Argumenta Oeconomica
Year 2024, Vol. 53, No. 2
ISSN 2720-5088
journals.ue.wroc.pl/aoe

Causal linkages between stock, crude oil and gold returns in Central Europe

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Quote as: Mamcarz, K. (2024). Causal linkages between stock, crude oil and gold returns in Central Europe. *Argumenta Oeconomica*, 2(53), 66-89.

DOI: 10.15611/aoe.2024.2.05

JEL: G11, G15, C32

Abstract: The aim of this paper was to evaluate the relationship between the stocks, crude oil and gold markets of Central Europe in the short and long-term by applying a vector error correction model (VECM), and the Granger-causality analysis followed by a forecast error variance decomposition (FEVD) and impulse response function (IRF) analysis. Since gold seems to demonstrate a low or negative correlation with stocks, while the correlation between crude oil and gold is positive, it is important to investigate the interrelations in the markets in question to understand the nature of the linkages between them and their implications. It is assumed that there exists a long-term equilibrium between the analysed assets and that the changes in the prices in the gold and crude oil markets impact the stock market. The research findings confirm a long-term relationship between the markets as the prices of the analysed assets are cointegrated. In the long-term, the increase in the crude oil price (Brent) caused a raise in the gold price, whereas the impact of the stock price (Central European Blue Chip Index CETOP) was opposite. The author indicated two cases of unidirectional causality, hence the gold returns Granger-cause the stock returns, as expected. However, the latter determined the crude oil returns, which contradicts the research hypothesis. One can observe the negative impact of gold returns on the stock returns, whilst the stock returns have a positive impact on the crude oil returns. To the best of the author's knowledge, no similar research with the use of VECM was devoted to the interrelations between the stock, crude oil and gold markets of Central Europe described in this paper. Most of the research focused on countries classified as the key producers and consumers of gold.

Keywords: capital investments, stock, crude oil, gold, Granger causality

1. Introduction

Stocks, crude oil and gold can be a form of capital investment. Stocks and gold are regarded as alternative forms of capital allocation since gold demonstrates a low or negative correlation with stocks. Low returns, and in particular collapsing stock markets (stock market crashes, bear markets), encourage investors to return to gold, perceived as a relatively safe investment, whereas rising stock prices weaken investors' interest in this precious metal. Crude oil prices affect both stock and gold prices. The rise in oil prices increases the cost of production in the economy and should result in a fall in stock prices, whereas the correlation between crude oil and gold is positive as shown by, among others, Singh (2014), Beckmann, Berger & Czudaj (2015), and Tursoy & Faisal (2018). This relationship can be explained by cost inflation associated with the rise in oil prices, which can lead to increased gold demand and higher prices of this precious metal as investors place their capital in gold seen as a hedge against inflation. Investors' decisions to allocate their capital in the aforementioned markets determine the type and direction of causality between these assets. It is important to investigate the interrelations in these three markets.

The aim of this paper was to evaluate the relationship between stocks, crude oil and gold markets in the short and long-term by applying the VECM approach and the Granger-causality analysis, followed by an FEVD, and IRF analyses. The research focused on the links between the markets of these assets in Central Europe, namely Hungary, Slovakia, Romania, Slovenia, Czechia, Poland, and Croatia, for which the Central European Blue-Chip Index (CETOP) was applied as a benchmark reflecting stock market prices. Moreover, this study used the Europe Brent Spot Price FOB in the case of crude oil and the LBMA Gold Spot Price for gold, expressed in EUR. This region, compared with countries classified as the key producers and consumers of gold, was not investigated so far.

The following research hypothesis was formulated: the analysed markets are cointegrated and the changes in prices on the gold and crude oil markets have impact on the stock market.

The paper is organized as follows. Section 2 presents a review of the literature. Section 3 is devoted to methodology of research describing, among others, the VECM model specification and the issue of cointegration. Section 4 describes the data sample. Section 5 contains the empirical results, following the analysis of stationarity and cointegration of the variables, causality relations, and the FEVD and IRFs analyses. Section 6 presents a discussion and conclusions.

2. Literature review

The links between major classes of assets, in particular stocks, crude oil and gold have been analysed by numerous authors. The studies were related to various countries and geographical areas. The authors focused on investigating the causal relationships between these financial variables, and most of them applied the vector autoregressive models (VAR) and the Granger test.

In most cases the research examined the interrelations between two asset classes, where stocks and gold or stocks and crude oil were considered the pairs of variables. For instance, Bhuvaneshwari & Ramya (2017) analysed causal relationships between the stock index (S&P CNX Nifty) and gold market in India. The data span was from January 2011 to December 2015 on a monthly basis; no long-term equilibrium between the gold rates and the stock index was revealed after applying the Johansen cointegration test. A causal relationship was also not reported between the considered variables, i.e. the stock prices do not have impact on the gold rate. Al-Ameer et al. (2018) examined the causal relationship between the prices of gold and the Frankfurt Stock Exchange index (HDAX), and the data covered the period between August 2004 and September 2016. The existence of a long-term relationship between the variables under analysis and the lack of Granger causality was characteristic of the whole period as well as for three subperiods, i.e. before, during and after the financial crisis. Siemaszkiewicz (2020) applied the dynamic conditional correlation (DCC-GARCH) model to investigate the dynamic relationship between gold, silver, platinum, and copper, and the Central European stock markets (Czechia, Hungary, Poland, and Slovakia) in the period from 01.01.2007 to 30.06.2020. The research aimed to determine the role of the considered metals in investment portfolios. According to the findings, gold and silver are regarded as investment assets, while platinum and copper as industrial metals, whilst silver serves as a safe-haven instrument. Moreover, gold – during financial crises – is also a safe- haven asset, due to the negative values of correlations between gold and indices (WIG, PX, SAX, BUX). On the other hand, when the market was facing extreme shocks, the correlation proved to be positive (as in late 2009). Bermudez Delgado, Bermudez Delgado & Saucedo (2018) implemented a vector autoregression Model (VAR) to analyse the relation between oil prices, the exchange rate, the stock market index and the consumer price index in the Mexican economy. The examined period included monthly data from January 1992 to June 2017. Their results show that the exchange rate has a negative and statistically significant impact on the Mexican stock market index. Moreover, the impact of the exchange rate on the Mexican consumer price index is positive and also statistically significant. The negative and statistically significant effect of crude oil on the exchange rate was also indicated. Al Kharusi & Basci (2019) investigated the correlations between gold prices and the indices of seven stock markets of countries affiliated with the Gulf Cooperation Council (GCC) on the basis of the VAR model; their sample covered the data between 2010 and 2016. They conducted the Johansen test, and the Granger-causality test to examine the long and short-term relations, respectively; the study reported five cases of bilateral correlation and nine instances of a unilateral correlation between the gold and stock indices. Tiwari, Adewuyi & Roubaud (2019) analysed correlations between the gold markets and stock markets in Brazil, China, India, Indonesia, Korea, Mexico, Russia, and Turkey, running from January 2002 to July 2018. The results of Granger causality based on quantile-on-quantile regression (QQR) for the entire period revealed a weak positive correlation in quantile for gold and returns on stock. The overall results for two sub-periods (before and after the crisis) were similar, except for those obtained for Turkey, China and Indonesia. The results of testing for causality-in-mean and causality-in-variance show no causal relationships in the period preceding the crisis, while in the period after the crisis, causality in the direction from gold to stocks was revealed in some of the markets. Peng et al. (2020) applied the linear and nonlinear Granger-causality tests, combined with the bivariate empirical model decomposition model (BEMD), to explore the dynamic multiscale interaction and the volatility effect between China's stock market and the international oil market. They used as benchmarks the Brent future price (FOB) and the Shanghai Stock Exchange (SSE) Composite Index, respectively. The sample period covered the data from 2005/01/06 to 2016/07/08. From the long-term perspective, they stated that there exists a strong bidirectional linear and nonlinear spillover effect between the international oil market and stock market. In the short term, the results show that analysed markets might be correlated, which can also be a cause of market fluctuations in the two markets apart from the observed supply-demand disequilibrium. Moreover, the Brent oil market may have an impact on the stock market, whereas as effect in the opposite direction was not found. Regardless of the analysis period adopted, the results do not prove an obvious bidirectional linear and non-linear Granger causality. Enwereuzoh, Odei-Mensah & Junior (2021) applied a structural vector autoregressive (SVAR) model and a two-state regime smooth transition regression models to investigate the impact of oil price shocks (delineated into oil supply shock, global demand shock and oil specific shock) on stock returns of selected African economies over the period from January 2000 to July 2018 with a monthly frequency. They included two groups of countries, namely oil exporters (Nigeria, Tunisia, and Egypt) and oil importers (Botswana, South Africa, Kenya, and Mauritius), indicating that global demand shock does not play an important role in the case of oil-importing countries. However, the oil-demand shock is an important factor in stock's returns for oil-exporting countries. The oil supply shock seems to have no effect on the real stock's return for both oil-exporting and oil-importing countries, whereas oil-specific shock is significant in most cases. The impact of the price shocks is asymmetric with higher influence in the case of those negative. Due to the indicated linkages between the oil and stock markets in the analysed countries, the investors should consider portfolio diversification while investing in these capital markets to avoid negative consequences of the oil prices volatility. For the same reason, policymakers should be aware of the fluctuation of the revenues derived from oil. Moreover, for oil-importers, diversification can be a means of cushioning against the oil price shocks.

Some authors included three types of assets in their research, i.e. gold, crude oil and stocks. Irshad et al. (2014) focused on the interrelations between equity, oil and the gold market in Pakistan. Their study was based on monthly data from the period 2002-2010. The Karachi Stock Exchange Index KSE-100 Index, crude oil, and gold prices were the variables taken into consideration in the research. The results of the cointegration analysis carried out by means of the Johansen-Juselius test revealed no relationship in the long-term for the time series analysed. Moreover, the Granger causality analysis showed the absence of causality from any of the considered variables to the other variables in either direction. The authors also applied the impulse response function as the measure of the standard deviation in the series due to one standard deviation change in other series. The results of the impact of the changes in the analysed time series indicated that these three series were not affected by the other's fluctuations and were mainly explained by their own shocks; this was also confirmed by the variance decomposition findings. Bouri et al. (2017) analysed the correlations between the global markets of gold, oil and the Indian stocks in the period between June 2009 and May 2016. They used the implied-volatility indices (VIX) to reflect changes in these markets. While analysing the cointegration and non-linear causality they found a positive impact of the implied volatility of gold and oil prices on the stock market under analysis, which also revealed a reverse bidirectional causality between implied volatility of the gold prices and the oil prices. Lodha (2017) analyses the long and short-term interdependence between daily USD/INR exchange rates, gold and crude oil prices from May 2005 to June 2014 in India. The results of the Johansen cointegration test show no long-term relation between the non-stationary variables. To examine the short-term relation, the Granger causality test and VAR model was applied on the return series. According to the results obtained, there exists a bidirectional Granger causality between crude oil and the dollar-rupee exchange rate, while unidirectional Granger causality runs from crude oil to gold, whereas no Granger causality between gold prices and exchange rates was found. Tursoy & Faisal (2018) examined the interrelations between the stock, gold and oil prices in the Turkish market in the short and long run, based on data from January 1986 to November 2016. The analysis was carried out on a monthly basis by applying the autoregressive distributed lag (ARDL) model. The authors stated that both in the long-term and short-term perspective, there was a negative correlation between gold prices and stock prices, and a positive correlation between oil prices and stock prices. The results of the Granger causality test confirm the unidirectional causality between the gold price and the stock price. Mensi, Reboredo & Ugolin (2021) applied the Markov-switching vector autoregressive model to examine price-switching spillovers between the US and Chinese stock, crude oil, and gold futures markets before and during the COVID-19 pandemic. They showed that the stock markets were mainly determined by their own shocks, however the effects were dependent on the regime shifts. In the case of the low-volatility regime lasting from January 2019 to February 2020, the gold and stock markets were net contributors of spillovers, while oil was a major receiver of spillovers. In other words, the impact of gold and oil price returns on the Chinese stock markets, i.e. Shanghai, Shenzhen indices returns, was observed during that time. Moreover, gold price returns also affected the S&P500 index returns, which, in turn, contributed positively to oil price returns, whereas in the high-volatility regime covering the period between March 2020 and May 2020, the aforementioned markets played the opposite roles, respectively. The authors highlighted that spillovers from commodity markets to the US and Chinese stock markets became more intensive due to the COVID-19 pandemic, especially in March 2020, which suggests that investors should consider the public health issues as a risk factor. Gold proved to be a strong safe-haven asset protecting against the investment risk during global health crises as it was used when facing financial and energy crises in the past. Chkili (2022) applied standard VAR and Markov switching VAR models to investigate the links between gold and oil prices and the Islamic stock market. The weekly data covered the period 1996-2020, including the recent COVID-19 crisis. The empirical findings concerning the VAR estimates demonstrated that the relationship between oil and the Islamic stock markets was positive, while there existed a negative relationship between the Islamic equity market and gold. These results proved the financialisation process of the crude oil market, and the role of gold as a strong hedge for Islamic market volatility. In the case of the Markov-switching approach, the results indicate that under the low volatility regime, gold can serve as a hedge for Islamic market movements, whereas for the high volatility regime it can be regarded as a safe haven.

As well as the variables mentioned above, the exchange rate was included in this analysis. Gold, which is usually priced in USD in the global markets, is negatively correlated with the values of domestic currencies expressed in USD. Sujit & Kumar (2011) concentrated on the causal relationship between the prices of gold, stocks (S&P500), exchange rates, and the prices of crude oil (WTI, Brent). The empirical data covered the period from 2 January 1998 to 5 June 2011. They applied two VAR models and the cointegration analysis in their studies. The variables included in the first model were gold (USD), WTI, exchange rate and S&P, while in the second one the authors focused on relationship between Brent oil prices, exchange rates, WTI, and gold (EUR). They observed a significant impact of the exchange rate on the other variables, and a limited impact of stock prices on exchange rates. As regards the second model, a weak long-term correlation between the variables was revealed. Additionally, the impulse response function, and error variance decomposition was applied as a tool of a detailed analysis. Jain & Biswal (2016) analysed the relation between the global prices of gold, crude oil, the USD–INR exchange rate, and the stock market in India using the DCC-GARCH (standard, exponential, threshold) models. The analysis was carried out based on daily data for the span of ten years, i.e. the period from 2006 to 2015. The study examined the lead lag linkages by means of symmetric and asymmetric nonlinear causality tests. According to the results of the symmetric test, the gold price affected the exchange rate, whereas the stock market was determined by the exchange rate. After applying the asymmetric test, it was found that the fall in gold prices led to the depreciation of the Indian rupee, while the depreciation of the Indian currency caused a drop in the stock market index. On the other hand, no nonlinear causal relationships were found between crude oil prices and gold prices. Das et al. (2018) examined the relationship between stocks (S&P 500 Index), gold (USD/oz), and crude oil (WTI) with financial stress, adopting as a proxy financial stress index (FSI). They applied the nonparametric causality-in-quantile test. Their study was based on the weekly data covering the period between 31 December 1993 and 24 March 2017. According to their findings, there existed the bilateral causality in mean and variance for gold and crude oil with respect to financial stress. However, stocks proved to be influential to financial stress both in mean and variance more strongly, while the causality of financial stress over stocks was weaker. Singhal, Choudhary & Biswal (2019) used the ARDL approach to examine the long-term dynamic relations among international oil prices, international gold prices, the exchange rate and the stock market index in Mexico. To test the order of variables integration, they applied various unit root tests (ADF, KPSS and Phillips Perron), and concluded that time series are cointegrated and estimated the cointegrating equation using error correction term. According to their findings, international gold prices positively affected the stock price of Mexican market while oil prices had a negative impact on them. The exchange rate was negatively influenced by the oil prices, whereas the price of gold price did not have any significant impact on the exchange rate. Akbar, Iqbal & Noor (2019) analysed the dynamic relationships between gold, stock, the exchange rates (INR/USD) and interest rates in Pakistan in the period between January 2001 and December 2014. One the basis of the classic VAR model and the Bayesian VAR model, they investigated the correlations in the short-term perspective as no cointegration between variables was found. They indicated a reverse bilateral correlation between stock and gold prices, and between the rupee exchange rates and gold, whereas a positive bilateral correlation was reported in the case of stock prices and the rupee exchange rates. Moreover, the impulse response function analysis showed the existence of the relationship between volatility in the stock, gold and foreign exchange markets. Fluctuations in the exchange rates caused stock and gold prices to move in the reverse direction. A more diverse set of macroeconomic and firm-specific factors influencing stock prices of the companies listed on the stock exchanges of the V4 countries was the field of interest for Aliu, Nadirov & Nuhin (2021). They applied regression analyses based on a pooled OLS and fixed effect models to show that total equity had a significant impact on the individual weekly stock prices in the period from 2013 to 2018, while the exchange rate and inflation influence was negative and less significant. Moreover, the impact of gold and oil prices, along with economic activity, debt level, cash flow and company size on the stock movements mattered, however the influence was limited due to the overall inefficiency of the markets under investigation.

To sum up, the results concerning the relationship between stock, crude oil and gold, presented in this section showed that the unidirectional causality was indicated as the most frequent. The causality between gold and stock was reported to be in first place, between stock and crude oil in the second, and finally that between crude oil and gold. The cases of the lacking causality or bilateral relationship between variables were relatively rare. To assess and compare the results, one should however consider that some authors applied different methods (models) and their research covered various periods (Table 1).

Table 1. Summary of the literature review

Asset classes/Authors	Findings
stocks and gold	
Bhuvaneshwari & Ramya (2017)	No long-term equilibrium; the lack of Granger causality
Al-Ameer et al. (2018)	A long-term relationship; the lack of Granger causality
Bermudez Delgado, Bermudez Delgado & Saucedo (2018)	The exchange rate – negative and statistically significant impact on the Mexican stock market index; positive impact of the exchange rate on the Mexican consumer price index; negative effect of crude oil on the exchange rate
Al Kharusi & Basci (2019)	A bilateral correlation or unilateral correlation between gold and stock
Tiwari, Adewuyi & Roubaud (2019)	A weak positive correlation in quantile for gold and returns on stock; in the period after the crisis: causality in the direction from gold to stocks
Siemaszkiewicz (2020)	The negative values of correlations between gold and indices (WIG, PX, SAX, BUX) during financial crisis; positive in periods of the extreme market shocks
stocks and crude oil	
Peng et al. (2020)	A strong bi-directional linear and nonlinear spillovers; oil market impacts the stock market
Enwereuzoh, Odei-Mensah & Junior (2021)	The oil-demand shock impacts stock's returns for oil-exporting countries; no effect of the oil supply shock on the real stock's return for both oil-exporting and oil-importing countries; oil-specific shock was significant in most cases.
gold, crude oil, and stocks	
Irshad et al. (2014)	No relationship in the long term; the lack of Granger causality
Bouri et al. (2017)	A positive impact of the implied volatility of gold and oil prices on the stock market
Lodha (2017)	No long-term relation; bidirectional Granger causality between crude oil and dollar-rupee exchange rate; unidirectional Granger causality from crude oil to gold; Granger causality between gold prices and exchange rates
Tursoy & Faisal (2018)	A unidirectional causality between the gold price and the stock price
Mensi, Reboredo & Ugolin (2021)	The low-volatility regime: gold price returns affect the S&P500 index returns on the Chinese stock markets and US stock market; S&P500 index returns contribute positively to oil price returns; the high-volatility regime: the opposite impacts of the aforementioned assets
Chkili (2022)	The positive relation between oil and the Islamic stock markets; the negative relation between the Islamic equity market and gold
gold, crude oil, stocks and exchange rate	
Sujit & Kumar (2011)	A significant impact of the exchange rate on the other variables, and a limited impact of stock prices on exchange rates
Jain & Biswal (2016)	The gold price Granger-cause of the exchange rate; the stock market is determined by the exchange rate; no nonlinear causal relationships between crude oil prices and gold prices
Das et al. (2018)	The bilateral causality in mean and variance for gold and crude oil with respect to financial stress
Singhal, Choudhary & Biswal (2019	The international gold prices positively affect the stock price while oil price has negative impact on them
Akbar, Iqbal & Noor (2019)	A reverse bilateral correlation between stock and gold prices, and between rupee exchange rates and gold; a positive bilateral correlation between stock prices and rupee exchange rates
Aliu, Nadirov & Nuhin (2021)	A limited impact of gold and crude oil, and other macroeconomics or firm-specific factors

Source: own elaboration.

3. Research methodology

To fit a VECM for the financial data included in the analysis, in the first step the author carry out the ADF, DF-GLS, Phillips-Perron, and KPPS tests in order to investigate if there exists a unit root in the log-prices of analysed time series (at levels) and at their first differences. If the variables are logarithms of asset prices, their first differences can be presented as:

$$lnP_t - lnP_{t-1} = ln\frac{P_t}{P_{t-1}}, \quad (1)$$

where P_t – asset price in period t, P_{t-1} – asset price in period t-1. In that way, the log-returns are obtained.

Prices expressed in the form of logarithms were used, since logarithmisation allows the transformation of non-linear relationships into linear ones, and the calculated continuous rates of return have the property that they are more normally distributed than discrete rates of return. Thus, the assumption of capital market models was fulfilled (Steiner & Bruns, 1996, p. 53). Additionally, the nonstationary variables (at levels) are an essential assumption for time series used in a VECM.

Next, the study identified the number of lags. One can use the likelihood ratio statistics (LR) or criteria based on the forecasting objectives including the final prediction error (FPR) criterion, Akaike information criterion (AIC), Hannan-Quinn criterion (HQ), and Bayesian Schwarz criterion (SC). For these four criteria, order (p) was chosen by minimising the value of the criterion. The formulas and detailed characteristics of the test statistics are presented by Lütkepohl (2005, pp. 153-157).

The process also involved identifying the number of cointegrating vectors. The author conducted the Johansen cointegration test (Johansen & Juselius, 1990) with variables that are integrated of order one or *I(1)* to examine the existence of the long-term equilibrium between the gold, stock index, and crude oil log-prices. The Johansen cointegration testing procedure was based on sequential testing the null hypothesis H_0 assuming that $rk(\Pi) = r_0$ against the alternative hypothesis H_1 that $r_0 < rk(\Pi) \leq K$. The rank of matrix Π is equal to the number of its characteristic roots that differ from zero, while K is the number of variables in the model. In terms of cointegration testing, one can consider a different trend specification in VECM and cointegration relationship: (1) without the deterministic trend; (2) with deterministic trend consisting only of a simple constant mean; (3) with a linear trend; (4) with a linear trend in the variables and without in the cointegration relations. Additionally, the model with quadratic trend (5) incorporated in variables is possible (Lütkepohl, 2005, p. 328; Becketti, 2013, p. 401).

For p-variable model, the r is the rank of Π matrix ($\alpha\beta'$) such as $0 \leq r < K$, informing about the number of linearly independent cointegrating relationships among the elements of vector y_t. This relationship describes the long-term equilibrium between the non-stationary variables of vector y_t, and refers to the error correction mechanism (ECM) included in the VECM. There are four possible cases depending on rank r of Π: (1) $r = 0$, which means that all the elements of the matrix are 0 and the model is estimated as a standard VAR on first-differenced variables of vector y_t without the ECM representation; (2) $r = K$, i.e. matrix is full rank, then the time series of vector y_t are stationary and VAR is an unrestricted model for variables in levels; (3) $r = 1$ indicates that there is one cointegrating relationship included in VECM, while more cointegration relations should be included in VECM if $1 \leq r < K$ (Kusideł, 2000, p. 49).

Depending on the results of the cointegration test and the number of lags recommended, the author applied the VECM approach to analyse the causal relationships between the gold, stock, and crude oil log-returns. Converting the VAR representation (equation 2) of the analysed time series to the VECM representation (equation 3) involved a reduction of the number of lags by one. The formulas are as follows (Becketti, 2013, pp. 392, 399-402; Enders, 2010, pp. 298-299):

$$y_t = \mu + \sum_i^p \Phi_i y_{t-1} + \epsilon_t, \quad (2)$$

$$\Delta y_t = \gamma + \tau t + \alpha(\beta' y_{t-1} + \nu + \rho t) + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-1} + \epsilon_t, \quad (3)$$

where $y_t = [\ln\_GOLD\_EUR \quad \ln\_CETOP \quad \ln\_BRENT\_EUR]'$ – vector of gold, stock index, and crude oil prices expressed in logarithm (*ln*) in period t; γ, τ – linear trend and quadratic trend parameters incorporated in y_t, respectively; ν, ρ – deterministic terms in the cointegrating equations representing the means and linear trends of those relationships, respectively; α – speed of adjustment, β' – matrix of cointegrating vectors, Γ_i – matrix of lagged values of variables in first differences, Δy_t – vector of first differences, $\epsilon_t = [e_{GOLD} \ e_{CETOP} \ e_{BRENT}]'$ – vector of error terms which are white-noise processes with zero means, constant variances, and are individually serially uncorrelated.

As various restrictions can be imposed on the VECM model, the study considered different trend specifications depending on the set of parameters $(\gamma, \tau, \nu, \rho)$ to be included in the model. The statistical significance of the parameters of the estimated models was tested. The issue of nested models was analysed by means of the likelihood-ratio test. Five possible cases are presented in Table 2.

Table 2. VECM model specifications

Calibri	Characteristics and restrictions
Unrestricted trend (trend)	• estimation of all four parameters, • quadratic trend in the level of variable y_t • cointegrating equations are trend stationary
Restricted trend (rtrend)	• only linear trend in the level of the variables of y_t • cointegrating equations are trend stationary • $\tau = 0$
Unrestricted constant (constant)	• variables follow linear trend • cointegrating equations are stationary around constant means • $\tau = 0, \rho = 0$
Restricted constant (rconstant)	• no trend in the variables of y_t • cointegrating equations are stationary around constant mean • $\tau = 0, \rho = 0, \gamma = 0$
No trend (none)	• no nonzero means or trends, • $\tau = 0, \rho = 0, \gamma = 0, \nu = 0$

Source: Becketti, 2013, p. 392.

After the estimation based on a given trend specification, the author applied the Wald test for parameters of the selected model to indicate the Granger causality between log-returns from investments on the markets under investigation. The Granger test allowed to determine whether variable *X* was the cause of *Y* in the sense of Granger (*X*→*Y*). Therefore, the study examined whether the current values of *Y* can be predicted with greater precision based on the past values of variable *X* compared to the situation without including it in the model, as long as the other information does not change. The relationship in the opposite direction (*Y*→*X*) also had to be considered. The author tested null hypothesis H_0: *X* is not a Granger cause of *Y*, i.e. coefficients at *X* of $\sum \Gamma_i = 0$, against alternative hypothesis H_1: there is a causality from *X* to *Y*, i.e. coefficients at *X* of $\sum \Gamma_i \neq 0$ (Charemza & Deadman, 1997, p. 158).

The study also analysed the forecast error variance decomposition (FEVD) under alternative orderings to justify the robustness of the obtained results. By FEVD investigation it was possible to obtain information about the proportion of changes into variables of vector y_t which are attributed to their own shocks, and to what extent they can be explained by the shocks to the other variables. Such an arrangement allowed for the distinction between the most exogenous variables and endogenous ones. If shocks in the other variables explain none of the forecast error variance in a given variable at all forecast horizons, that variable is entirely exogenous. On the other hand, for the entirely endogenous variable this was explained by the shocks to the other variables. The stronger the correlations between the residuals from subsequent equation of the model, the larger the differences between the results (Enders, 2010, pp. 314-315).

To analyse the response of one variable to the impulse in another variable in a system the author plotted the impulse response functions which depict the response of variable *j* to a unit shock, i.e. forecast error, in variable *k*. Referring to the moving-average (MA) representation (4), the coefficients of Φ_{jk} (i) in period *i* were used to generate effects of ε_{jt} and ε_{kt} innovations on the entire time path of *j*-th and *k*-th variable:

$$y_t = \mu + \sum_{i=0}^{\infty} \Phi_i \varepsilon_{t-i} \quad (4)$$

where Φ_i – *i*-th coefficient matrix of MA representation.

Even though an unstable, integrated or cointegrated VAR(*p*) process does not possess valid MA representation, Φ_i can still be calculated in a similar way and show the impulse response relations as for the stable process (Enders, 2010, p. 308; Lütkepohl, 2005, pp. 51-52, 263).

The properties of autocovariances and autocorrelations of the residuals of estimated VECM were also examined. At this stage of the model's diagnostics, the author applied the portmanteau test for overall significance of the residual autocorrelation up to given lag *h* (H_0: $R_h = (R_1, \ldots, R_h) = 0$ vs. H_1: $R_h \neq 0$) and the LM test for residuals autocorrelation (H_0: no autocorrelation at lag order) which is more useful in the case of low order autocorrelations (Lütkepohl, 2005, pp. 345-348).

In the next step, the author conducted testing for residuals non-normality involving skewness and kurtosis of the normal distribution with the Jarque-Bera test (Lütkepohl, 2005, pp. 174-177), as well as the Shapiro-Wilk test. Finally, testing for the structural breaks of residuals was conducted using the cumulated sum of the forecast errors (CUSUM) test (Enders, 2010, pp. 106-107), followed by the test of stationarity of ECM residuals. All the calculations were conducted in STATA software.

4. Empirical data

The data for this study included the Central European Blue Chip Index (CETOP) which reflects the performance of the companies with the biggest market value and turnover in Central Europe, and serves as a benchmark for the stock investment in this region. The index consists of securities of these shares that are listed on at least one of the following stock exchanges: the Budapest Stock Exchange, the Bratislava Stock Exchange, the Bucharest Stock Exchange, the Ljubljana Stock Exchange, the Prague Stock Exchange, the Warsaw Stock Exchange, and the Zagreb Stock Exchange. The other two variables are the gold price (GOLD_EUR) and the Europe Brent Spot Price FOB (BRENT_EUR), both expressed in euros with monthly frequency, as the stock index is calculated based on the market capitalisation of the companies expressed in euros. The author obtained the historical data from the Budapest Stock Exchange (BSE), the World Gold Council (WGC), the US Energy Information Administration (EIA), and stooq.pl websites. The sample covered the period from 2002 to 2021, including 240 observations. Figure 1 shows the plot of the analysed assets prices and Table 3 describes their summary statistics.

Apart from a few short periods, the stock index (CETOP) and the crude oil price (BRENT_EUR) showed a similar development trend, while the gold price pattern did not correspond to the changes in those two variables. In the periods in which these markets collapsed, investors could choose gold as an alternative to stock and crude oil investments (Figure 1). Later in this study, variables expressed as logarithms were applied to facilitate the transformation of non-linear correlations to linear correlations.

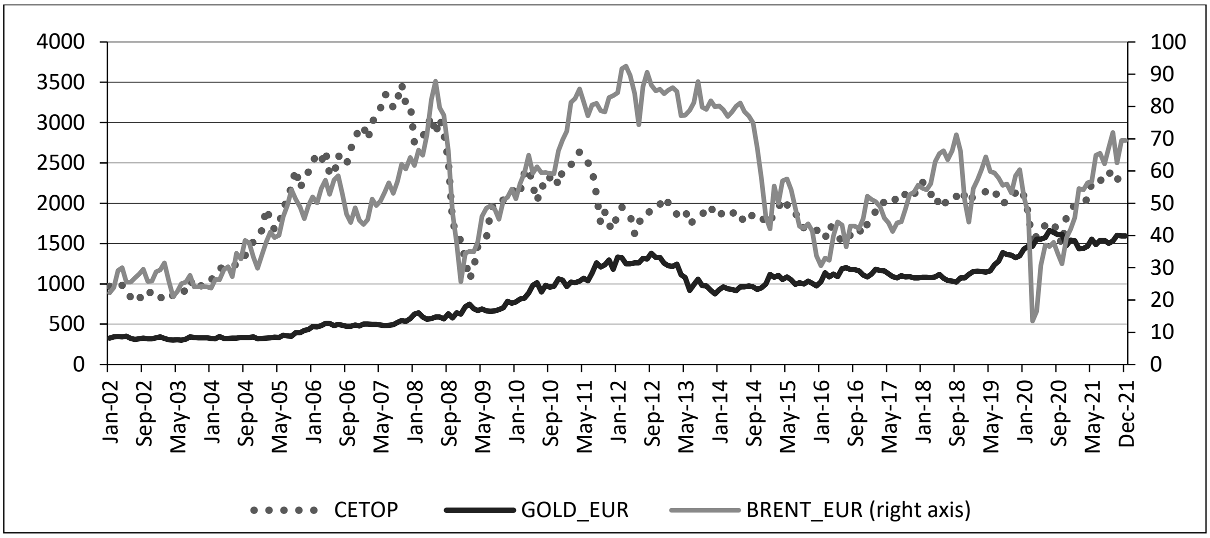

Fig. 1. The CETOP index, gold, and crude oil prices time series in the period 2002-2021 (end-of-month)

Source: own elaboration based on BSE, WGC, EIA, stooq.pl.

According to data in Table 3, the CETOP index exhibits the greatest price fluctuations in absolute terms (standard deviation of 563.61) and the lowest variation coefficient (29.03%), whereas crude oil price (BRENT_EUR) was characterised by the lowest deviation from mean (18.76) and higher volatility in comparison with stock (34.95%). Whilst the gold price proved to be the most volatile (44.63%), all the variables under analysis exceeded the minimum required value for a volatility coefficient (V>10.0%), which means that the conditions for model analysis were satisfied. Two variables (CETOP, BRENT_EUR) were right-skewed, while the gold price was left-skewed. All the variables were leptokurtic which means the strong concentration around the mean value compared to the normal distribution (a mesokurtic distribution). Referring to the first differenced logarithms of stock and crude oil prices, these log-returns were left-skewed, while the gold returns were right-skewed. All the returns were leptokurtic, whilst the crude oil returns were the most volatile.

Table 3. Descriptive statistics for time series in the period 2002-2021 (end-of-month)

Variable	Mean	Standard deviation	Variation coefficient	Min	Max	Skewness	Kurtosis
GOLD_EUR	883.89	394.47	44.63	301.30	1661.65	–0.026	1.825
CETOP	1941.41	563.61	29.03	781.86	3478.16	0.099	3.199
BRENT_EUR	53.67	18.76	34.95	13.46	92.50	0.160	2.149
D_ln_GOLD_EUR	0.0066	0.0461	6.9701	–0.1599	0.1369	0.0053	3.6958
D_ln_CETOP	0.0037	0.0687	18.3651	–0.3486	0.2103	–0.8624	6.4992
D_ln_BRENT_EUR	0.0048	0.1324	27.7676	–1.2393	0.6204	–3.1874	36.2355

Source: own calculations.

5. Results

Firstly, the author presents the results of the stationarity analysis of the time series. Table 4 provides the statistics of the augmented Dickey-Fuller test, the DF-GLS and the Philips-Perron test for log-prices and log-returns, i.e. for variables at levels and their first differences, respectively. Moreover, the statistics of the KPSS test are summarised in Table 5.

When comparing the augmented Dickey-Fuller test statistics of log-prices (at levels) with the interpolated estimates of the 1%, 5%, and 10% critical values, one has to accept the null hypothesis of a unit root for all the analysed variables, except for crude oil (BRENT_EUR, at level) which was significant only in one case (at 10%.). The results were also confirmed by the *p*-values obtained, whereas the results for the log-returns (first differences) showed that the null hypothesis should be rejected at all the significant levels considered. The DF-GLS test results prove that all the variables at levels were nonstationary. The unit root was not confirmed for log-returns in the case of CETOP and BRENT_EUR at any significant level, while for GOLD_EUR in two out of three cases, i.e. at 5% and 10%. The Phillips-Perron test for unit root results showed that the null hypothesis was rejected for BRENT_EUR (at levels) when taking 5% and 10% significance levels, not at 1%. The log-returns proved to be stationary regardless of the significance level adopted. Referring to the KPSS test, all the variables were nonstationary at levels, whilst their first differences were stationary at 5%. To sum up, the time series analysed were nonstationary at levels and become stationary after differentiation. This means that they were characterised by first order of integration.

Table 4. Statistics of the ADF test, the DF-GLS and the Philips-Perron test for unit root

Variable	At levels			At first differences		
	CETOP	BRENT_EUR	GOLD_EUR	CETOP	BRENT_EUR	GOLD_EUR
Augmented Dickey-Fuller test						
Z(*t*) statistics	–2.527[a)]	–2.722[a)]	–1.246[a)]	–7.624[a)]	–3.465	–5.095
p-value	0.1091	0.0702*	0.6536	0.000***	0.000***	0.000***
Critical value						
1%	–3.465	–3.464	–3.466	–3.465	–3.465	–2.582
5%	–2.881	–2.881	–2.881	–2.881	–2.881	–1.95
10%	–2.571	–2.571	–2.571	–2.571	–2.571	–1.619
DF-GLS test						
Test statistic	–0.725	–2.235	–1.682	–5.129***	–2.843***	–2.864**
Critical value						
1%	–2.5810	–3.4800	–3.4800	–2.5810	–2.5810	–3.4800
5%	–2.0110	–2.9100	–2.8850	–1.9500	–1.9900	–2.8420
10%	–1.6960	–2.6220	–2.5990	–1.6190	–1.6780	–2.5600
Phillips-Perron test for unit root						
Z(rho)	–8.379[a)]	–17.091[a)]	–1.209	–206.099	–193.414	–262.257
Z(*t*)	–2.302[a)]	–3.145[a)]	–0.977	–13.418	–13.932	–17.323
p-value	0.1713	0.0234**	0.7614	0.0000***	0.0000***	0.0000***

Note [a)] MacKinnon approximate *p*-value for *Z*(*t*), H_0: is rejected at significance levels: *10%, **5%, ***1%.

Source: own calculations.

Table 5. KPSS test results

Lag order	Variable at levels			Variable at first differences		
	Test statistics [a)]			Test statistics [b)]		
	CETOP	BRENT_EUR	GOLD_EUR	CETOP	BRENT_EUR	GOLD_EUR
0	2.410**	3.100**	4.010**	0.137	0.054	0.095
1	1.230**	1.610**	2.030**	0.121	0.049	0.108
2	0.828**	1.110**	1.370**	0.119	0.053	0.116
3	0.629**	0.855**	1.030**	0.112	0.059	0.116
4	0.510**	0.702**	0.833**	0.107	0.066	0.120
5	0.431**	0.598**	0.699**	0.106	0.072	0.120
6	0.375**	0.524**	0.604**	0.106	0.075	0.116
7	0.333**	0.467**	0.532**	0.105	0.077	0.115
8	0.301**	0.423**	0.477**	0.105	0.080	0.113
9	0.275**	0.388**	0.433**	0.106	0.082	0.113
10	0.254**	0.359**	0.397**	0.107	0.084	0.113
11	0.237**	0.335**	0.367**	0.108	0.086	0.112
12	0.222**	0.315**	0.341**	0.108	0.089	0.110

Notes: [a)] H_0: trend stationary, H_1: unit root (critical values for H_0: 10%: 0.119; 5%: 0.146; 2.5%: 0.175; 1%: 0.216); [b)] H_0: level stationary, H_1: unit root (critical values for H_0: 10%: 0.347; 5%: 0.463; 2.5%: 0.574; 1%: 0.739); ** *H0* is rejected at 5%.

Source: own calculations.

The number of the recommended lags by the various information criteria is presented in Table 6. The likelihood-ratio test (LR), the final prediction error (FPE), the Akaike information criterion (AIC), and the test statistics of Hannan-Quinn information criterion (HQC) suggest two lags, while Schwarz's Bayesian information criterion (SBIC) indicates that a single lag should be sufficient.

Table 6. Number of lags by information criterion of VECM model (max lags 8)

Lag	LL	LR	df	P	FPE	AIC	HQIC	SBIC
0	–227.944				0.00147	1.9909	2.00887	2.03547
1	847.004	2149.9	9	0.00	1.5×10^{-7}	–7.19831	–7.12641	–7.02003*
2	862.953	31.899*	9	0.00	1.4×10^{-7}*	–7.25822*	–7.1324*	–6.94623

Source: own calculations.

Referring to the restrictions imposed which are presented in Table 1, a cointegration test was carried with different assumptions regarding trend specification. In the case of the Johansen test, the author started with testing the null hypothesis, assuming that the model had no cointegration vectors (H_0: $r = 0$), against an alternative hypothesis H_1: $r \leq 1$, and so on. The results regarding the number of the cointegrating vectors for VECM with two lags in VAR representation are presented in Table 7.

Table 7. Number of cointegrating vectors under different possible trend specifications of VECM with two lags in VAR representation

Trend specification	Null hypothesis	LR statistics and critical values			
		Trace	5%	Max	5%
Unrestricted trend (trend)	$r(\Pi)=0$	40.3606	34.55	26.4469	23.78
	$r(\Pi)=1$	13.9137*	18.17	9.7526*	16.87
	$r(\Pi)=2$	4.1610	3.74	4.1610	3.74
Restricted trend (rtrend)	$r(\Pi)=0$	41.0599*	42.44	26.4677	25.54
	$r(\Pi)=1$	14.5922	25.32	9.7553*	18.96
	$r(\Pi)=2$	4.8369	12.25	4.8369	12.52
Unrestricted constant (constant)	$r(\Pi)=0$	30.1787	29.68	18.8124*	20.97
	$r(\Pi)=1$	11.3663*	15.41	9.0546	14.07
	$r(\Pi)=2$	2.3117	3.76	2.3117	3.76
Restricted constant (rconstant)	$r(\Pi)=0$	37.9654	34.91	21.0203*	22.00
	$r(\Pi)=1$	16.9452*	19.96	11.0537	15.67
	$r(\Pi)=2$	5.8915	9.42	5.8915	9.24
No trend (none)	$r(\Pi)=0$	29.5468	24.31	19.0139	17.89
	$r(\Pi)=1$	10.5328*	12.53	10.2339*	11.44
	$r(\Pi)=2$	0.2990	3.84	0.2990	3.84

Note: * Null hypothesis is accepted at 5%.

Source: own calculations.

The trace statistic favours one cointegration vector with one exception as the null of zero rank cannot be rejected. The max statistics indicates one vector in three out of the five specifications.

The author selected a VECM with two lags in VAR representation and one cointegrating vector, and then checked to what extent it was possible to trim the specification with an unrestricted trend. The results of the likelihood-ratio test are presented in Table 8.

Table 8. Comparison of VECM model specifications on the basis of the likelihood-ratio test

Assumption	LR chi2(2)	Prob > chi2
H_0: rtrend with 2 lags nested in trend with 2 lags	0.68	0.7123
H_0: constant with 2 lags nested in rtrend with 2 lags	7.66	0.0057**

Note: ** H_0 is rejected at 5%.

Source: own calculations.

It was possible to reduce the model to a restricted trend case by accepting the nested model at 5%. However, the model could not be limited to unrestricted constant specification since it was not possible to eliminate the trend term in the cointegration relation due to the rejection of the null at 5%.

The short-term equations of VECM with ECM component (_ce1) are presented in Table 9, while the long-term equation with a linear trend in Table 10.

Table 9. Short-term equations with ECM component of VECM (ordering of equations GOLD, CETOP, BRENT). Sample: March 2002 – December 2021

Equation 1.				
D_ln_GOLD_EUR	Coef.	Std. Err.	z	P>z
_ce1 L1.	0.0071	0.0124	0.5700	0.5680
ln_GOLD_EUR LD.	-0.1212*	0.0665	-1.8200	0.0680
ln_CETOP LD.	0.0031	0.0465	0.0700	0.9470
ln_BRENT_EUR LD.	-0.0142	0.0248	-0.5700	0.5670
_cons	0.0071**	0.0030	2.3300	0.0200
Equation 2.				
D_ln_CETOP	Coef.	Std. Err.	z	P>z
_ce1 L1.	0.0178	0.0180	0.9900	0.3230
ln_GOLD_EUR LD.	-0.3007***	0.0970	-3.1000	0.0020
ln_CETOP LD.	0.1051	0.0678	1.5500	0.1210
ln_BRENT_EUR LD.	0.0307	0.0361	0.8500	0.3960
_cons	0.0049	0.0044	1.1100	0.2660
Equation 3.				
D_ln_BRENT_EUR	Coef.	Std. Err.	z	P>z
_ce1 L1.	0.1709***	0.0330	5.1700	0.0000
ln_GOLD_EUR LD.	-0.2222	0.1777	-1.2500	0.2110
ln_CETOP LD.	0.3729***	0.1243	3.0000	0.0030
ln_BRENT_EUR LD.	0.1036	0.0662	1.5600	0.1180
_cons	-0.0008	0.0081	-0.1000	0.9210

Note: H_0 is rejected at the significance levels: *10%; **5%; ***1%, respectively, standard errors in parentheses.

Source: own calculations.

Table 10. Error correction term coefficients

_ce1	Coefficient	Standard error	*z*	P>*z*
ln_GOLD_EUR	1.0000			
ln_CETOP	0.6560***	0.2031	3.2300	0.0010
ln_BRENT_EUR	–1.1058***	0.1740	–6.3500	0.0000
_trend	–0.0060***	0.0007	–8.2300	0.0000
_cons	–6.5265	.	.	.

Note: ***H_0 is rejected at 1%

Source: own calculations.

In the long-term equation of VECM including the deterministic trend, the stock price as well as the crude oil price had a significant impact on the gold price, which means that they determined the gold market in the long period. In the long run the decrease in the stock price caused the increase in the gold price, while the impact of the crude oil price was the opposite. In the case of the short-term relationship only the crude oil returns adjusted to the long-term equilibrium as the ECM_{t-1} component had a significant impact on this variable. In the first equation, the lagged gold returns were significant at 10%, and with constant term at 5%, while in the second equation the impact of the lagged gold returns on the stock returns was statistically significant at 1%, but negative. Moreover, in the third equation lagged stock returns had a significant and positive impact on the crude oil returns at 1%.

On the basis of the estimated models, the author analysed the Granger causality. The Wald test of the parameters of the estimated VECM model with one lag (p – 1)[1] is presented in Table 11.

Table 11. Granger-causality Wald tests for the VECM model with two lags in VAR representation

Equation	Excluded	Statistics		
		chi2	df	Prob>chi2
D_ln_GOLD_EUR	D_ln_CETOP	0.00	1	0.9471
D_ln_GOLD_EUR	D_ln_BRENT_EUR	0.33	1	0.5675
D_ln_GOLD_EUR	ALL	0.35	2	0.8713
D_ln_CETOP	D_ln_BRENT_EUR	0.72	1	0.3961
D_ln_CETOP	D_ln_GOLD_EUR	9.61	1	0.0019***
D_ln_CETOP	ALL	9.87	2	0.0072***
D_ln_BRENT_EUR	D_ln_CETOP	9.00	1	0.0027***
D_ln_BRENT_EUR	D_ln_GOLD_EUR	1.56	1	0.2112
D_ln_BRENT_EUR	ALL	11.33	2	0.0035***

Note: H_0 is rejected at the significance levels of: *10%; **5%; ***1%, respectively.

Source: own calculations.

According to the Wald test results, the gold returns impacted on the stock returns. Moreover, the latter determined the crude oil returns. Therefore, one could only observe two cases of the unidirectional causality running from gold to the stock market, and from the stock market to the crude oil market.

The Granger-causality directions for the VECM model are summarised in Figure 2.

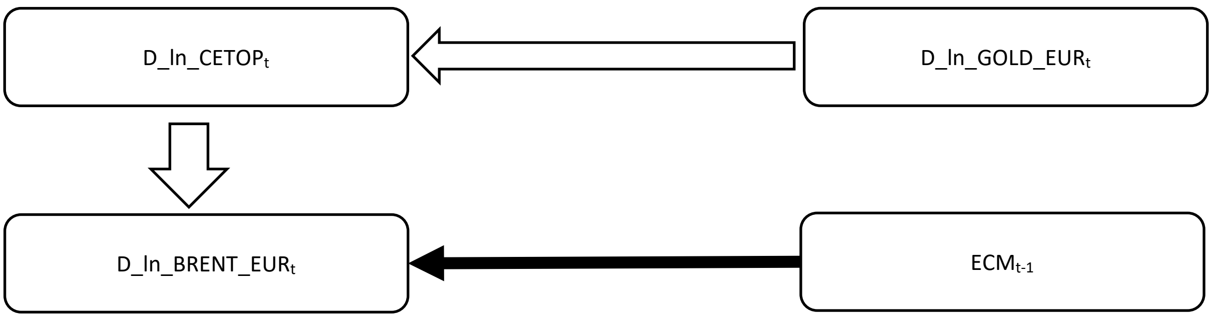

Fig. 2. The type of the Granger causality for VECM (r=1)

Source: own elaboration.

[1] When converting the VAR representation of the log-prices to the VECM representation based on the log-returns, it was essential to reduce the number of lags by one.

As the ordering of variables may have an impact on results, the author compared the forecast error variance decompositions (FEVD) under different orderings. The results are summarised in Table 12. The IRF functions under selected ordering were also plotted (see Figures 3 to11).

Table 12. Summary of the FEVD of GOLD_EUR, CETOP, and BRENT_EUR systems under different orderings of variables (minimal, maximal, and mean share) in a 24-month horizon

Equation	Share of variable in FEVD		
Max	GOLD_EUR	CETOP	BRENT_EUR
GOLD_EUR	99.52%	1.16%	0.99%
CETOP	4.39%	96.47%	3.86%
BRENT_EUR	14.42%	51.62%	52.87%
Min	GOLD_EUR	CETOP	BRENT_EUR
GOLD_EUR	97.94%	0.00%	0.16%
CETOP	1.44%	91.99%	1.91%
BRENT_EUR	10.69%	32.84%	37.34%
Mean	GOLD_EUR	CETOP	BRENT_EUR
GOLD_EUR	98.81%	0.54%	0.65%
CETOP	2.86%	94.30%	2.83%
BRENT_EUR	12.63%	42.30%	45.07%

Source: own elaboration.

For the analysed model, gold seems to be on average the most independent variable as was explained in nearly 99% by its own shocks, with the stock index in second place, whereas for crude oil the extent to which was explained by its own shocks was much lower than for stocks (94.3% vs. 45.07%). It was decided to adopt the following ordering when estimating the model and plotting the impulse response functions for: GOLD_EUR, CETOP, BRENT_EUR. Referring to this ordering, the 24-month horizon FEVD for the gold equation was explained in 99.01% by its own values, in less than 1% by crude oil, while the impact of stocks in less than 0.01%. In the stock equation, the share of stock was 93.93%%, for gold – 4.15%, and crude oil was responsible for about 2% of the FEVD. In the third equation, the share of gold was 11.04%, the percentage of stock was less than 52%, while for crude oil the share was lower than 38%.

It was observed that the most of the impulse response functions did not die out entirely (Figures 3 to 11). The IRF presenting the impact of gold on other variables declined initially, then increased with varying speed, i.e. sharply in the case of crude oil, and slightly for stocks. Finally, the functions stabilised, however following a different number of periods; for crude oil and stocks, it took about 10 to12 months. These responses differed by the sign of the IRF's values (negative vs. positive). The response of gold to its own shocks was preceded by a short period of decrease and a small upward trend afterwards, stabilising after three periods. The IRF pattern describing the impact of stock price shocks on gold is characterised by a decrease lasting approximately 12 months, followed by periods of stabilisation. On the other hand, the impact of stocks innovations on crude oil tended to increase sharply up to three months, followed by a decline, and eventually its levels normalised. The course of the IRF presenting the impacts of the impulses attributed to the stock index on itself was fairly similar. Referring to the impact of crude oil impulses on the other variables, it was concluded that for the gold response was negative and that there was a sharp decline one period ahead, while in subsequent periods the reaction rate was weaker, and eventually the downward trend slowed down and stabilised. In the case of the stock index reaction, there was a short-lived positive increase followed by a downward trend with negative values, which then stopped. Only the response of crude oil to its own shocks almost died out after a period of decline lasting up to 10 months.

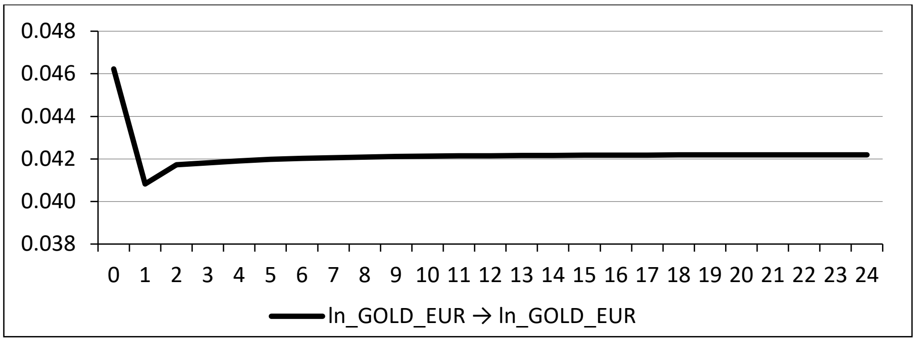

Fig. 3. IRF: impulse ln_GOLD_EUR, response ln_GOLD_EUR

Source: own elaboration.

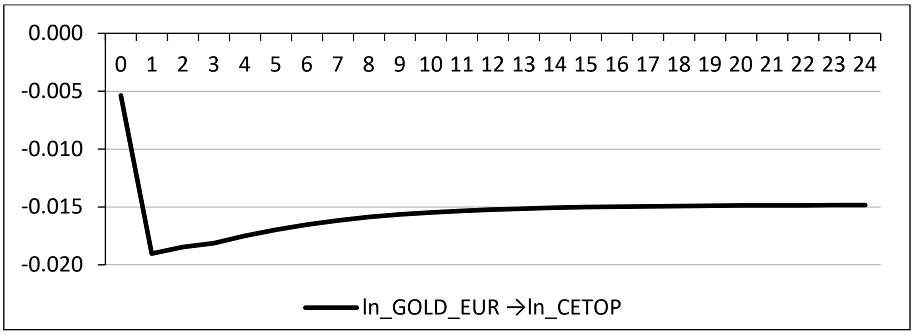

Fig. 4. IRF: impulse ln_GOLD_EUR, response ln_CETOP

Source: own elaboration.

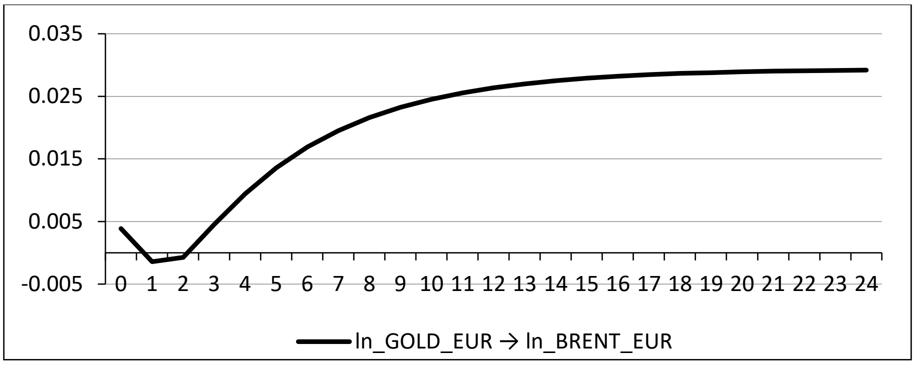

Fig. 5. IRF: impulse ln_GOLD_EUR, response ln_BRENT_EUR

Source: own elaboration.

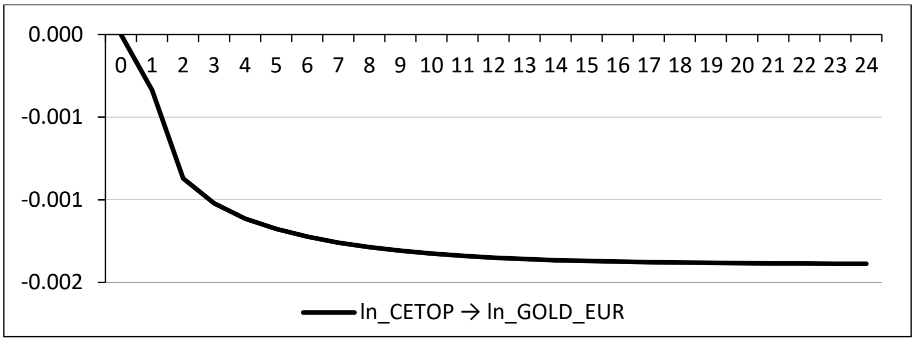

Fig. 6. IRF: impulse ln_CETOP, response ln_GOLD_EUR

Source: own elaboration.

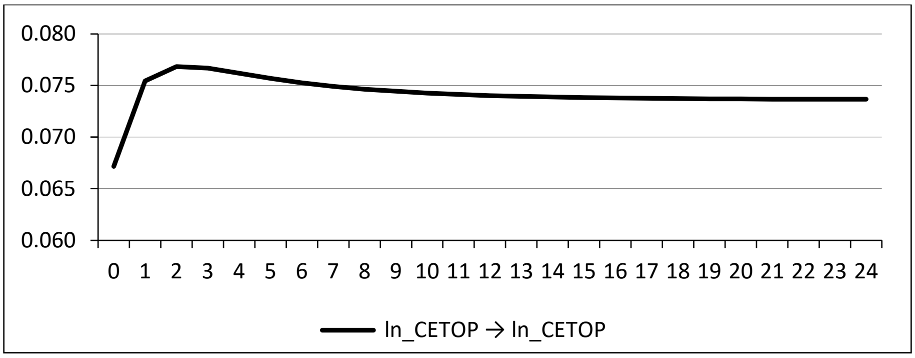

Fig. 7. IRF: impulse ln_CETOP, response ln_CETOP

Source: own elaboration.

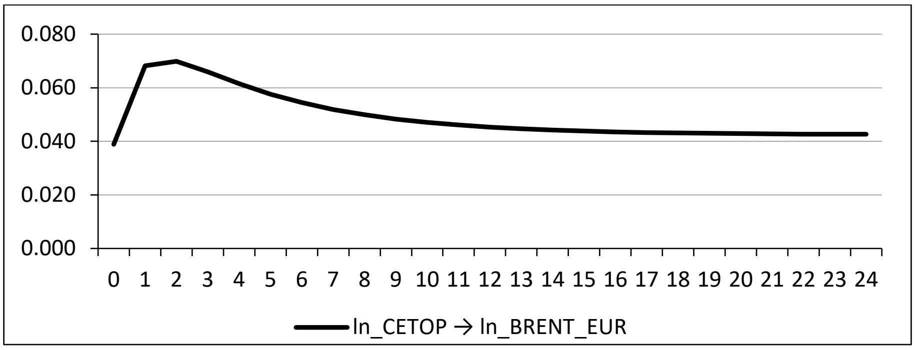

Fig. 8. IRF: impulse ln_CETOP, response ln_BRENT_EUR

Source: own elaboration.

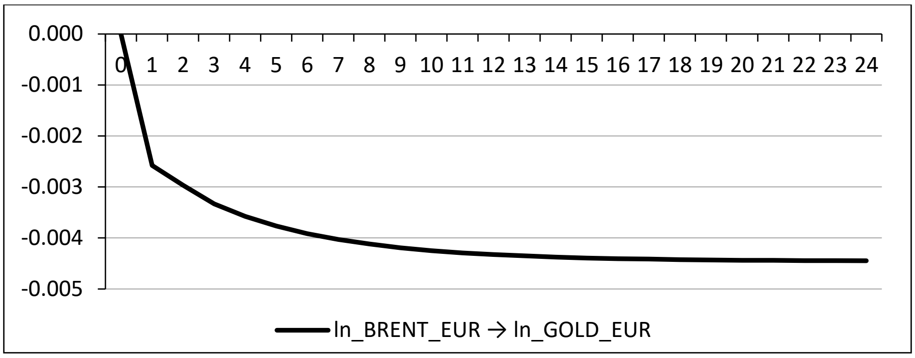

Fig. 9. IRF: impulse ln_BRENT_EUR, and response ln_GOLD_EUR

Source: own elaboration.

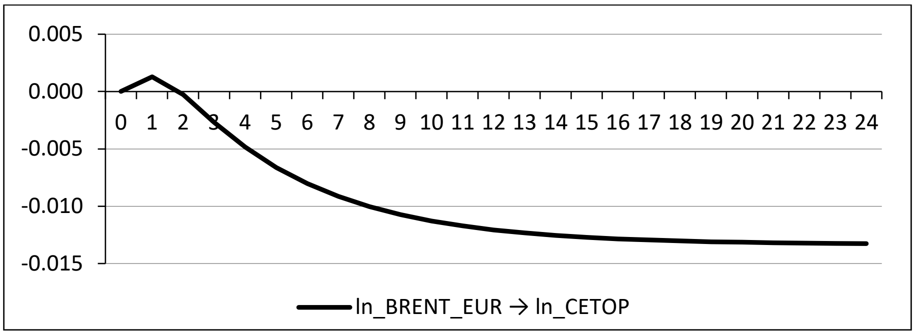

Fig. 10. IRF: impulse ln_BRENT_EUR, and response ln_CETOP

Source: own elaboration.

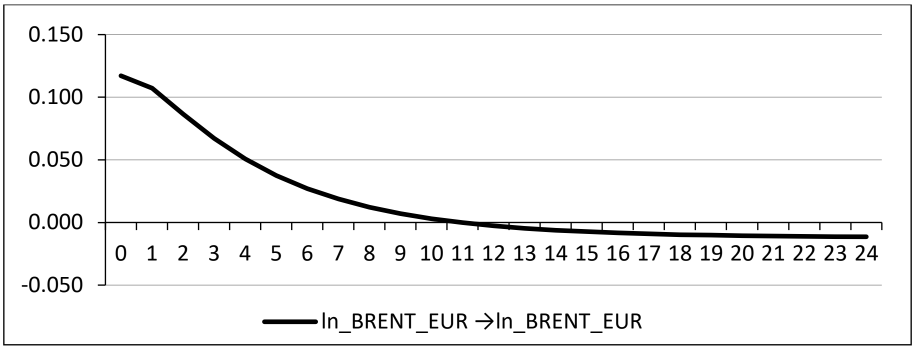

Fig. 11. IRF: impulse ln_BRENT_EUR, and response ln_BRENT_EUR

Source: own elaboration.

After the estimations, the author also ran diagnostic tests of the estimated model, starting with checking on the stationarity (Table 13). Further investigation involved analysing the plots and properties of equation residuals and ECM (autocorrelation, white-noise, stationarity, parameters stability). The detailed results are presented below.

Table 13. Results of the eigenvalue stability condition of the VECM model

Eigenvalue	Modulus
1	1
1	1
0.7879438	0.787944
0.2719203	0.27192
–0.07131156 + 0.03805217i	0.080829
–0.07131156 – 0.03805217i	0.080829

Source: own calculations.

The VECM specification imposed two unit moduli, the other being inside the unit circle.

The study plotted the residuals (Figures 12 to 14) and estimated the cointegration relationship (Figure 15). While analysing the plots for residuals, it was observed that the outlier observation occurred in March 2020 for the CETOP equation, which can be associated with the beginning of the spread of the coronavirus pandemic in Europe falling in this period. In general, the fluctuations were much higher during the pandemic, as was also the case for the BRENT equation residuals. Moreover, the impact of the financial crisis in November 2008 could be spotted. The GOLD equation residuals seemed to be the most volatile. The impact of the pandemic and the financial crisis was also apparent in the pattern of the ECM plot.

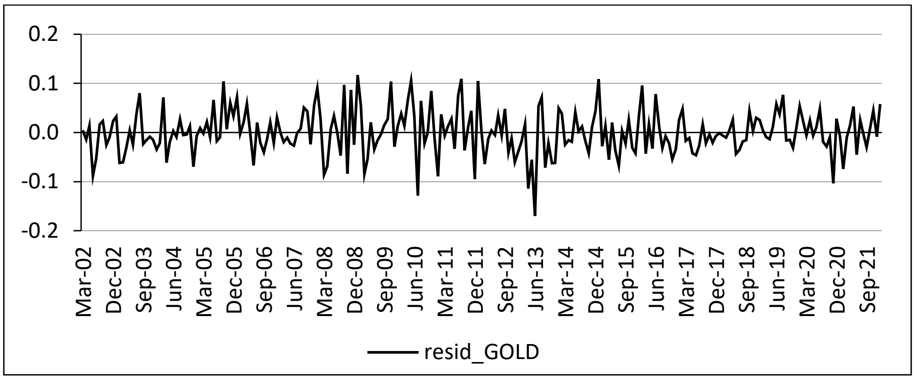

Fig. 12. Residuals of D.ln_GOLD_EUR equation

Source: own elaboration.

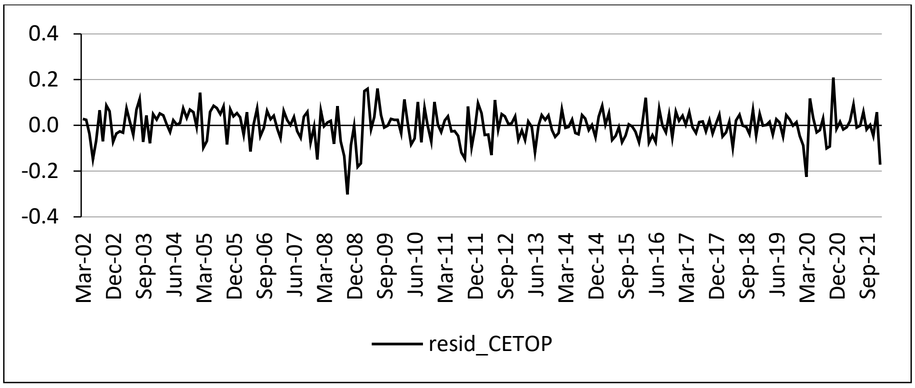

Fig. 13. Residuals of D.ln_CETOP equation

Source: own elaboration.

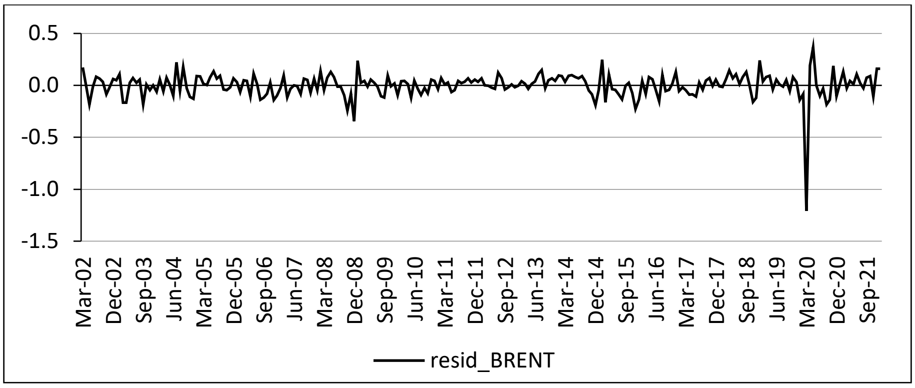

Fig. 14. Residuals of D.ln_BRENT EUR equation

Source: own elaboration.

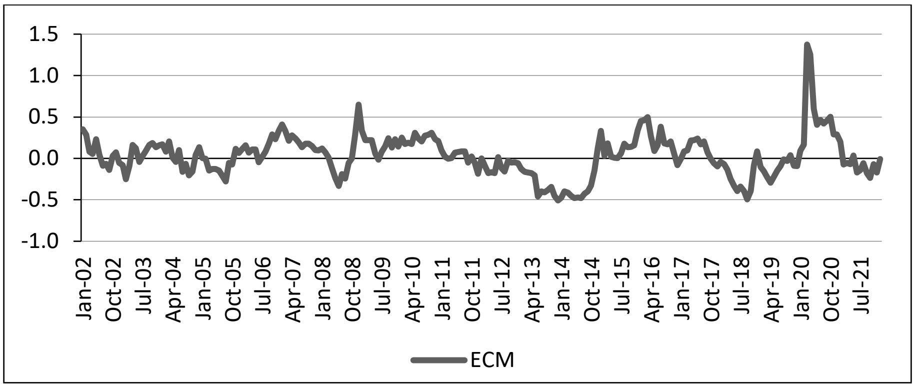

Fig. 15. Estimated cointegrating relation

Source: own elaboration.

To find out if the VECM disturbances were normally distributed a variety of tests for normality were applied, whose results are summarised in Table 14.

Table 14. Tests for normality of D_ln_GOLD_EUR, D_ln_CETOP, and D_ln_BRENT_EUR residuals

1. Jarque-Bera test			
Equation	chi2	df	Prob>chi2
1. D_ln_GOLD_EUR	4.944	2	0.08443
2. D_ln_CETOP	53.403	2	0.00000***
3. D_ln_BRENT_EUR	9595.561	2	0.00000***
ALL	9653.908	6	0.00000***

2. Skewness test				
Equation	Skewness	chi2	df	Prob>chi2
1. D_ln_GOLD_EUR	–0.01109	0.005	1	0.944340
2. D_ln_CETOP	–4.0512	11.680	1	0.00063***
3. D_ln_BRENT_EUR	–0.3826	439.737	1	0.00000***
ALL		451.422	3	0.00000***
3. Kurtosis test				
Equation	Kurtosis	chi2	df	Prob>chi2
1. D_ln_GOLD_EUR	3.7057	4.939	1	0.026260**
2. D_ln_CETOP	5.0512	41.723	1	0.000000***
3. D_ln_BRENT_EUR	33.385	9155.823	1	0.000010***
ALL		9202.485	3	0.000000***
4. Shapiro-Wilk W test				
Equation	W	V	z	Prob>z
1. D_ln_GOLD_EUR	0.98654	2.33800	1.97200	0.02432**
2. D_ln_CETOP	0.97727	3.94700	3.18700	0.00072***
3. D_ln_BRENT_EUR	0.75547	42.47200	8.70100	0.00000***

H_0 is rejected at **5%, ***1%

Source: own calculations.

The null hypothesis of normal disturbance was rejected by the Jarque-Bera test for equations 2 and 3 at 1% significance level, while at 5% it could not be rejected for equation 1. The evidence of non-normality was confirmed also for equations 2 and 3 by the skewness test. The evidence for instability was also supported by the results of the kurtosis test for all the equations at 5% – however not at 1% for equation 1. The Shapiro-Wilk test results suggest that the residuals of equations 2 and 3 were not normally distributed due to the rejection of the null hypothesis at 1%, while this was rejected at 5% but not at 1% in the case of the equation 1 residuals.

The results of the autocorrelation tests for the residuals are presented in Table 15. According to the portmanteau test and the Lagrange multiplier test there was no evidence of residual autocorrelation at any lag order as the null hypothesis was not rejected at 5%.

Table 15. White-noise tests statistics

1. Portmanteau test for white noise of residuals, lags(12)		
Equation	Portmanteau statistic *Q*	Prob > chi2
D_ln_GOLD_EUR	7.9140	0.7918
D_ln_CETOP	7.3848	0.8312
D_ln_BRENT_EUR	5.9757	0.9173
2. Lagrange-multiplier test (df=9)		
lag	chi2	Prob > chi2
1	6.9332	0.64407
2	7.9504	0.53915
3	7.1769	0.61871
4	10.8846	0.28371
5	5.5009	0.78864
6	6.4247	0.69677
7	15.9099	0.06879
8	13.2094	0.15336
9	10.5051	0.31116
10	4.5705	0.87003
11	7.1236	0.62425
12	13.4982	0.14133

Note: H_0: no autocorrelation at lag order, $p > 5\%$

Source: own calculations.

The study also provided the results of the cumulative sum test for parameter stability (the CUSUM test) for the equations residuals in Table 16.

Table 16. CUSUM test results

Equation	Statistic	Test statistic	Critical value		
			1%	5%	10%
D_ln_GOLD_EUR	recursive	0.6426**	1.143	0.9479	0.8500
D_ln_CETOP	recursive	0.5211**	1.143	0.9479	0.8500
D_ln_BRENT_EUR	recursive	0.2923**	1.143	0.9479	0.8500

Note: H_0: No structural break; **H_0 is accepted at 5%

Source: own calculations.

The null hypothesis of coefficient stability at 5% could not be rejected as the test statistics were less than the 5% critical value. The model's parameters were stable.

The author also carried out the Dickey-Fuller test for the residuals of the cointegrating equation (Table 17), which were stationary as the null hypothesis of non-stationarity at 1% was rejected. There was a long-term equilibrium between the log-prices of gold, stock, and crude oil.

Table 17. Dickey-Fuller test statistics for long-term equation residuals

Test statistic $Z(t)$	Critical values for regression-residuals based cointegration test		
–4.572***	10%	5%	1%
	–3.47	–3.78	–4.35

Note: ***H_0 is rejected at 1%

Source: own calculations.

6. Discussion and conclusions

There is a large body of research concerned with cointegration and the causal relationship between the markets of numerous asset classes, mainly stock, crude oil, and gold, which were also the focus of this paper. To assess and compare the results, one should however consider that some authors applied different methods (models) and their studies covered various periods. To the best of the author's knowledge no similar research using the VECM approach addressed the interrelations between stock, crude oil, and the gold markets of Central Europe examined in this paper. Yet, one can compare the patterns observed in other regions or countries with these results.

The issue of the long-term equilibrium has been analysed by many authors. Al-Ameer et al. (2018) reported the long-term relationship between variables, while the other cited research shows no cointegration, e.g. Bhuvaneshwari & Ramya (2017), Irshad et al. (2014), Lodha (2017), Singhal, Choudhary & Biswal (2019), which determined the type of model applied in the further analysis (VAR vs. VECM). The author considered different trend specifications while carrying out the Johansen test, which was not always the case for the cited authors, and the same refers to the VECM specification. The study achieved mixed results concerning the number of cointegration vectors (r=0 vs. r=1) depending on the statistics, however rank r=1 was more frequent. To this end, the research hypothesis stating that market prices are cointegrated was confirmed by the Johansen cointegration test. Moreover, all the coefficients in the long-term equations were statistically significant and the ECM residuals were stationary. What is more, the signs of the coefficients for the log-prices stayed in line with financial market theory, i.e. the positive relation between gold and crude oil, and the negative one for gold and the stock index. As the log-prices were integrated of order 1, the study analysed the correlation between the log-returns to avoid the problem of spurious regression. A weak negative and statistically non-significant correlation was observed between gold and stock returns (–0.0573, *p*-value=0.3777>5%), whilst the positive one between crude oil and gold (0.0422, *p*-value=0.5164>5%). On the other hand, a statistically significant positive correlation was found between crude oil and stock returns (0.3301, *p*-value=<1%).

The results presented in the literature review show that unidirectional causality between the aforementioned assets was the most common. Firstly, the authors reported the links between gold and stock. Secondly, the cases of interrelations concerning stock and crude oil were reported, however being less frequent. The lack of causality or bilateral relationship between the variables were relatively rare. For the short-term equations, which were the basis to carry out the linear causality analysis, not all the coefficients were statistically different from zero. The residuals of the estimated model were not autocorrelated, and they did not follow the normal distribution, however the model parameters were stable. Regarding this, the study showed that gold returns Granger-cause stock returns, which was consistent with the results obtained by many authors, cf. Al Kharusi & Basci (2019), Tiwari, Adewuyi & Roubaud (2019), Bouri et al. (2017), Tursoy & Faisal (2018), and Mensi, Reboredo & Ugolini (2021). Moreover, the author indicated that stock returns impact on crude oil whereas the other authors reported the causality running in the opposite direction. Crude oil as a Granger-cause for stock was proved, among others, by Peng et al. (2020), Enwereuzoh, Odei-Mensah & Junior (2021), Bouri et al. (2017), Singhal, Choudhary & Biswal (2019). Based on the Granger linear causality test, the formulated research hypothesis assuming that the changes of prices in the gold and crude oil markets have an impact on the stock market was confirmed only in the first case (gold vs. stock) as the second considered relationship ran in the opposite direction, i.e. from the stock to the crude oil market.

According the FEVD analysis, gold was the most independent variable in the system, as it was mainly explained by its own shocks, however the residuals were characterised by the highest volatility. The response to the gold impulses was negative in the case of stock index, and positive for crude oil. On the other hand, gold reacted negatively to the stock and crude oil shocks. The response of stock to crude oil innovation was negative, while the answer of the crude oil to stock error was positive. Thus, the asymmetry for this pair of variables in their reactions was observed, while the symmetry was characteristic of gold and the stock index.

These findings are important for those considering investment in the Central European stock exchanges. While diversifying their portfolios, they should consider the cointegration of asset prices and the direction of causality between the analysed returns. One can assume that the rapid increase in the gold prices due to the COVID-19 pandemic lasted for a relatively short time to have any significant impact on the obtained results, still there is no doubt that such events, along with the economic slowdown and an unprecedented increase in the oil prices due to the outbreak of the war in Ukraine, will affect interrelations between the analysed markets. Moreover, the linear analysis can be extended by applying non-linear time-series models, since financial variables may exhibit nonlinear behaviour. For that reason, not all the interrelations are captured by the linear models and causality tests which are in common use. As an alternative, one can apply the Markov-switching models and time-switching autoregressive models (TAR), whilst the GARCH classes models for modelling volatility are also useful. Parametric and non-parametric methods are being developed to test nonlinear linkages between financial time series. A classification, including a wide range of possible tests for models' linearity and nonlinear approach to the Granger-causality testing was presented by Osińska (2008, pp. 219-240). An investigation of the nonlinear dependences will be the field of further research.

References

Akbar, M., Iqbal, F., & Noor, F. (2019, August). Bayesian analysis of dynamic linkages among gold price, stock prices, exchange rate and interest rate in Pakistan. *Resources Policy, 62*, 154-164. https://doi.org/10.1016/j.resourpol.2019.03.003

Al Kharusi, S., & Basci, E. (2019). Cointegration and causality between the GCC stock indices and gold indices. *Business and Economic Horizons, 15*(1), 60-69. https://doi.org/10.15208/beh.2019.4

Al-Ameer, M., Hammad, W., Ismail, A., & Hamdan, A. (2018). The relationship of gold price with the stock market: The case of Frankfurt Stock Exchange. *International Journal of Energy Economics and Policy, 8*(5), 357-371.

Aliu, F., Nadirov, O., & Nuhin, A. (2021). Elements indicating stock price movements: The case of the companies listed on the V4 stock exchanges. *Journal of Business Economics and Management, 22*(2), 503-517. https://doi.org/10.3846/jbem.2021.14181

Becketti, S. (2013). *Introduction to time series using Stata.* College Station: Stata Press Publication.

Beckmann, J., Berger, T., & Czudaj, R. (2015). Does gold act as a hedge or a safe haven for stocks? A smooth transition approach. *Economic Modelling, 48*, 16-24. https://doi.org/10.1016/j.econmod.2014.10.044

Bermudez Delgado, N. A., Bermudez Delgado, E., & Saucedo, E. (2018). The relationship between oil prices, the stock market and the exchange rate: Evidence from Mexico. *North American Journal of Economics and Finance, 45*, 266-275. https://doi.org/10.1016/j.najef.2018.03.006

Bhuvaneshwari, D., & Ramya, K. (2017). Causal relationship between stock prices and gold rate: empirical evidence from India,. *Afro-Asian Journal of Finance and Accounting, 7*(4), 305-316. https://doi.org/10.1504/AAJFA.2017.087502

Bouri, E., Jain, A., Biswal, P., & Roubaud, D. (2017). Cointegration and nonlinear causality amongst gold, oil, and the Indian stock market: evidence from implied volatility indices. *Resources Policy, 52*, 201-206. https://doi.org/10.1016/j.resourpol.2017.03.003

Charemza, W. W., & Deadman, D. F. (1997). *Nowa ekonometria.* Państowe Wydawnictwo Ekonomiczne.

Chkili, W. (2022). The links between gold, oil prices and Islamic stock markets in a regime switching environment. *Eurasian Economic Review, 12*, 169–186. https://doi.org/10.1007/s40822-022-00202-y

Das, D., Kumar, S. B., Tiwari, A. K., Shahbaz, M., & Hasim, H. M. (2018). On the relationship of gold, crude oil, stocks with financial stress: A causality-in-quantiles approach. *Finance Research Letters, 27*, 169-174. https://doi.org/10.1016/j.frl.2018.02.030

Enders, W. (2010). *Applied Econometric Time Series* (3 ed.). Wiley & Sons.

Enwereuzoh, P. A., Odei-Mensah, J., & Junior, P. O. (2021). Crude oil shocks and African stock markets. *Research in International Business and Finance, 55*, 101346. https://doi.org/10.1016/j.ribaf.2020.101346

Financial portal stooq.pl: https://stooq.pl/q/d/?s=eurusd (accessed: 07.01.2022)

Irshad, H., Bhatti, G., Qayyum, A., & Hussain, H. (2014). Long run relationship among oil, gold and stock prices in Pakistan. *Journal of Commerce, 6*(4), 6-21.

Jain, A., & Biswal, P. (2016). Dynamic linkages among oil price, gold price, exchange rate, and stock market in India. *Resources Policy, 49*, 179-185. https://doi.org/10.1016/j.resourpol.2016.06.001

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration with applications to the demand for money. *Oxford Bulletin of Economics & Statistic, 52*(2), 169-210. https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x

Kusiedł, E. (2000). *Modele wektorowo-autoregresyjne VAR: metodologia i zastosowania.* Absolwent.

Lodha, S. (2017). A cointegration and causation study of gold prices, crude oil prices and exchange rates. *The IUP Journal of Financial Risk Management, 14*(1), 55-67.

Lütkepohl, H. (2005). New Introduction to Multiple Time Series Analysis. Springer-Verlage.

Mensi, W., Reboredo, J. C., & Ugolini, A. (2021). Price-switching spillovers between gold, oil, and stock markets: Evidence from the USA and China during the COVID-19 pandemic. *Resources Policy*, 73, 102217. https://doi.org/10.1016/j.resourpol.2021.102217

Osińska, M. (2008). *Ekonometryczna analiza zależności przyczynowych*. Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika.

Peng, Y., Chen, W., Wei, P., & Yu, G. (2020). Spillover effect and Granger causality investigation between China's stock market and international oil market: A dynamic multiscale approach. *Journal of Computational and Applied Mathematics*, 367, 112460. https://doi.org/10.1016/j.cam.2019.112460

Siemaszkiewicz, K. (2020). Dynamic relationship between precious metals and Central European stock markets. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, 64(12), 101-112.

Singh, D. (2014). The dynamics of gold prices, crude oil prices and stock in-dex comovements: Cointegration evidence of India. *Finance India*, 28(4), 1265–1274.

Singhal, S., Choudhary, S., & Biswal, P. (2019). Return and volatility linkages among international crude oil price, gold price, exchange rate and stock markets: Evidence from Mexico. *Resources Policy*, 60, 255-261. https://doi.org/10.1016/j.resourpol.2019.01.004

Steiner, M., & Bruns, C. (1996). Wertpapiermanagement. Schäffer Poeschel Verlag.

Sujit, K. S., & Kumar, B. R. (2011). Study on dynamic relationship among gold price, oil price, exchange rate and stock market returns. *International Journal of Applied Business and Economic Research*, 9(2), 145-165.

The Budapest Stock Exchange (BSE): https://www.bse.hu/pages/market-overview#CETOP (accessed: 07.01.2022)

The U.S. Energy Information Administration (EIA): https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm (accessed: 07.01.2022)

The World Gold Council (WGC): https://www.gold.org/goldhub/data/gold-prices (accessed: 07.01.2022)

Tiwari, A. K., Adewuyi, A., & Roubaud, D. (2019). Dependence between the global gold market and emerging stock markets (E7+1): Evidence from Granger causality using quantile and quantile-on-quantile regression methods. *The World Economy*, 42(7), 2172-2214. https://doi.org/10.1111/twec.12775

Tursoy, T., & Faisal, F. (2018). The impact of gold and crude oil prices on stock market in Turkey: Empirical evidences from ARDL bounds test and combined cointegration. *Resources Policy*, 55, 49-54. https://doi.org/10.1016/j.resourpol.2017.10.014

Received: October 2022, revised: June 2023