Causality in mean and variance between returns of crude oil and metal prices, agricultural prices and financial market prices

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Abstract. In the short run the rate of return on commodities mostly depends on investors' reaction to incoming information on the world economic situation, that is the global demand, as well as information on the fluctuations in the supply of those commodities. The paper presents the analysis of dependencies between the prices of crude oil and various metals, energy sources, agricultural raw materials, food and beverages and the variables specific for the financial market. The methodology was based on Cheung and Ng and Hong tests, which allow to analyse Granger causality of daily returns both in mean and variance. The results of the analysis indicated the existence of simultaneous dependencies between the prices of crude oil and the prices of other commodities. The analysis also revealed that the price of crude oil is the Granger cause of natural gas, S&P 500, coffee, corn, cotton and copper prices. The results of the analysis indicate that the prices of platinum, natural gas and the value of US 30 Year Bonds were the Granger cause of the crude oil prices. Causality of returns in variance was observed in several pairs only.

Keywords: crosscorelations, arma-egarch, causality in mean, causality in variance.

JEL Classification: C32, G15, O13, Q37
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1 Introduction

The rise in the prices of a substantial number of commodities can be observed recently. This phenomenon can be explained by the fact that certain sources react to global macroeconomic factors in a similar way. Energy, mostly obtained from crude oil and gas, is mostly used in industry. Thus, an expected increase in production and an increased demand for metals used in industry (copper, silver, platinum) should cause the reaction of the prices of energy sources. Energy prices should also react to the changes in the values of stock market indices (SP 500) or the monetary policy (US30Y Bond), which might be treated as aggregate data on the condition of the US economy and the world economy. On the other hand, key information for the crude oil supply (mainly armed conflicts on the areas belonging to oil producers) will influence metal prices and the state of the world economy. It can be expected that there will be connections between USD dollar exchange (USD Index) and the prices of commodities paid for in dollars even though produced in countries with other currencies. The links between crude oil prices and crops (coffee, cocoa, soybean, rice and cotton) are different. Kilian, Park [9] claim that the price of crude oil has the greatest influence on food prices, because an increasing price of crude oil increases both the transport costs and food production costs through the increase of fuel costs for mechanized farming. Additionally, growing prices of crude oil increase the economic motivation for the production of biofuels (corn, soybean, sugar cane, oil palm, etc.). This means that farmers replace e.g. cotton with corn, which in turn leads to the increase of cotton prices due to its lack. Also, the demand for coffee, cocoa, rice and soybean is not flexible (consumers' habits). Coffee and cocoa are produced on the southern hemisphere, but consumed mostly on the northern hemisphere (Europe, the USA), so the prices of those products depend on the costs of transport (crude oil), unlike soybean or cotton, which are mainly produced and processed in Asia (China). Additionally, those plants are annual, which means that the changes in their prices can lead to the changes of crops; they are also sensitive to weather factors. As a result, the existence of the cycles can be expected in case of those plants (similar to so called pork cycles). Gold is a different category, as it does not play an important role in the industry and is treated as a form of capital investment.

All above mentioned commodities are traded on commodities exchanges. A significant volume of transactions is not connected with the physical delivery of commodities, but is based on the settlement of contracts (the

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differences between the prices of an underlying instrument and an exercise price). Thus, for most participants commodities are a form of securing of investment portfolios. In this case, it may turn out that in the short run the prices of commodities are shaped not by fundamental factors but by broadly understood investors' strategies.

The aim of the paper is to check short term connections between a wide range of financial instruments, such as, prices of energy sources, metals, food, currencies, treasury bills and crude oil. The approach adopted in the analysis allowed for the evaluation of causality in mean (for the rate of return) and causality in variance. In the first case, the hypothesis verified states that past values of return of one instrument are correlated with current returns of another instrument. In the second case, the connections between conditional variance of instruments returns are analysed. This approach allows for the analysis of price co-movement and information transmission analysis.

The paper investigates the following research hypotheses: in the short run the rates of return of crude oil should be the Granger cause of rates of return of all above mentioned financial instruments; the rates of return of metals, treasury bills, index SP500 and natural gas are the Granger causes of crude oil; the rates of return of food are not the Granger cause of crude oil.

2 Research literature

The analysis of connections between the prices of energy sources and factors shaping the economic condition (the growth of GDP, metals prices, food prices) has been dealt with in many works. Most of them use the methodology developed for multidimensional autoregressive models (cointegration, impulse response, Granger causality). Campiche's et al. [3] findings confirmed the lack of cointegration between oil and corn, sorghum, sugar, soybeans, soybean oil, and palm oil markets. Different results appeared in Harii et al [6], who identified a long term equilibrium relationship between oil prices and all agricultural prices except wheat. Basher, Haug, Sadorsky [1] found out that positive shocks to oil prices tend to depress emerging market stock prices and the US dollar exchange rates in the short run. Nazlioglu, Soytas [10] used panel cointegration and studied dynamic relationships between the world oil prices and the prices of various agricultural commodities. The results obtained provided strong evidence of the impact of world oil price changes on agricultural commodity price. Papież, Śmiech [13] analysed the relations between crude oil prices and the prices of other energy sources, and their results confirmed a dominating role of crude oil on the primary fuels market. The dependencies between the prices of crude oil and metals were investigated by Soytas et al. [18] and Sari et al. [17] while the gas market was described by Wasilewski [19] and Rychlicki, Siemek [15]. The dynamics of the changes in the prices of raw materials can be investigated with the use of price indices, widely described by e.g. Białek [2].

3 Methodology

Most of the existing empirical studies regarding return or volatility spillover use various kinds of Granger tests in which residuals (squared residuals) of one variable are regressed by their own lags or lags of other variables. This is the way how multivariate GARCH model works. Cheung and Ng [4] proposed a two-step procedure to detect patterns of spillover between markets. The greatest advantage of this procedure is the flexible specification of the innovation process and robustness to asymmetric and leptokurtic errors. In the first step, it is necessary to estimate a time-varying conditional mean and variance models of returns in different markets,

Here we assumed that returns of each instrument price $y_{i,t}$ are characterized by the process:

$$y_{1,t} = \mu_{i,t} + z_{i,t}\sigma_{i,t} \tag{1}$$

where $\mu_{i,t}$ is the conditional mean, $\sigma_{i,t}^2$ is the conditional variance of $y_{1,t}$, $z_{i,t}$ is an independent white noise process with zero mean and unit variance. The conditional variances $\sigma_{i,t}^2$ are characterized by EGARCH models, first proposed by Nelson [11]. During the next stage, cross-correlation functions (CCF) of standardized innovations from these models are used to test causality in mean and causality in variance effects. Both kinds of causality are here interpreted as return or volatility spillover. In the paper we used modified test statistics proposed by Hong [7].

4 Data and empirical results

The analysis of causalities was conducted using the daily data (five working days per week) from the period 4 January 2006 – 30 December 2011. The data used in the analysis included the prices of futures contracts traded on the Commodity Exchange (COMEX), the New York Mercantile Exchange (NYMEX) and the Chicago Board

of Trade (CBOT) and indices. The following are the variables describing the following markets: the energy market, the financial market, the agricultural market and the metals market. The detailed description of the data set and descriptive statistics for daily time series data are presented in Table 1.

Variable	Symbol	Unit	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis
Crude oil	CL.F	$/bbl	79.3	76.2	144.9	34.4	20.04	0.60	3.50
Natural gas	NG.F	c/mmBtu	6.0	5.6	13.6	2.5	2.15	0.99	3.80
USD Index	USD_I	-	58.0	57.9	67.7	50.6	3.49	0.24	2.74
S&P 500	^SPX	-	1226.9	1266.3	1565.2	676.5	190.09	-0.56	2.72
US30Y Bond	US.F	-	119.5	117.9	146.1	105.1	9.05	0.90	3.31
Cocoa	CC.F	$/t	2442.0	2598.0	3748.0	1380.0	610.00	-0.25	1.78
Coffee	KC.F	c/lb	151.2	132.2	305.6	94.0	52.58	1.30	3.38
Corn	C.F	¢/bu	444.5	394.6	786.0	204.0	148.77	0.55	2.29
Soybean	S.F	¢/bu	1012.3	987.0	1635.0	537.0	269.68	0.00	2.05
Cotton	CT.F	c/lb	76.9	66.0	218.6	40.1	34.69	1.90	6.38
Copper	HG.F	¢/lb	320.5	332.5	463.1	127.9	72.78	-0.61	3.01
Gold	GC.F	$/ozt	996.2	921.4	1903.3	521.3	339.65	0.69	2.52
Platinum	PL.F	$/ozt	1433.2	1410.1	2258.3	765.2	310.65	0.26	2.32
Silver	SI.F	$/ozt	1843.6	1521.0	4846.0	884.0	862.20	1.41	3.95

Table 1 Summary statistics for daily time series

Specifically, the returns are defined as $r_t = \ln(p_t / p_{t-1})$ where p_t is the opening price on day *t*. Next, it needed to be checked if the analysed variables contain a structural break which should by taken into account. It is shown in Rodrigues et al. [14], that the procedures presented in Cheung and Ng and Hong are not resistant if there is a structural break in the volatility. Therefore, we examined the return series for the presence of a structural break in unconditional variance. We used the test proposed first by Inclan, Tiao [8] and then improved by Sanso et al., [16]. The effect of a structural brake was eliminated by the method proposed by Nouira et al. [12]. The method suggested by Nouira et al. [12] was used to eliminate the effect of a structural break in variance and to obtain filtered return series. Further analysis was conducted on these filtered series. Next, using the augmented Dickey–Fuller (ADF) method and KPSS test, it was verified that all return prices rejected the null hypothesis of the existence of a unit root, which means that the considered return series were stationary.

Because the analysis of causality in these tests was conducted on standardized residuals of ARMA-EGARCH, at first this kind of models was estimate. The models were chosen on the basis of the Akaike's information criterion. Due to lack of space, the paper contains only the classes of models without the estimated values of parameters for particular financial instruments. EGARCH (1,1) model with the Student-t distribution was estimated for cocoa, corn, soybean, cotton, copper, gold, platinum, and silver; EGARCH (1,1) model with the normal distribution was estimated for the USD Index; AR (1) – EGARCH (1,1) model with the Student-t distribution for crude oil; GARCH (1,1) model with the Student-t distribution for natural gas and coffee; GARCH (1,1) model with the normal distribution for US30Y bond; and GARCH (1,2) model with the normal distribution for S&P 500. For the estimated models the values of Box-Pierce statistics for the first 20 autocorrelation of the standardized residuals and the squared standardized residuals were statistically insignificant.

	Natural gas	**USD Index**	**S&P 500**	**US30Y Bond**	**Cocoa**	**Coffee**	**Corn**	**Soybean**	**Cotton**	**Copper**	**Gold**	**Platinum**	**Silver**
Crude oil	**0.26**	**-0.31**	**0.33**	**-0.21**	**0.22**	**0.27**	**0.17**	**0.21**	**0.22**	**0.44**	**0.40**	**0.40**	**0.45**

Table 2 Correlations between standardized residuals of crude oil and standardized residuals of other commodities and financial investments

Note: All correlation coefficients are statistically significant at the 1% level, taking into account the effect of multiple testing.

The values of correlation coefficients between standardized residuals are presented in Table 2. These values may be interpreted as contemporaneous causality between the returns on the market). The strongest positive

correlation can be observed between the standardized residuals of crude oil price and metals prices (about 0.40-0.45). This indicates a large contemporaneous causality between the prices of the crude oil and metals (copper, gold, platinum, silver) in the years 2006-2011. A significant positive correlation coefficient can also be observed between standardized residuals of crude oil price and S&P 500. However, an average negative correlation exists between the prices of crude oil and the remaining variables characteristic for the financial market. This indicates an average contemporaneous causality between the prices of the crude oil and the USD index and US 30 year bond. A significant positive correlation can be seen between standardized residuals of oil price and the prices of agricultural market (cocoa, coffee, corn, soybean and cotton). Contemporaneous causality between the prices means that information is absorbed by both markets at the same time (within the same calendar day).

Further analysis will be aimed at checking the existence of Granger causality between the returns of crude oil and other commodities and financial investments. In order to test causality in mean, standardized residuals are used from ARMA-EGARCH models and cross-correlation functions were estimated. Test Q 1 was used in the analysis of causality in mean. The value of the test was estimated for one day (M = 1), for two days (M = 2), and for one week (M = 5). The construction of Cheung and Ng test, especially the hypotheses tested, resulted in a situation in which rejecting the null hypothesis for low M values causes the rejection of the null hypothesis also for higher M values. The results of the test for the null hypothesis (crude oil is not the Granger cause in mean of other commodities and financial investments) and the results of the test for the null hypothesis (other commodities and financial investments are not the Granger cause in mean of crude oil) are given in Table 3.

	Natural gas	**USD Index**	**S&P 500**	**US30Y Bond**	**Cocoa**	**Coffee**	**Corn**	**Soybean**	**Cotton**	**Copper**	**Gold**	**Platinum**	**Silver**
Null hypothesis: the crude oil price is not the Granger cause in mean of other commodities prices													
M=1	**0.001**	0.305	**0.046**	0.196	0.649	**0.006**	**0.000**	0.243	**0.000**	**0.002**	0.464	0.736	0.773
M=2	**0.000**	0.485	**0.017**	0.317	0.713	**0.000**	**0.000**	0.399	**0.000**	**0.000**	0.628	0.735	0.742
M=5	**0.000**	0.319	**0.050**	0.236	0.758	**0.000**	**0.000**	0.520	**0.000**	**0.000**	0.744	0.797	0.820
Null hypothesis: other commodities prices are not the Granger cause in mean of the crude oil price													
M=1	**0.019**	0.732	0.101	**0.027**	0.132	**0.000**	**0.000**	**0.033**	**0.000**	0.108	0.639	**0.000**	0.859
M=2	**0.001**	0.734	0.116	**0.003**	0.185	**0.000**	**0.000**	**0.006**	**0.000**	0.131	0.709	**0.000**	0.753
M=5	**0.001**	0.686	**0.031**	**0.002**	0.334	**0.000**	**0.000**	**0.024**	**0.000**	0.119	0.343	**0.000**	**0.028**

Table 3 Causality-in-mean test results in the years 2006-2011- *p*-value are given

The results of the causality-in-mean test show that in the period 2006-2011 the price of crude oil was not the Granger cause of USD index, cocoa, gold and silver and that those prices and the index were not the Granger cause of crude oil. This means that past information regarding the price of crude oil did not improve the forecasts of the price of cocoa, gold, silver and USD index (and vice versa). However, the price of crude oil was the Granger cause of natural gas, coffee, corn and cotton prices (and vice versa), which means that the price of crude oil improved the forecasts of average prices on the energy market and the prices on the agricultural market (and vice versa). The results of the analysis indicate that the price of crude oil was the Granger cause of the price of copper and index of S&P 500 (but those two variables were not the Granger cause of the price of crude oil). Thus, the forecast of the price of Copper and the value of index S&P 500 were improved by the values of the price of crude oil. A different situation could be observed in case of the prices of platinum, soybean and the value of US 30-year bonds. They were the Granger cause of the price of crude oil but the price of crude oil was not the Granger cause of those commodities.

Cheung and Ng [4] argued that the results obtained from causality tests in variance between two different markets (variables) are affected when there is evidence of causality in mean. Therefore, as Gebka, Serwa [5] suggest, ARMA-EGARCH were re-estimated to include the lagged return of series, which were the Granger cause (causality in mean) of a given variable. Re-estimation of the models allowed to eliminate the influence of causality in mean on the values of causality in variance test. Table 4 presents the values of correlation coefficients between the squared standardized residuals. The values of those coefficients can be interpreted as contemporaneous causality between the volatility of prices and indices. The greatest positive correlation can be seen between the squared standardized residuals of crude oil and copper (0.28) and crude oil and S&P 500 (0.28). This indicates large simultaneous links between the volatility of crude oil and copper as well as crude oil and financial markets. Also, contemporaneous causality could be observed between the volatility of the crude oil price and the volatility of other metals prices (gold, platinum, silver) and the volatility of the financial market (USD index, US 30-year bonds). However, there was no contemporaneous causality between the volatility of

crude oil prices and the volatility of agricultural market, except the volatility of coffee prices.

	Natural gas	**USD Index**	**S&P 500**	**US30Y Bond**	**Cocoa**	**Coffee**	**Corn**	**Soybean**	**Cotton**	**Copper**	**Gold**	**Platinum**	**Silver**
Crude oil	**0.16**	**0.15**	**0.28**	**0.08**	0.02	**0.10**	0.04	0.04	0.04	**0.28**	**0.20**	**0.18**	**0.19**

Table 4 Correlations between squared standardized residual of crude oil and squared standardized residuals of other commodities and financial investments

Similarly to the procedure described above, test Q1 was used in the analysis of causality in variance. The value of the test was estimated for one day (M = 1), for two days (M = 2), and for one week (M = 5). The results of the test for the null hypothesis (crude oil is not the Granger cause in variance of other commodities and financial investments) and the results of the test for the null hypothesis (other commodities and financial investments are not the Granger cause in variance of crude oil) are given in Table 5. The results of the causality-in-variance test indicate that in the period in question the volatility of crude oil prices was the Granger cause of the volatility of S&P500, the volatility of silver price and volatility of gold price after the period of one week (M= 5). This means that the volatility of crude oil prices influenced only the volatility of S&P 500 and the price of silver. On the other hand, the volatility of coffee price and the volatility of copper price were the Granger cause of the volatility of crude oil price.

	Natural gas	**USD Index**	**S&P 500**	**US30Y Bond**	**Cocoa**	**Coffee**	**Corn**	**Soybean**	**Cotton**	**Copper**	**Gold**	**Platinum**	**Silver**
Null hypothesis: the crude oil price is not Granger cause in variance of other commodities prices													
M=1	0.401	0.681	**0.001**	0.061	0.882	0.342	0.283	0.927	0.767	0.422	0.188	0.255	**0.021**
M=2	0.582	0.722	**0.000**	**0.038**	0.755	0.527	0.457	0.758	0.741	0.599	0.302	0.417	**0.001**
M=5	0.745	0.222	**0.000**	0.075	0.079	0.507	0.659	0.866	0.766	0.743	**0.007**	0.202	**0.014**
Null hypothesis: other commodities prices are not the Granger cause in variance of crude oil prices													
M=1	0.387	0.545	0.839	0.532	0.173	**0.000**	0.770	0.480	0.578	**0.048**	0.716	0.764	0.570
M=2	0.570	0.673	0.751	0.667	0.273	**0.000**	0.741	0.638	0.687	**0.019**	0.730	0.740	0.684
M=5	0.708	0.100	0.313	0.684	0.456	**0.000**	0.166	0.782	0.388	0.081	0.807	0.757	0.773

Table 5 Causality -in-variance test results in the years 2006-2011**-** *p*-value are given

5 Conclusions

The analysis of Granger causality in mean and variance between the price of crude oil and the prices of other commodities allowed to verify the hypothesis stated at the beginning of the paper. The analysis indicated simultaneous dependencies between the prices of crude oil and the prices of other commodities. This simultaneous causality may indicate that all analysed prices are influenced by similar fundamental factors. Unfortunately, on the basis of the analyses conducted it is not possible to answer the question whether it is the information on the world conjecture or the information on disturbances in supply. It is worth noticing that a significant negative correlation could be observed only between the prices of crude oil and the USD index and US 30 year bonds. The analysis indicated that contemporaneous causality was observed between the volatility of the crude oil price and the volatility of metals prices, and the volatility of financial market, but there were no simultaneous dependencies between the volatility of crude oil price and the volatility of the agricultural market, except the volatility of coffee prices. Unfortunately, the hypothesis stating that in the short run the rates of return of crude oil are the Granger cause of the rates of return of other commodities was not confirmed. The results of the causality-in-mean tests show that the price of crude oil was the Granger cause of the prices of natural gas, S&P 500, coffee, corn, cotton and copper. Similarly, it cannot be generalised that the rates of return of metals, treasury bills, index SP500 and natural gas were the Granger causes of crude oil. The results of the analysis indicate that the prices of platinum, natural gas and the value of US 30-year bonds were the Granger cause of the crude oil price. Also, the rates of return of food (except cocoa) were the Granger cause of crude oil.

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