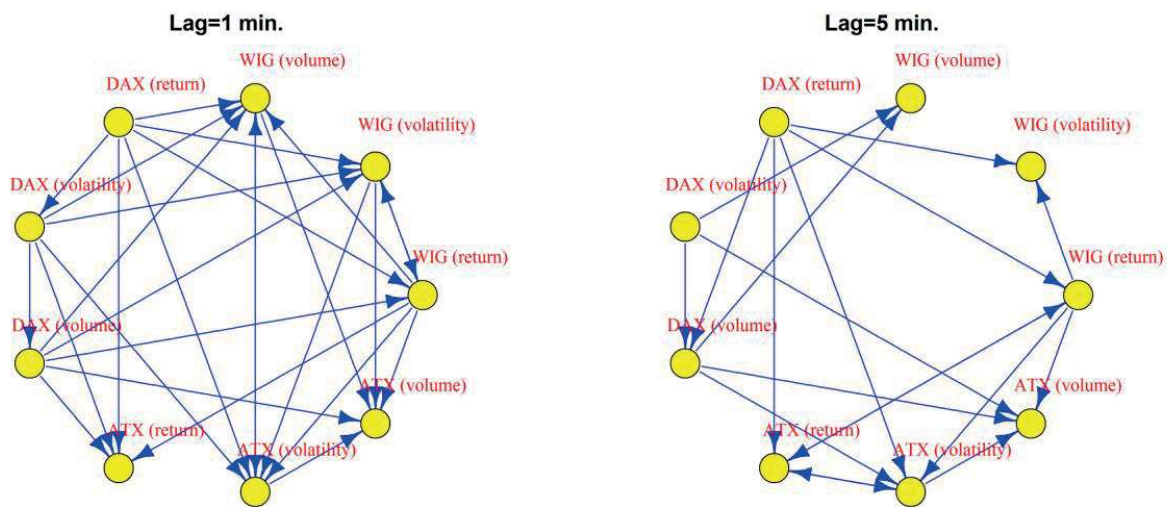


Figure 7. The results of nonlinear Granger causality tests (morning session, days with news announcements)

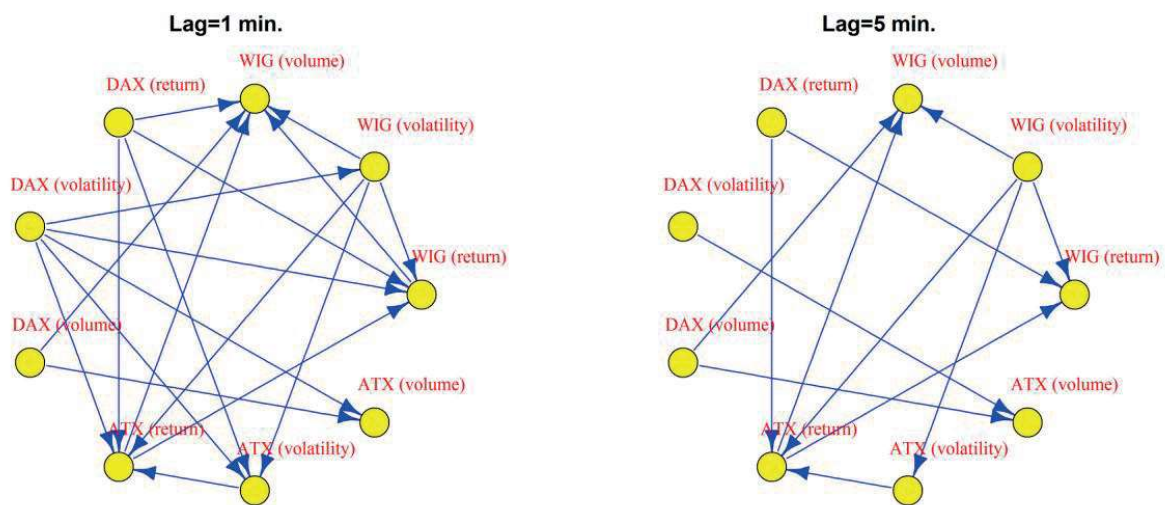


Figure 8. The results of nonlinear Granger causality tests (afternoon session, days without news announcements)

Similar to the results of analysis of linear causal links, one may claim that, as compared to the morning period, there are many more new significant nonlinear causal links that occur during the afternoon period on days with U.S. macroeconomic news announcements. Moreover, on days with news announcements, the duration of causal interference during the afternoon session seems to decrease in more cases than during the morning session.

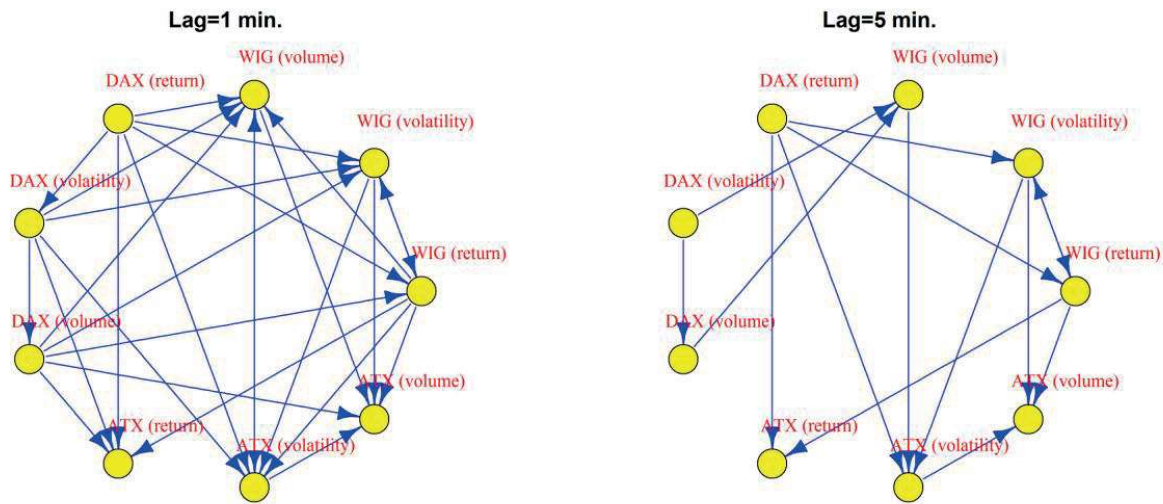


Figure 9. The results of nonlinear Granger causality tests (afternoon session, days with news announcements)

The results presented in Figures 6–9 once again confirm the dominant role of the Frankfurt Stock Exchange, especially during the afternoon session on days with US macroeconomic news announcements. These results provide some evidence to claim that, on days with the arrival of new information, smaller markets seem to be strongly influenced by the corresponding variables on the FSE.

5. Final remarks

We use ARMA(1,1)-EGARCH-M(1,1) to model conditional variance and then investigate linear and nonlinear Granger causalities on the three stock exchanges operating in Frankfurt, Vienna, and Warsaw, with Bayesian large sample correction of the critical values in significance tests. Based on the suggestions of Diks and Panchenko (2006), who found that the null hypothesis in the HJ (Hiemstra and Jones, 1994) test for nonlinear causality is generally not equivalent to Granger non-causality, we applied a modified variant of the nonlinear causality test. The modified test outperforms the HJ test, especially in terms of over-rejection and size distortion.

Besides examining linear and nonlinear causalities between returns, volatility, and trading volume on the three markets, we also analyze the changes in the duration of all of the causal interferences established.

The results of our study confirm the dominant role of the Frankfurt Stock Exchange, since the most significant relationship is the linear causality running

from DAX30 returns to the returns of the ATX20 and WIG20 (which is observed irrespective of the time of the day, presence of important public news, and lag of the underlying VAR model). The significant linear causalities from DAX30 returns to the returns of the WIG20 and ATX20 indicate the possibility of using the DAX30 data to improve modeling and forecasts of stock prices on CEE stock markets.

When it comes to the two remaining markets, one should underline that some WIG20-related variables impact ATX20-related ones during periods with U.S. news announcements and that this underlines the non-omittable role of the Warsaw Stock Exchange in the process of shaping cross-country relationships between stock markets in this part of Europe. Finally, we should underline that the results of the stability analysis refuted the possibility that the Vienna Stock Exchange significantly impacts the DAX30 and WIG20 on days with news announcements.

The second important conclusion relates to the role of public news announcements on the structure of causal links on and between the markets under study. The empirical results of this paper confirm the strong impact of announcements of macroeconomic news from the U.S. economy on the structure of the linear and nonlinear causal links between returns, volume, and return volatility on the European stock markets under study. On days with new information, more linear and nonlinear causal links become significant, especially those running from DAX30-related variables to the corresponding variables on the remaining two markets. It should be underlined that U.S. macroeconomic news announcements not only increase the number of significant causalities but also shorten the duration of both linear and nonlinear causal interferences, especially during the afternoon session. Finally, we may claim that the existence of lead-lag relationships between returns, volatility, and turnover observed on the FSE and WSE during periods with important news announcements supports the SIAH.

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