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RISK-RETURN-VOLUME CAUSALITY ON THE CROATIAN STOCK MARKET

Abstract

Purpose: Causality between stock returns, volatility and traded volume for 10 most liquid stocks from Zagreb Stock Exchange (ZSE) is examined in this paper.

Methodology: The paper relies on historical daily data regarding return, standard deviation and turnover for the period from 2015 to 2021. Vector Autoregressive Models (VARs) were estimated for each stock individually. Based on estimated VAR models, Granger-causality tests were performed to estimate causality between trading volume, stock returns and volatility for most liquid stocks from the Croatian stock market.

Results: Results strongly confirm that traded volume Granger causes volatility. Return remained irrelevant in terms of predicting traded volume and volatility of stock returns.

Conclusion: Causality from return to volatility or causality from volatility to return can be confirmed only in shorter periods. Traded volume causes volatility for the majority of stocks regardless of how volatility was calculated. Causality from volatility to return and causality from volatility to volume are valid for half of the sample and need to be further investigated.

Keywords: Stock returns, return volatility, trading volume, Granger causality, Zagreb Stock Exchange

1. Introduction

The literature on financial markets is traditionally focused on stock returns and volatility, while trading activity has attracted only peripheral attention. Trading data are generally available along with stock prices and can be easily obtained for every single stock. It still remains unclear whether trading volume is variable that contains specific information about future stock returns or volatility. Return volume-volatility relationships have been well investigated around the world. Two approaches have been identified; in the first case, causality was analyzed by observing one stock at a time, and in the second case by observing market indices. Similar research has not been conducted for Zagreb Stock Exchange (ZSE) stocks. In this paper, the Granger causality test is applied to examine the direction of return-volume-volatility causalities for ten most liquid stocks from Zagreb Stock Exchange. The following three key research questions are investigated: 1) Do return and volume Granger cause volatility, 2) do

traded volume and volatility Granger cause return, and 3) Do volatility and return cause traded volume for 10 stocks from ZSE.

According to the OECD (2021, p. 34), the Croatian stock market is characterized by low levels of liquidity in the secondary market and it is dominated by trades in a few individual stocks. In 2019, the overall turnover ratio for the three segments of the regulated market was only 1.5%. For the most liquid market, the Prime Market, it was only 3%. In that period, the turnover ratio for peer stock exchanges was significantly higher with 19% for the Warsaw Stock Exchange, 9% for the Prague Stock Exchange and an average of 58% for all stock exchanges in the European Union. Infrequent trading brings uncertainty to investors in terms of whether it will be possible to trade stock at a specific time and at a current market price.

This paper is structured as follows: Section 2 provides a brief review of literature; Section 3 discusses data and methodology. Results are presented in Section 4 and further elaborated in Section 5. The last section, Section 6, contains concluding remarks.

2. Previous research

Return-volume-volatility causality has been the subject of numerous studies. In this paper, previous research is sorted into two groups; the first group comprises papers that observe these relations at market level through observation of market indices, and the second group contains research results where these relations were observed by examining a single stock at a time. These two approaches yield some differences in results.

Many authors reported unidirectional linear causality from returns to volume by observing market indices. Unidirectional linear causality from returns to volume was reported in Tudor (2009) in the case of the Romanian stock market, Iqbal & Riaz (2015) observed the FTSE100 market index, Griffin et al. (2007) analyzed markets in 46 countries, Brüggemann et al. (2014) observed 16 selected European countries, Srinivasan et al. (2010) examined Asia-Pacific stock markets, Pisedtasalasai & Gunasekarage (2007) investigated emerging markets in South-East Asia-Indonesia, Malaysia, Philippines, Singapore and Thailand, and Chen et al. (2001) observed stock indices (the US, Japan, the UK, France, Canada, Italy, Switzerland, the Netherlands and Hong Kong). Dritsaki (2014) found an opposite interaction between return and trading volume in the direction from trading volume towards Athens Stock Exchange return.

When observing a volatility-volume relationship, many studies implied unidirectional causality from volume to volatility at the market level, e.g. Dritsaki (2014) for the Athens Stock Exchange, Tudor (2009) for the Romanian stock market, Le & Mehmgursed (2009) in Nordic countries - Sweden, Denmark, Norway, and Finland, Gursoy et al. (2008) in 12 emerging markets, and Pisedtasalasai & Gunasekarage (2007) observed emerging markets in South-East Asia-Indonesia, Malaysia, Philippines, Singapore and Thailand.

Yonis (2014) found a bi-causal relationship between volatility and volume for tiger economics except for the case of South Korea, explaining that volatility contains information to predict volume and vice versa. Similarly, Lu & Lin (2010) found a general bidirectional causal relationship between volatility and trading volume on the Taiwan stock market, and De Medeiros & Doornik (2006) for a theoretical portfolio composed of 57 stocks belonging to the Brazilian stock exchange index (Bovespa). Mubarik & Javid (2009) observed the Pakistani market and reported that Granger causality test results suggest that there is a feedback relationship between market return and volume. Hiemstra and Jones (1994) found evidence of significant bidirectional nonlinear causality between returns and volume for the Dow Jones Price Index.

Iqbal & Riaz (2015) and Gursoy et al. (2008) investigated a relationship between trading volume and volatility and reported that volume may be a good proxy for a stock-level analysis, but not for a market-level analysis. Iqbal & Riaz's (2015) study suggests that past volume does not cause returns, but there is evidence that past returns cause volume, suggesting that no bidirectional association is found among volume and returns for market and individual stocks. Other authors who observed market indices, Brüggemann (2014), Pisedtasalasai & Gunasekarage (2007) and Yonis (2014), also concluded that no evidence was found for the impact of trading volume on returns. Pisedtasalasai & Gunasekarage (2007) observed emerging markets in South-East Asia-Indonesia, Malaysia, Philippines, Singapore and Thailand, and found evidence of asymmetry in the relationship between stock returns and trading volume, i.e. returns are important in predicting their future dynamics as well as those

of trading volume, but trading volume has a very limited impact on the future dynamics of stock returns.

Research that examined volume-volatility-return relationships by observing a single stock at a time confirmed unidirectional causality from return to volume. Evidence that return causes volume was found in Gündüz and Hatemi-J (2005) in the case of Russia and Turkey, Miloudi et al. (2016) for the French stock market, Mubarik & Javid (2009) in the case of individual Pakistani market stocks, Kumar & Thenmozhi (2012) for developed and emerging markets, Gurgul et al. (2005) for Polish companies listed in the Wig20, and Ligocká (2019) for 67 companies listed on the Warsaw Stock Exchange.

Many research studies confirmed unidirectional causality from volume to volatility when one stock at a time was observed. Unidirectional causality from volume to volatility for stocks was confirmed in Ananzeh et al. (2013), who investigated 7 individual stocks from the Amman Stock Exchange (ASE), Baklaci & Kasman (2006), who observed the Turkish stock market, and Kiymaz & Girard (2009), who examined 30 stocks included in the Istanbul Stock Exchange. Unidirectional causality from volume to volatility was well documented in the case when market indices were observed.

Some researchers who observed a single stock at a time found a causal relationship from volatility to volume. Unidirectional causality from volatility to volume was found in Mestel et al. (2003) for 31 companies listed on the Austrian stock market, Baklaci & Kasman (2006) for stocks from the Turkish stock market, and Kumar & Thenmozhi (2012) for emerging markets.

Gündüz and Hatemi-J (2005) found a bidirectional causality relationship between stock prices and volume for Hungary. In the case of Poland, they found bidirectional causality between stock prices and volume and unidirectional causality running from market turnover to stock prices.

Kumar & Thenmozhi (2012) showed that trading volume does not Granger cause returns and volatility. On the contrary, some other studies determined the importance of trading volume as an information variable; Zada (2021) observed all companies listed on the Saudi Stock Market, Zolotoy & Melenberg (2007) examined a large sample of cross-listed firms, Mubarik & Javid (2009) observed the Pakistani market, Choi et al. (2013) analyzed the Asian stock markets, and Bohl and Henke (2003) observed 20 Polish stocks.

3. Data and methodology

A data set in this paper consists of 10 stocks from Zagreb Stock Exchange (ZSE). The observed stocks are constituents of the CROBEX10 index. These stocks are top 10 CROBEX index constituents by free float market capitalization and turnover. All stocks had more than 200 daily observations in a year, only one stock (KOEI) had 190 daily observations in 2018 and 2019. This general information is essential for such small market, where infrequent trading is an obstacle to conducting representative research. Daily prices and traded volumes were obtained from the ZSE database for the period from January 2015 to the end of December 2021. Three variables were calculated daily and individually for each stock, i.e. stock return, natural logarithm of turnover and standard deviation. These variables were calculated for the period from the beginning of January 2015 to the end of December 2021. In the further analysis causality between stock return, volatility and traded volume was estimated for one stock at a time.

At the beginning of the analysis, all series were tested for stationarity using the augmented Dickey-Fuller test. Testing for unit roots is essential since vector autoregressive models require all variables to be stationary. All series confirmed to be stationary except in five cases where series of standard deviations were calculated from the past 90 returns. These exceptions are reported in tables 2-11 and these variables were not taken further into the estimation of vector autoregressive models (VARs) and Granger causality testing. VAR models were specified using strictly stationary variables in level form (Gujarati & Sangeetha, 2007, p. 853). A VAR model is used to model a relationship among the observed variables. In the VAR model, all variables are endogenous, which practically means that every variable can be explained by lagged values of itself and other observed variables. In this study, three equations were estimated. Return can be explained by lagged values of return and lagged values of log turnover and lagged values of standard deviation. Turnover can be explained by its own lagged past values, lagged values of return and lagged values of standard deviation. Standard deviation was regressed to its own lagged past values and lagged val-

ues of log turnover and return. Estimations in VAR models are performed by using the OLS method. The Schwarz criterion was applied to choose an appropriate autoregressive lag length l.

The following VAR models were observed:

$$R_t = \alpha_1 + \sum_{i=1}^{l} \beta_{1i} R_{t-i} + \sum_{i=1}^{l} \gamma_{1i} TURN_{t-i} + \sum_{i=1}^{l} \delta_{1i} STDEV_{t-i} + \varepsilon_{1t}, \quad (1)$$

$$TURN_t = \alpha_2 + \sum_{i=1}^{l} \beta_{2i} TURN_{t-i} + \sum_{i=1}^{l} \gamma_{2i} R_{t-i} + \sum_{i=1}^{l} \delta_{2i} STDEV_{t-i} + \varepsilon_{2t}, \quad (2)$$

$$STDEV_t = \alpha_3 + \sum_{i=1}^{l} \beta_{3i} STDEV_{t-i} + \sum_{i=1}^{l} \gamma_{3i} R_{t-i} + \sum_{i=1}^{l} \delta_{3i} TURN_{t-i} + \varepsilon_{3t}, \quad (3)$$

where R is stock return calculated as the natural logarithm of the daily change in stock prices $\ln\left(P_{it}/P_{i,t-1}\right)$, TURN denotes trading volume calculated as the natural logarithm of turnover series, ε_t are error terms, and l denotes the autoregressive lag length.

Standard deviation of stock returns (STDEV) is calculated using the following expression:

$$STDEV_i = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}(R_i - \overline{R}_i)^2}, \quad (4)$$

where R_{it} is stock return of stock i in period t, $t \in [1,..,T]$, and $\overline{R}_i$ is the expected stock return of stock i.

Standard deviation was calculated from past returns. Since there is no unique procedure for calculating standard deviation as a measure of volatility from past returns, standard deviation for each day was calculated using the exact number of past returns (T). STDEV5, STDEV15, STDEV30, and STDEV90 were calculated using five past returns (T=5), fifteen past returns (T=15), thirty returns (T=30), and ninety returns (T=90), respectively. Each VAR model has four variations depending on which a measure of volatility was applied, i.e., Model 1 (STDEV5), Model 2 (STDEV15), Model 3 (STDEV30), and Model 4 (STDEV90). This approach can also be understood as an additional validity check of the obtained results.

The lag length was estimated for each model individually using the Schwarz criterion. The obtained VAR models were submitted to root test an LM autocorrelation test.

An important feature of VAR models is that they allow us to test the direction of causality. Once the VAR models have been estimated, causality can be tested using the Granger causality test. Causality is referred to as the ability of one variable to predict and therefore cause the other (Asteriou & Hall, 2007, p. 281). Causality testing can have the following four possible outcomes: 1) x causes y, 2) y causes x, 3) bidirectional causality, i.e., x causes y and y causes x, and 4) independence. In this paper, we investigate causality between three variables: return, volume and volatility.

4. Results

This paper contributes to the field of research on the return-volatility-volume relationships on small stock markets. The direction of causalities between return, traded volume and volatility for stocks from Zagreb Stock Exchange is examined in this paper. Related research on this topic does not give a unique answer about the direction of these causalities in the case of different markets and in the case of adopting a different approach, i.e., a market level analysis or a stock level analysis. VAR models are estimated and causality is tested for one stock at a time, as suggested in Iqbal & Riaz (2015) and Gursoy et al. (2008). Standard deviation was applied as a measure of volatility since it is widely adopted by both scientists and small investors. Expected values of four different standard deviations, stock returns and natural logarithms of turnover are given in Table 1. Among standard deviations presented, standard deviation calculated for the entire 7-year period has the highest value. All standard deviations calculated for shorter periods have a smaller value. STDEV90 has the highest value and it is closest to the standard deviation calculated for the whole sample. This conclusion holds for all ten stocks. The most traded stocks according to the natural log of turnover are: PODR, HT and RIVP, with the last two exhibiting a normal distribution of traded volumes.

Table 1 Descriptive statistics of standard deviations, returns and volumes

Ticker / Stock		STDEV5	STDEV15	STDEV30	STDEV90	R	TURN
ADPL AD Plastik	Mean	0.0128	0.0135	0.0140	0.0146	0.0003	11.48
	Std. Dev.	0.0095	0.0082	0.0077	0.0063	0.0159	1.49
ADRS2 Adris Grupa	Mean	0.0091	0.0098	0.0102	0.0109	0.0001	12.75
	Std. Dev.	0.0068	0.0059	0.0055	0.0044	0.0116	1.47
ARNT Arena Hospitality Group	Mean	0.0122	0.0133	0.0138	0.0148	0.0000	11.21
	Std. Dev.	0.0104	0.0091	0.0086	0.0073	0.0163	1.69
ATGR Atlantic Grupa	Mean	0.0107	0.0112	0.0114	0.0118	0.0004	11.31
	Std. Dev.	0.0076	0.0062	0.0055	0.0045	0.0126	1.86
ATPL Atlantska Plovidba	Mean	0.0263	0.0285	0.0293	0.0300	0.0001	11.61
	Std. Dev.	0.0168	0.0131	0.0110	0.0076	0.0316	1.61
ERNT Ericsson Nikola Tesla	Mean	0.0106	0.0115	0.0120	0.0124	0.0002	11.83
	Std. Dev.	0.0081	0.0064	0.0054	0.0042	0.0131	1.31
HT HT	Mean	0.0067	0.0074	0.0077	0.0081	0.0001	13.48*
	Std. Dev.	0.0052	0.0043	0.0037	0.0027	0.0085	0.95
KOEI Koncar	Mean	0.0140	0.0146	0.0149	0.0152	0.0002	11.03
	Std. Dev.	0.0084	0.0061	0.0053	0.0041	0.0158	1.79
PODR Podravka	Mean	0.0101	0.0109	0.0113	0.0121	0.0005	13.22
	Std. Dev.	0.0089	0.0076	0.0069	0.0054	0.0132	1.65
RIVP Valamar Riviera	Mean	0.0111	0.0120	0.0125	0.0131	0.0003	13.34*
	Std. Dev.	0.0094	0.0084	0.0081	0.0071	0.0150	1.01

* HT-TURN passes the Jarque- Bera normality test 0.099487 (prob. 0.951473)
**RIVP-TURN passes the Jarque-Bera normality test 1.47 (prob. 0.48058).

Source: Author´s calculations

Research data is composed of series of standard deviations, stock returns and natural logs of turnover for every single stock. The ADF test was applied to test the stationarity of series. All series were stationary except STDEV90 series for stocks ERNT, ATPL, KOEI, ADRS2 and HT. These series were not taken into further estimation of VAR models and Granger causality testing. In this paper, a strict rule was applied that all series must be stationary, and preferably all series must be taken into analysis at level form. In further analysis, VAR models were estimated according to equations 1, 2 and 3 for each stock individually. The lag length was selected according to the Schwarz criterion. The Granger causality test was performed based on the estimated VAR models to determine the direction of return-volatility-volume causalities. The results of the obtained test statistics are presented in tables 2-11, each table summarizes results for one stock at a time. The causality test results are presented in four columns, each column reports results for one of the four different standard deviations applied in the model along with the optimal lag length.

Table 2 Granger causality test results for the AD Plastik stock

ADPL	Model 1		Model 2		Model 3		Model 4	
Number of lags	Chi-sq	6	Chi-sq	2	Chi-sq	2	Chi-sq	4
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.	STDEV90	Prob.
R→STDEV	32.35	0.0000	15.59	0.0007	1.65	0.4388	5.37	0.3727
TURN→STDEV	17.55	0.0075	10.21	0.0061	7.34	0.0255	14.65	0.0120
STDEV→R	36.98	0.0000	0.87	0.6470	4.39	0.1115	43.40	0.0000
TURN→R	5.83	0.4423	4.44	0.1085	4.35	0.1136	4.74	0.4486
STDEV→TURN	6.15	0.4071	2.46	0.2918	3.47	0.1761	6.96	0.2233
R→TURN	2.06	0.9138	0.43	0.8080	0.60	0.7392	2.05	0.8424

*All series are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -7.74 (0.0000), STDEV15 -5.56 (0.0000), STDEV30 -4.96 (0.0000), STDEV90 -3.26 (0.0170), R -15.00 (0.0000), TURN -11.01 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

According to results given in Table 2, there is one bilateral causal relation between volatility and return when standard deviation is calculated from past five returns. This bilateral causality is not confirmed in models 2, 3 and 4. Unidirectional causality from return to volatility appears in Model 2. Unidirectional causality from volatility to return appears in Model 4. The only proven causal relation in all four models is causality from traded volume to volatility. The results show that all lagged coefficients of volume are statistically significant, indicating a unidirectional casual relation from traded volume to volatility (STDEV5, STDEV15, STDEV30, and STDEV90).

Table 3 Granger causality test results for the Adris Grupa stock

ADRS2	Model 1		Model 2		Model 3	
Number of lags	Chi-sq	6	Chi-sq	1	Chi-sq	1
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.
R→STDEV	24.08	0.0005	2.34	0.1264	2.15	0.1422
TURN→STDEV	22.86	0.0008	6.53	0.0106	12.88	0.0003
STDEV→R	25.65	0.0030	0.65	0.4194	0.02	0.8566
TURN→R	5.11	0.5293	0.04	0.8347	0.13	0.7184
STDEV→TURN	7.04	0.3173	20.19	0.0000	12.63	0.0004
R→TURN	4.13	0.6597	0.00	0.9846	0.02	0.8813

*All series except STDEV90 are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -8.55 (0.0000), STDEV15 -5.18 (0.0000), STDEV30 -4.37 (0.0003), STDEV90 -2.78 (0.06), R -21.00 (0.0000), TURN -10.93 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

In Table 3, a causal relation from traded volume to volatility is the only causal relation proven in all three models. The results show that all lagged coefficients of volume are statistically significant and indicate unidirectional causality from volume to volatility (STDEV5, STDEV15, and STDEV30). Bilateral causality between volatility and volume is confirmed in Model 2 and Model 3, where standard deviation was calculated from past fifteen and thirty returns. This bilateral causality is not confirmed in Model 1. Bilateral causality between volatility and return was confirmed in Model 1, where standard deviation is calculated from past five returns.

Table 4 Granger causality test results for the Arena Hospitality Group stock

ARNT	Model 1		Model 2		Model 3		Model 4	
Number of lags	Chi-sq	6	Chi-sq	4	Chi-sq	4	Chi-sq	4
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.	STDEV90	Prob.
R→STDEV	82.84	0.0000	66.43	0.0000	27.29	0.0000	18.28	0.0011
TURN→STDEV	16.90	0.0096	3.73	0.4440	3.40	0.4927	12.53	0.0138
STDEV→R	51.9	0.0000	22.83	0.0001	26.01	0.0000	42.51	0.0000
TURN→R	3.42	0.7550	3.41	0.4919	3.64	0.4574	3.24	0.5189
STDEV→TURN	12.86	0.0449	13.69	0.0083	18.83	0.0008	16.76	0.0022
R→TURN	2.44	0.8752	0.71	0.9496	0.82	0.9356	1.17	0.8837

*All series are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -7.98 (0.0000), STDEV15 -5.02 (0.0000), STDEV30 -4.73 (0.0001), STDEV90 -2.99 (0.0357), R -16.59 (0.0000), TURN -14.12 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

According to results given in Table 4, bilateral causality between return and volatility can be confirmed. All observed coefficients are statistically significant as a group in all four models. Return causes standard deviation and standard deviation causes return, no matter how volatility was measured. Bilateral causality between volatility and volume was confirmed for the ARNT stock in models 1 and 4. Volatility causes volume and volume causes volatility when standard deviation from 5 and 90 returns was calculated. Unidirectional causality from volatility to volume was confirmed in models 2 and 3. When observing return and volume, all observed coefficients in both directions in all four models are not statistically significant, indicating independence between return and volume.

Table 5 Granger causality test results for the Atlantic Grupa stock

ATGR	Model 1		Model 2		Model 3		Model 4	
Number of lags	Chi-sq	2	Chi-sq	2	Chi-sq	2	Chi-sq	4
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.	STDEV90	Prob.
R→STDEV	1.36	0.5056	0.72	0.6976	2.29	0.3185	0.35	0.8391
TURN→STDEV	17.61	0.0002	10.32	0.0058	8.21	0.0164	10.78	0.0046
STDEV→R	1.81	0.4052	5.94	0.0513	3.38	0.1847	2.49	0.2880
TURN→R	8.52	0.0142	8.59	0.0137	8.62	0.0135	8.36	0.0153
STDEV→TURN	2.06	0.3576	4.54	0.1035	7.23	0.0269	7.35	0.0253
R→TURN	4.93	0.0850	4.89	0.0867	4.84	0.0889	4.55	0.1026

*All series are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -6.57 (0.0000), STDEV15 -5.02 (0.0000), STDEV30 -4.74 (0.0001), STDEV90 -2.99 (0.0357), R -16.59 (0.0000), TURN -14.12 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

According to results given in Table 5, volume is relevant for the ATGR stock. Volume causes volatility (STDEV5, STDEV15, STDEV30, and STDEV90) and volume causes return in all four models. Return-volume causality is bidirectional in models 3 and 4.

Table 6 Granger causality test results for the Atlantska Plovidba stock

ATPL	Model 1		Model 2		Model 3	
Number of lags	Chi-sq	6	Chi-sq	3	Chi-sq	3
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.
R→STDEV	13.28	0.0388	0.77	0.8561	8.49	0.0369
TURN→STDEV	44.79	0.0000	10.50	0.0148	12.84	0.0050
STDEV→R	11.42	0.0762	0.73	0.8655	4.33	0.2277
TURN→R	33.33	0.0000	22.36	0.0001	20.57	0.0001
STDEV→TURN	1.50	0.6095	2.07	0.5574	3.02	0.3889
R→TURN	10.96	0.0897	8.16	0.0428	8.76	0.0326

*All series except STDEV90 are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -10.30 (0.0000), STDEV15 -5.64 (0.0000), STDEV30 -4.78 (0.0001), STDEV90 -2.81 (0.0568), R -39.68 (0.0000), TURN -5.32 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

Results presented in Table 6 are very similar to those for the ATGR stock. Volume is significant in all three models. Volume causes volatility (STDEV5, STDEV15, and STDEV30) and volume causes return in all three models. Return causes volatility in Model 1 and Model 3, where standard deviation was calculated from past five and thirty returns. Bilateral causality exists between return and volume in models 2 and 3. Causality from volatility to volume is not significant in all three models, and all observed coefficients are not statistically significant, indicating that volatility (STDEV5, STDEV15, and STDEV30) does not cause volume.

Table 7 Granger causality test results for the Ericsson Nikola Tesla stock

ERNT	Model 1		Model 2		Model 3	
Number of lags	Chi-sq	6	Chi-sq	2	Chi-sq	2
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.
R→STDEV	19.66	0.0032	2.33	0.3119	5.28	0.0713
TURN→STDEV	29.36	0.0001	16.80	0.0002	10.68	0.0048
STDEV→R	9.69	0.1384	1.56	0.4578	2.71	0.2575
TURN→R	4.74	0.5776	1.27	0.5311	1.18	0.5543
STDEV→TURN	10.60	0.1017	3.25	0.1966	2.49	0.2877
R→TURN	6.92	0.3285	1.79	0.4085	1.75	0.4169

*All series except STDEV90 are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -9.20 (0.0000), STDEV15 -5.33 (0.0000), STDEV30 -4.33 (0.0004), STDEV90 -2.08 (0.2539), R -46.77 (0.0001), TURN -16.16 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

According to results given in Table 7, volume causes volatility in all three models when standard deviation is calculated from past five, fifteen and thirty returns. Causality from volume to volatility is the only significant causality in all three models for the ERNT stock. No other causality is significant, besides causality from return to volatility when volatility is calculated from past five returns (Model 1).

Table 8 Granger causality test results for the HT stock

HT	Model 1		Model 2		Model 3	
Number of lags	Chi-sq	6	Chi-sq	2	Chi-sq	2
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.
R→STDEV	23.60	0.0006	6.07	0.4800	1.30	0.5689
TURN→STDEV	47.62	0.0000	16.12	0.0003	25.73	0.0000
STDEV→R	11.84	0.0656	1.90	0.3859	1.88	0.3912
TURN→R	9.77	0.1675	5.15	0.0762	6.52	0.0385
STDEV→TURN	5.44	0.4885	5.94	0.0512	6.29	0.0430
R→TURN	7.47	0.2796	3.63	0.1632	4.02	0.1342

*All series except STDEV90 are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -8.21 (0.0000), STDEV15 -5.84 (0.0000), STDEV30 -4.93 (0.0001), STDEV90 -2.78 (0.06), RETURN -44.29 (0.0001), LNVOL -6.92 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

Results for the HT stock are very similar to those for the ERNT stock. Volume causes volatility in all three models when standard deviation is calculated from past five, fifteen and thirty returns. Bidirectional causality between volume and volatility is confirmed in Model 3, where standard deviation is calculated based on the past thirty returns. Unidirectional causality from volume to return is significant only in Model 3. Return appeared to be relevant in Model 1. Return causes volatility in Model 1, where volatility is calculated from past five returns.

Table 9 Granger causality test results for the Koncar stock

KOEI	Model 1		Model 2		Model 3	
Number of lags	Chi-sq	1	Chi-sq	1	Chi-sq	2
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.
R→STDEV	0.65	0.4215	2.57	0.1091	5.07	0.0793
TURN→STDEV	2.74	0.0978	1.32	0.2503	1.43	0.4884
STDEV→R	7.25	0.0071	1.39	0.2382	2.19	0.3353
TURN→R	9.06	0.0026	8.76	0.0031	10.14	0.0063
STDEV→TURN	0.18	0.6713	1.31	0.2520	3.17	0.2050
R→TURN	0.29	0.5875	0.30	0.5842	0.95	0.6234

*All series except STDEV90 are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -8.63 (0.0000), STDEV15 -4.28 (0.0005), STDEV30 -4.17 (0.0008), STDEV90 -2.12 (0.2382), R -45.11 (0.0001), TURN -17.55 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

According to results given in Table 9, volume causes return in all three models, where three different standard deviations were applied. All lagged coefficients of volume in all three models are statistically different from zero. Volatility Granger causes return in Model 1. A causal relation from volume to volatility was not confirmed for the KOEI stock.

Table 10 Granger causality test results for the Podravka stock

PODR	Model 1		Model 2		Model 3		Model 4	
Number of lags	Chi-sq	6	Chi-sq	2	Chi-sq	2	Chi-sq	2
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.	STDEV90	Prob.
R→STDEV	60.30	0.0000	30.72	0.0000	22.00	0.0000	19.62	0.0001
TURN→STDEV	26.38	0.0002	15.82	0.0004	15.24	0.0005	3.5	0.1739
STDEV→R	31.43	0.0000	0.42	0.8102	2.41	0.2995	4.83	0.0894
TURN→R	5.06	0.5360	2.15	0.3413	1.50	0.4729	1.7	0.4268
STDEV→TURN	9.22	0.1616	6.76	0.0340	3.30	0.1920	3.58	0.1667
R→TURN	1.66	0.2641	0.26	0.8781	0.28	0.8711	0.27	0.8747

*All series are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -9.07 (0.0000), STDEV15 -5.64 (0.0000), STDEV30 -5.59 (0.0000), STDEV90 -3.30 (0.0152), R -47.38 (0.0001), TURN -9.82 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

Results for the PODR stock indicate that both return and traded volume cause volatility. Causality from return to volume is statistically significant in all four models, while causality from volume to volatility is significant in models 1, 2 and 3. Bidirectional causality between volatility and return is reported in Model 1, where volatility is calculated from past five returns. Bidirectional causality between volatility and volume is confirmed in Model 2, where volatility is calculated based on the past fifteen returns.

Table 11 Granger causality test results for the Valamar Riviera stock

RIVP	Model 1		Model 2		Model 3		Model 4	
Number of lags	Chi-sq	6	Chi-sq	1	Chi-sq	5	Chi-sq	5
Causality relation	STDEV5	Prob.	STDEV15	Prob.	STDEV30	Prob.	STDEV90	Prob.
R→STDEV	67.01	0.0000	19.89	0.0000	4.65	0.4654	2.72	0.7432
TURN→STDEV	80.55	0.0000	28.19	0.0000	18.90	0.0020	12.58	0.0277
STDEV→R	30.54	0.0000	0.23	0.6255	59.7	0.0000	89.56	0.0000
TURN→R	9.15	0.1652	0.00	0.9652	12.88	0.0245	11.56	0.0413
STDEV→TURN	12.82	0.0461	35.65	0.0000	20.21	0.0011	15.6	0.0081
R→TURN	6.16	0.4055	0.15	0.6995	5.02	0.4136	5.87	0.3090

*All series are stationary at level form. Augmented Dickey-Fuller test statistics with corresponding probabilities; STDEV5 -7.60 (0.0000), STDEV15 -5.03 (0.0000), STDEV30 -5.26 (0.0000), STDEV90 -3.09 (0.0273), R -15.03 (0.0000), TURN -11.73 (0.0000). No root lies outside the unit circle. VAR models satisfy the stability condition.

Source: Author´s calculations

According to results given in Table 11, it can be concluded that return causes volatility only in models 1 and 2. Volatility causes return in models 1, 3 and 4, while volume causes return in models 3 and 4. Volatility causes traded volume and volume causes volatility in all four models. The results confirm bidirectional causality between traded volume and volatility in all four models regardless of how volatility was calculated (STDEV5, STDEV15, STDEV30, and STDEV90).

5. Discussion

Table 12 shows a summary of the results for 10 observed stocks and four models applied. Models 1, 2 and 3 were calculated for all 10 stocks, while Model 4 was calculated only for those stocks where STDEV90 series proved to be stationary at level form, i.e., for 5 stocks altogether.

Table 12 Number of significant causal relations

Causality relation	Model 1	Model 2	Model 3	Model 4
R→STDEV	8	4	3	2
TURN→STDEV	9	8	8	4
STDEV→R	6	1	2	3
TURN→R	3	3	5	2
STDEV→TURN	2	4	5	3
R→TURN	0	1	1	0

Source: Author´s calculations

Assuming that every investor can rely on standard deviation as a measure of volatility, daily standard deviations were calculated from past, 5, 15, 30, and 90 daily returns. This approach additionally supported the results, while the results of all four models are confirmed by each other. This is evident in the case of causality from volume to volatility and causality from return to volume. In all three models and in the last fourth model, it is confirmed that volume causes volatility. Irrespective of the method used to calculate volatility, it is clear that volume causes volatility. Volume causes volatility (9 out of 10 stocks in Model 1) and this result is confirmed further in models 2 and 3 (8 out of 10 stocks) and model 4 (4 out of 5 stocks). These results were well documented when observing one stock at a time (Ananzeh et al., 2013; Baklaci & Kasman, 2006; Kiymaz & Girard, 2009; Dritsaki, 2014; Tudor, 2009; Le & Mehmed, 2009; Gursoy et al., 2008; Pisedtasalasai & Gunasekarage, 2007; and Le & Mehmed, 2009).

The results strongly confirm that return does not cause volume. Return does not cause traded volume (0 significant results in Model 1) and this conclusion is confirmed further in models 2 and 3 (1 significant result out of 10 stocks) and Model 4 (0 significant results out of 5 stocks). This conclusion is in line with Mestel et al. (2003), who observed stocks from the Austrian stock exchange.

The results indicate that return causes volatility (8 stocks) and volatility causes returns (6 stocks) only in Model 1, where standard deviation is calculated from previous 5 returns. The return-volatility relationship is proven to be bidirectional for five stocks when Model 1 was applied (standard deviation was calculated based on the past five returns). Return volatility causality appears less frequently in models 3 and 4. All VAR models for all 10 stocks require 4 lags in order to estimate Model 1. This roughly means that past 4 standard deviations cause return.

Although the obtained results are very clear, they are very difficult to interpret. It has been proven that traded volume causes volatility measured by standard deviation, independently of the length of series of stock returns used for the calculation of standard deviation. The results strongly support the conclusion that return has no impact on turnover. Turnover does not cause return; this causality appears in only few cases. It seems that turnover contains information valuable to investors, and this information is reflected in volatility. Turnover does not Granger cause returns, but it is confirmed that it has a significant impact on the average deviation of stock returns from expected return. A possible explanation is that past turnover data incorporate decisions of investors whether to buy or sell stock in certain quantities and somehow determine how far stock returns will move from expected return. It is possible that past turnover data control expected return rather than daily returns. However, this assumption is beyond the scope of this research and should be further examined. The impact of turnover on volatility is persistent and valid for standard deviations calculated from past 5, 15, 30, and 90 returns.

Return causes volatility and volatility causes return only within a very short period, and this bidirectional causality is confirmed only in Model 1. This causality is expected since standard deviation is calculated in this model from past 5 returns, therefore in this short period return causes volatility and volatility causes volume. Return volatility and volatility return causality becomes insignificant in the remaining models because past returns do not contain all valuable information to predict future volatility. Generally speaking, investors who observe past traded volumes are one step ahead compared to investors who observe only volatility. It remains to be investigated what trading volume incorporates, investor reactions to news, reactions to past trading activity or information from fundamental data. Further research should focus on possible traded volume-expected return causality.

These results open numerous questions as to whether return-volume-volatility relationships depend on the length of the observed time period, whether the selection/ calculation of volatility measure affects results, why standard deviation as a volatility measure fails to cause return and traded volume, and generally, whether volume could be more helpful in predicting future returns/volatility.

6. Conclusions

In this paper, empirical relationships between stock returns, return volatility and trading volume (the natural log of turnover) were examined for 10 stocks from Zagreb Stock Exchange. Research design relies on historical daily data on return, volatility and traded volume for the period from 2015 to 2021. Standard deviations were calculated from past 5, 15, 30, or 90 returns. Vector Autoregressive Models (VARs) were estimated for each stock individually. Based on estimated VAR models, Granger-causality tests were performed to estimate causality between trading volume, stock returns and volatility. The results strongly confirm unidirectional causality from traded volume to volatility regardless of the model applied for the calculation of a volatility measure (standard deviation from past 5, 15, 30, or 90 returns). Causality from volume to volatility was well documented in previous studies. Generally, results give strong evidence that trading volume contains valuable information not available from prices. Morgan (1976) suggested that volume is regarded as a major risk factor contributing to the volatility of returns, especially in less liquid and thin markets, including emerging markets.

The results also give clear and strong evidence that return does not Granger cause volume. Return does not cause traded volume (0 significant results in Model 1) and this finding is confirmed further in models 2 and 3 (1 significant result out of 10 stocks) and Model 4 (0 significant results out of 5 stocks). Returns appear to be significant relative to volatility only if volatility is calculated from past five returns (Model 1). According to Model 1, in 8/10 cases return Granger causes volatility and in 6/10 cases volatility Granger causes return. It can roughly be said that return-volatility causality is valid only when the observed period is no longer than 10 trading days. This is in line with Gurgul et al. (2005), who concluded that trading volume cannot improve short-run return forecasts and vice versa. Causality from volatility to return and causality from volatility to volume are valid only for half of the sample and should be further investigated. Further research should investigate return-volatility-volume relationships in the short and long term. All similar research studies should be cross-checked by applying different volatility measures. Conclusions relating to top 10 stocks should not be extended to the entire market due to the infrequent trading of ZSE stocks. The observed stocks had more than 200 daily observations in a year; however, one stock had only 190 daily observations in 2018 and 2019.

References

1. Ananzeh, I. E. N., Jdaitawi, Q. M. & Al-Jayousi, A. M. (2013). Relationship between market volatility and trading volume: Evidence from Amman stock exchange. *International Journal of Business and Social Science*, *4*(16), 188-198.
2. Asteriou, D. & Hall, S. G. (2007). *Applied Econometrics*. Palgrave Macmillan.
3. Baklaci, H. & Kasman, A. (2006). An empirical analysis of trading volume and return volatility relationship in the Turkish Stock Market. *Ege Academic Review*, *6*(2), 115-125.
4. Bohl, M. T. & Henke, H. (2003). Trading volume and stock market volatility: The Polish case. *International Review of Financial Analysis*, *12*(5), 513-525. https://doi.org/10.1016/S1057-5219(03)00066-8
5. Brüggemann, R., Glaser, M., Schaarschmidt, S. & Stankiewicz, S. (2014). *The Stock Return-Trading Volume Relationship in European Countries: Evidence from Asymmetric Impulse Responses* (Working Paper No. 2014-24). Konstanz: Department of Economics, University of Konstanz.
6. Chen, G. M., Firth, M. & Rui, O. M. (2001). The dynamic relation between stock returns, trading volume, and volatility. *Financial Review*, *36*(3), 153-174. https://doi.org/10.1111/j.1540-6288.2001.tb00024.x
7. Choi, K. H., Kang, S. H. & Yoon, S. M. (2013). Relationship between Stock Returns and Trading Volume: Domestic and Cross-Country. Evidence in Asian Stock Markets. In *Proceedings of the 2013 International Conference on Economics and Business Administration* (pp. 33-39).
8. De Medeiros, O. R. & Doornik, B. F. N. V. (2006). *The empirical relationship between stock returns, return volatility and trading volume in the Brazilian stock market*. Available at SSRN: https://ssrn.com/abstract=897340. https://doi.org/10.2139/ssrn.897340
9. Dritsaki, C. (2014). The Dynamic Relationship between Stock Volatility and Trading Volume from the Athens Stock Exchange. *International Journal of Empirical Finance*, *3*(3), 152-165.
10. Griffin, J. M., Nardari, F. & Stulz, R. M. (2007). Do investors trade more when stocks have performed well? Evidence from 46 countries. *The Review of Financial Studies*, *20*(3), 905-951. https://doi.org/10.1093/rfs/hhl019
11. Gujarati, D. N. & Sangeetha, N. (2007). *Basic Econometrics* (4th ed). McGraw-Hill.
12. Gündüz, L. & Hatemi-J, A. (2005). Stock price and volume relation in emerging markets. *Emerging Markets Finance and Trade*, *41*(1), 29-44. https://doi.org/10.1080/1540496X.2005.11052599
13. Gurgul, H., Majdosz, P. & Mestel, R. (2005). Joint dynamics of prices and trading volume on the Polish stock market. *Managing Global Transitions*, *3*(2), 139-156.
14. Gursoy, G., Yuksel, A. & Yuksel, A. (2008). Trading volume and stock market volatility: evidence from emerging stock markets. *Investment Management and Financial Innovations*, *5*(4), 200-210.
15. Hiemstra, C. & Jones, J. D. (1994). Testing for linear and nonlinear Granger causality in the stock price-volume relation. *The Journal of Finance*, *49*(5), 1639-1664. https://doi.org/10.1111/j.1540-6261.1994.tb04776.x
16. Iqbal, H. & Riaz, T. (2015). The empirical relationship between stocks returns, trading volume and volatility: evidence from stock market of United Kingdom. *Research Journal of Finance and Accounting*, *6*(13), 180-192.
17. Kiymaz, H. & Girard, E. (2009). Stock market volatility and trading volume: an emerging market experience. *IUP Journal of Applied Finance*, *15*(6), 5-32.
18. Kumar, M. & Thenmozhi, M. (2012). Causal effect of volume on stock returns and conditional volatility in developed and emerging market. *American Journal of Finance and Accounting*, *2*(4), 346-362. https://doi.org/10.1504/AJFA.2012.046876
19. Le, Q. T. & Mehmed, M. (2009). *The relationship between trading volume, stock index returns and volatility: Empirical evidence in Nordic countries*. [Master thesis, Lund University]. Lund: Lund University.

20. Ligocká, M. (2019). The empirical relationship between stock returns and trading volume: the case of Polish companies. *Acta academica*, *19*(2), 42-53. https://doi.org/10.25142/aak.2019.019

21. Lu, W. C. & Lin, F. J. (2010). An empirical study of volatility and trading volume dynamics using high-frequency data. *The International Journal of Business and Finance Research*, *4*(3), 93-101.

22. Mestel, R., Gurgul, H. & Majdosz, P. (2003). The empirical relationship between stock returns, return volatility and trading volume on the Austrian stock market. *University of Graz, Institute of Banking and Finance, Research Paper*, *4*(6), 231-244.

23. Miloudi, A., Bouattour, M. & Benkraiem, R. (2016). *Relationships between Trading Volume, Stock Returns and Volatility: Evidence from the French Stock Market*. No. hal-01363700.

24. Morgan, I. G. (1976). Stock prices and heteroscedasticity. *The Journal of Business*, *49*(4), 496-508. https://doi.org/10.1086/295881

25. Mubarik, F. & Javid, A. Y. (2009). Relationship between stock return, trading volume and volatility: Evidence from Pakistani stock market. *Asia Pacific Journal of Finance and Banking Research*, *3*(3).

26. OECD (2021), *OECD Capital Market Review of Croatia: Capital market reforms for recovery and improved business dynamics in Croatia*. *OECD Capital Market Series*. http://www.oecd.org/corporate/OECD-Capital-Market-Review-Croatia.htm

27. Pisedtasalasai, A. & Gunasekarage, A. (2007). Causal and dynamic relationships among stock returns, return volatility and trading volume: Evidence from emerging markets in South-East Asia. *Asia-Pacific Financial Markets*, *14*(4), 277-297. https://doi.org/10.1007/s10690-008-9063-3

28. Srinivasan, K., Devanadhen, K. & Deo, M. (2010). Price changes, trading volume and time-varying conditional volatility: Evidence from Asia Pacific stock market. *International Review of Applied Financial Issues and Economics*, *2*(2), 379.

29. Tudor, C. (2009). *Testing the Impact of Trading Volume on Market Return and Volatility: The Case of the Romanian Stock Market*. Available at SSRN: https://ssrn.com/abstract=1327687

30. Yonis, M. (2014). *Trading Volume and Stock Return: Empirical Evidence for Asian Tiger Economies* [Master thesis, Umeå University]. Umeå: Umeå University.

31. Zada, R. S. E. (2021). The Relationship between Trading Volume, Stock Returns and Volatility in the Saudi Stock Market. *Qalaai Zanist Journal*, *6*(3), 790-822. https://doi.org/10.25212/lfu.qzj.6.3.27

32. Zolotoy, L. & Melenberg, B. (2007). *Trading Volume, Volatility and Return Dynamics: Individual and Cross-Market Analysis*. Available at SSRN: https://ssrn.com/abstract=1032193. https://doi.org/10.2139/ssrn.1032193