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CAUSAL RELATIONSHIPS BETWEEN THE METALS MARKET AND THE STOCK MARKET IN THE FACE OF THE CHANGES TAKING PLACE IN THE MODERN WORLD

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Purpose: The high uncertainty on the industrial metals market that has occurred in recent years is an important premise for looking for methods that will allow for a good predict of the price of these raw materials and their volatility in the future. The detection of causal relationships between the price of metals and the rate of certain financial instruments may improve the quality of forecasts by reducing the variance of the prediction error. The aim of the research is to test of the causality between the rate of the selected metals and the factors influencing their price.
Design/methodology/approach: In order to study the causal relationships between the selected variables, the linear Granger test and the non-parametric Diks-Panchenko test were used. The second test can be used to detect causal relationships that are not necessarily linear.
Findings: In the first phase of the research, the Granger linear causality test of variable pairs was carried out. For this purpose, the equations of the VAR model with the same number of lags for both variables were estimated and the test of the total significance of the delays of a given variable was applied in the equation explaining the second variable. Then, in order to compare the obtained results, the non-parametric Diks-Panchenko test was used for the same variables.
Research limitations/implications: The indications of the Diks-Panchenko test depend on the number delays of variables. At a later stage of the research, one should, inter alia, check in more detail the influence of the delays adopted for the variables in this test.
Practical implications: Application in making investment decisions on the capital market.
Originality/value: The use of information on causal relationships to improve the quality of industrial metal price forecasts.

Keywords: Causality in the Granger sense, Diks-Panchenko test, metals market, the impact of the crisis and the pandemic.

Category of the paper: Research paper.

1. Introduction

Currently, metals are the subject of many market transactions and play a large role in various business strategies, where they are often treated as alternative and safe the investment assets. Therefore, it is important to observe and analyze the reasons that influence the changes in the price of these raw materials. The determinants of metal prices include, among others, the dollar exchange rate, rates of return on stock exchange indices, and crude oil. Research has shown that also demographic, macroeconomic and political factors influence the formation of commodity prices. However, there are many reasons for the volatility of commodity prices, and it is very difficult to determine which of them are the most important.

This article is largely empirical. Its overarching goal is to test the causality between the prices of copper and silver and the prices of specific financial instruments. For this purpose, the linear Granger test and the non-parametric Diks-Panchenko test were used. The literature (Syczewska, 2014) discusses the impact of the financial crisis on changes in the relationship of returns from financial instruments. Therefore, the results of the causality analysis for the crisis and in the pre-crisis period, and the results before and during the coronavirus pandemic were compared. The research used time series composed of the closing prices of selected financial assets obtained from the investment portals stooq.pl and investing.com. The research period covers the years 2005-2022, narrowed down to sub-periods in individual analyzes.

The article consists of two main parts: the first is theoretical (the methodology used in the analysis is briefly discussed and references to the literature are given), and the second is the analysis of financial data and its conclusions. The article ends with a summary.

2. Reasons for changes in copper and silver prices

Many industries today would not work without copper and silver. Copper is essential in the process of production, transmission, distribution and, above all, use of electricity. It is also a very good heat conductor, which is why it is of great importance in obtaining environmentally friendly energy, and therefore its importance for the energy sector is growing. The developments and breakthroughs made in telecommunications over the decades would not have been possible without this metal. Copper has also long played a vital role in the automotive industry. Without copper electrical and electronic components, intelligent motor and drive control would not be possible.

Silver, on the other hand, due to its properties, is used not only in jewelry, but also like copper, mainly in the manufacturing industry. It is an excellent guide and additionally has antibacterial properties. It is used in medicine and dental services, in the production of batteries and accumulators, LED chips, touch screens, in the construction of nuclear reactors, in photography and water treatment, and many other industries.

Therefore, it can be concluded that the demand of the global industry is the most important factor influencing the prices of copper and silver. The prices of these metals are rising in line with the increase in global industrial production. In good times, their prices rise, and in case of a risk of recession, they drop. As copper is used in almost all electronics and machinery and equipment power applications, its price is one of the better leading indicators showing trends across the economy.

However, the development of technology is not the only factor that affects copper and silver prices. The world prices of these metals are also shaped by the supply and demand game on the world's leading commodity exchanges. In addition, the prices of these metals are given and settled in US dollars, therefore the level of their prices is also affected by the exchange rate, i.e. the relation of the dollar to other currencies. When the dollar depreciates against other currencies, the prices of copper and silver increase, and when the dollar appreciates, the prices of these metals decrease (Figure 1).

It should not be forgotten that the level of inventories also affects the prices of copper and silver in the global markets. The higher the stocks, the slower the prices of metals grow in the context of an economic boom, and their prices fall faster in a downturn.

The price of metals may also be affected by changes in the price of crude oil. This is due to the fact that crude oil, as a popular raw material used in industry, can be regarded as a signal of its future economic situation. An increase in industrial production may lead to an increase in the demand for crude oil and its prices. Taking into account the use of metals in industry, the relationship between the price of crude oil and the prices of metals (e.g. silver and copper - Figure 1) may also result from the fact that an increase in industrial production entails an increase in demand for metals in industrial applications, which may translate into an increase in their prices (Kasprzak-Czelej , 2018).

Copper and silver prices also changing under the speculative behavior of investors, inflation, stock indices, and events of global importance.

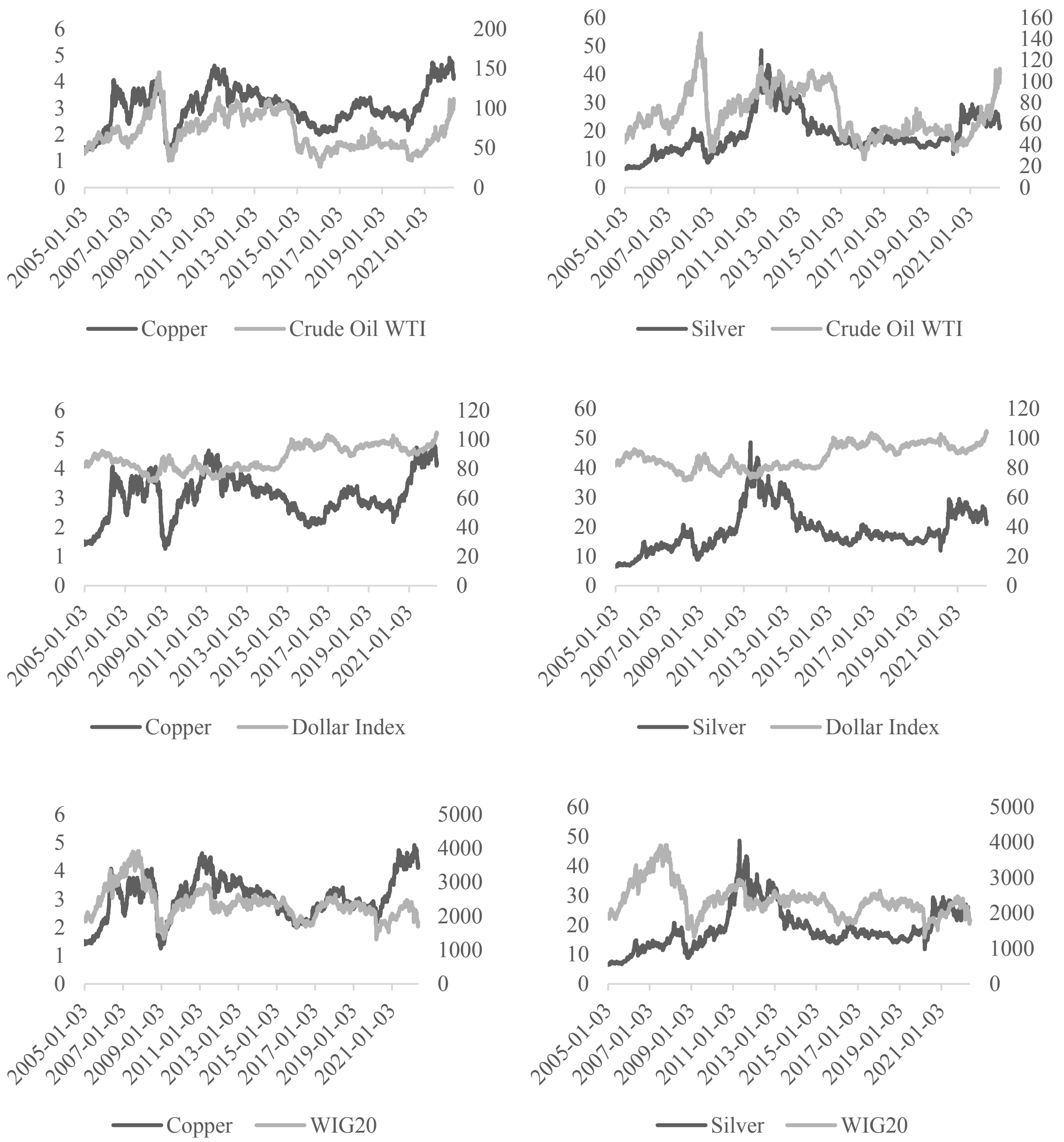

Figure 1. Development of silver and copper prices in comparison with the quotations of crude oil, the dollar index and the WIG20 stock exchange index in 2005-2022.

Source: own study.

3. Granger causality

Causality in the sense of Granger (Grenger, 1969) occurs when the variable *X* is the cause of the variable *Y*, i.e. if the current values of *Y* can be predicted with greater accuracy using the historical values of *X*, with the remaining information unchanged (Charemza, Deadman, 1997). This means that the forecast error for the *Y* variable will be smaller if the model includes the *X* variable than if it is omitted.

The definition of causality formulated by Granger concerns the occurrence of causal relationships between the stationary processes X_t and Y_t in the category of conditional probability distributions. By this definition, X_t is not the cause of Y_t if:

$$F\left(Y_t \middle| \left(X_{t-l_x}, \dots, X_{t-1}; Y_{t-l_y}, \dots, Y_{t-1}\right)\right) = F\left(Y_t \middle| \left(Y_{t-l_y}, \dots, Y_{t-1}\right)\right) \tag{1}$$

for any delay $l_x, l_y \geq 1$. In a situation where equation (1) does not hold, then X_t is the cause of Y_t, which in particular makes it possible to use the past values of X_t to predict Y_t.

The study of the occurrence of causal relationships consists in verifying the null hypothesis that X_t is not the cause of Y_t, which by definition is equivalent to condition (1). However, in econometric practice, the verification of the difficult-to-apply condition (1) is replaced by more operational methods (Orzeszko, Osińska, 2007). One of them is the limitation of the scope of the study to the identification of only linear causal relationships. In such a situation, the test consists in building and analyzing the VAR model with the same number of delays for both variables, k, and applying the test of the combined significance of the delays of a given variable in the equation explaining the second variable:

$$y_t = \alpha_{10} + \sum_{j=1}^{k} \alpha_{1j} y_{t-j} + \sum_{j=1}^{k} \beta_{1j} x_{t-j} + \varepsilon_{1t} \tag{2}$$

$$x_t = \alpha_{20} + \sum_{j=1}^{k} \alpha_{2j} x_{t-j} + \sum_{j=1}^{k} \beta_{2j} y_{t-j} + \varepsilon_{2t} \tag{3}$$

In equation (2), the null hypothesis:

$$H_0: \beta_{11} = \beta_{12} = \dots = \beta_{1k} = 0 \tag{4}$$

denotes no causal dependence in the Granger sense of the variable *X* to *Y*.

However, in the case of equality (3), the null hypothesis:

$$H_0: \beta_{21} = \beta_{22} = \dots = \beta_{2k} = 0 \tag{5}$$

denotes the lack of (linear) causality of the variable *Y* to *X*.

Causality in the Granger sense enables the study of information transmission between variables and the identification of the directions of the causality flow of the observed changes (Orzeszko, Osińska, 2007).

4. Nonlinear dependency test

Let (X, Y, Z) denote a random vector of the form $(X, Y, Z) = \left(X_{t-l_x}^{t-1}, Y_{t-l_y}^{t-1}, Y_t\right)$, and *f* is the probability density function. Diks and Panchenko (2006) proved that the null hypothesis, according to which X_t is not the cause of Y_t, means that the equality is satisfied:

$$\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \frac{f_{Y,Z}(y,z)}{f_Y(y)} \tag{6}$$

They also indicated that the following equality is equivalent to the key formula of Hiemstra and Jones (1994) as the starting point for nonlinear causality analysis:

$$\frac{E[f_{X,Y,Z}(x,y,z)]}{E[f_Y(y)]} = \frac{E[f_{X,Y}(x,y)]}{E[f_Y(y)]}\frac{E[f_{Y,Z}(y,z)]}{E[f_Y(y)]} \tag{7}$$

where

$$E[f_W(w)] = \int f_W^2(s)\,ds \tag{8}$$

is interpreted as a measure of the concentration of the random vector W.

In their study, they showed that in order to study causality, one should not focus on equality (7), but study the following formula:

$$E\left[\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} - \frac{f_{X,Y}(x,y)}{f_Y(y)}\frac{f_{Y,Z}(y,z)}{f_Y(y)}\right] = 0 \tag{9}$$

Thus, the implication of the null hypothesis is as follows.

$$E\left[\left(\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} - \frac{f_{X,Y}(x,y)}{f_Y(y)}\frac{f_{Y,Z}(y,z)}{f_Y(y)}\right) g(X,Y,Z)\right] = 0 \tag{10}$$

where $g(X, Y, Z)$ is a positive weighting function. Assuming that the null hypothesis is true, this expression is zero because by the formula (9) the value in parentheses is equal to zero. We reject the null hypothesis when the calculated value of the test statistic is too high. For $g(X, Y, Z) = f_Y^2(Y)$ formula (10) takes the form:

$$E[f_{X,Y,Z}(x,y,z)f_Y(y) - f_{X,Y}(x,y)f_{Y,Z}(y,z)] = 0 \tag{11}$$

Its estimator is based on the indicator function and is expressed by the formula:

$$T_n = \frac{(2\varepsilon)^{-l_x-l_y-1}}{n(n-1)(n-2)}\sum_i\left[\sum_{k,k\neq i}\sum_{j,j\neq i}\left(I_{ik}^{XYZ}I_{ij}^{Y} - I_{ik}^{XY}I_{ij}^{YZ}\right)\right] \tag{12}$$

where *n* is number of observations, *I*(.) is indicator function:

$$I_{i,j}^{W} = I(\|W_i - W_j\| \leq \varepsilon) = \begin{cases} 1, & \|W_i - W_j\| \leq \varepsilon \\ 0, & \|W_i - W_j\| > \varepsilon \end{cases} \tag{13}$$

$\|.\|$ denotes norm supremum.

5. Empirical analysis of causality

Conducting a study of linear and nonlinear causality requires quite a complicated time series analysis. In the study, for each analyzed variable, daily time series covering the period from the beginning of 2005 to May 2022 were prepared. Days for which one or more variables were missing were removed from the sample. To carry out the necessary analyzes, selected data were taken from the investment portals stooq.pl and investing.com. All calculations were made with the use of Gretl and GC programs and Microsoft Excel package. The abbreviations used in the further considerations and the basic descriptive statistics for the variables under consideration are presented in Tables 1 and 2:

Table 1.
Full and abbreviated variable names

Full name of the time series	Abbreviate name of the time series
Copper Futures	CU_F
Silver Futures	SI_F
Crude Oil WTI Futures	CL_F
U.S. Dollar Index Futures	DX_F
Stock Exchange Index WIG20	WIG20
KGHM Polska Miedź SA	KGH

Source: own study.

The selection of the above series for the study was based on a previous analysis of the factors influencing changes in the prices of copper and silver. On the other hand, the testing of causality between the prices of these metals and the closing prices of KGHM was dictated by the fact that the company is the largest producer of copper and silver in Poland.

Table 2.
Selected statistics for the full sample

Series	Mean	Median	Stan. Dev.	Kurtosis	Skewness	Range	Min	Max	ADF	*p*-value
CU_F	3.0627	3.0955	0.7377	-0.2589	-0.0874	1714875	230105	2638969	-2.6502	0.2578
SI_F	18.881	17.1450	7.1728	0.7417	0.9184	42.1570	865778	48.5840	-2.3787	0.3907
CL_F	69.739	63.6300	22.0957	-0.5165	0.5665	119.080	26.2100	145.2900	-1.8739	0.668
DX_F	87.499	86.5900	8.0746	-1.2639	0.0086	33.520	71.3300	104.8500	-2.2124	0.4821
WIG20	2366.7	2324.820	459.9313	1.2995	0.9510	2612.140	1305.73	3917.870	-3.1209	0.1013
KGH	86.123	89.7430	43.6544	-0.0890	0.3446	212.5444	678136	221.9200	-2.5998	0.2804

Source: own study.

The stationarity study of the time series under consideration is a starting point in the Granger causality study. The ADF test (Table 2) provided a solid basis for stating that all the time series considered are non-stationary (stationarity tests were performed at a significance level of 5%).

Table 3.
Selection of the number of delays in the VAR model and the results of the Granger test for pairs of returns on financial instruments

Variable pairs	AIC	BIC	Hypothesis H_0	Test G [*p*-value]	Hypothesis H_0	Test G [*p*-value]
CU_F /CL_F	0.731(3)	0.749(2)	CU_F ⟶ CL_F	0.7481 [0.5233]]	CL_F ⟶ CU_F	**5.8630 [0.0005]**
CU_F / DX_F	-2.066(2)	-2.052(1)	CU_F ⟶ DX_F	**3.7562 [0.0234]**	DX_F ⟶ CU_F	0.0981 [0.9066]
CU_F / WIG20	6.665(3)	6.680(2)	CU_F ⟶ WIG20	0.5987 [0.6158]	WIG20 ⟶ CU_F	**3.8510 [0.0091]**
CU_F / KGH	1.212(4)	1.228(2)	CU_F ⟶ KGH	1.6977 [0.1476]	KGH ⟶ CU_F	**11.739 [0.0000]**
SI_F/ CL_F	5.121(6)	5.143(2)	SI_F ⟶ CL_F	**2.9910 [0.0064]**	CL_F ⟶ SI_F	**4.5383 [0.0001]**
SI_F / DX_F	2.253(3)	2.263(1)	SI_F ⟶ DX_F	**3.6662 [0.0118]**	DX_F ⟶ SI_F	1.5236 [0.2062]
SI_F / WIG20	11.11(5)	11,12(1)	SI_F ⟶ WIG20	**3.4833 [0.0038]**	WIG20 ⟶ SI_F	1.0738 [0.3727]
SI_F / KGH	5,689(5)	5,707(2)	SI_F ⟶ KGH	**3.9627 [0.0014]**	KGH ⟶ SI_F	**6.8678 [0.0000]**

Source: own study.

In the next step, the results of studies on linear and non-linear causality are presented. The numbers in Tables 3 and 4 represent the values of the Granger test (G test) and the Diks-Panchenko test (D-P test) and the probability values (in square brackets) obtained when testing the null hypothesis of no causality. The situations in which the test showed the existence of causality at the significance level of 10% are marked in bold (Gurgul, Lach, 2009).

Table 4.
Diks-Panchenko test results for pairs of returns on financial instruments

Hypothesis H_0	l	Test D-P [p-value]	Hypothesis H_0	l	Test D-P [p-value]
CU_F → CL_F	1	**3.589[0.0002]**	CL_F → CU_F	1	**2.579[0.0049]**
	2	**2.994[0.0014]**		2	**2.370[0.0089]**
	3	**2.304[0.0106]**		3	**2.748[0.0029]**
	4	0.667[0.2524]		4	**1.288[0.0989]**
CU _F → DX_F	1	**2.811[0.0025]**	DX_F → CU_F	1	**1.406[0.0799]**
	2	**2.543[0.0055]**		2	**1.909[0.028]**
	3	0.113[0.4549]		3	**2.106[0.0176]**
	4	-0.208[0.5824]		4	**1.526[0.0635]**
CU_F → WIG20	1	**5.225[0.0000]**	WIG20 → CU_F	1	**2.641[0.0041]**
	2	**2.615[0.0045]**		2	**1.717[0.0429]**
	3	**1.611[0.0536]**		3	0.970[0.1661]
	4	1.269[0.1022]		4	**1.608[0.0539]**
CU _F → KGH	1	**5.995[0.0000]**	KGH → CU _F	1	**2.595[0.0047]**
	2	**3.783[0.0001]**		2	**2.586[0.0049]**
	3	**1.604[0.0544]**		3	1.032[0.1509]
	4	1.067[0.1431]		4	0.341[0.3667]
SI_F → CL_F	1	**3.747[0.0001]**	CL_F → SI_F	1	**3.815[0.0001]**
	2	**2.300[0.0107]**		2	**2.410[0.0079]**
	3	**2.268[0.0117]**		3	**2.469[0.0068]**
	4	**2.217[0.0133]**		4	**2.375[0.0088]**
SI_F → DX_F	1	**2.894[0.0019]**	DX_F → SI_F	1	**3.314[0.0005]**
	2	**2.076[0.0189]**		2	**2.037[0.0208]**
	3	**1.688[0.0457]**		3	**1.676[0.0469]**
	4	1.006[0.1572]		4	0.579[0.2812]
SI_F → WIG20	1	**3.383[0.0004]**	WIG20 → SI_F	1	**2.650[0.0040]**
	2	**1.882[0.0299]**		2	**2.387[0.0085]**
	3	**1.923[0.0273]**		3	**1.938[0.0263]**
	4	**1.707[0.0439]**		4	1.237[0.1081]
SI_F → KGH	1	**3.890[0.0001]**	KGH → SI_F	1	**1.973[0.0243]**
	2	**2.414[0.0079]**		2	**2.250[0.0122]**
	3	1.395[0.0815]		3	1.239[0.1076]
	4	0.857[0.1956]		4	0.067[0.4732]

Source: own study.

For each of the models considered, the maximum delay order was set at the level $\boldsymbol{r_{max}}$= 10, and then, using the Akaike information criteria (AIC) and Bayesian Schwarz criterion (BIC), the optimal delay order was selected from the $\{1, 2, ..., \boldsymbol{r_{max}}\}$ set. Their values were determined for 10 delays, and the optimal number of delays for each criterion was given in brackets (Table 3). Then, the models for the logarithmic returns were estimated (Osińska, 2008) and the cumulative significance test was applied to the first 2 delays, corresponding to the null hypothesis. It should also be added that in the case of nonlinear tests for each of the analyzed pairs of variables (Table 4), different delay levels were used: l = 1, 2, 3, 4 and the parameter ε = 0.5 (Syczewska, 2014).

In the causality analysis carried out using the Granger test among 8 pairs of variables, 2 two-way relationships were recorded (for pairs silver and crude oil, and silver and KGHM) and 6 one-way relationships. It was also noted that changes in the prices of crude oil and KGHM's shares are driving the price of metals. Additionally, the price of the WIG20 stock exchange index has an impact on copper. It follows that the inclusion of appropriate delayed variables in the individual equations allows for a better explanation and prediction of the development of the studied phenomena.

The results of the Diks-Panchenko test calculation (Table 4) indicate that the statistic may have different values with a different number of lags in the pair of variables. The analysis focused on the results for the value l = 1. The obtained results indicated the existence of bidirectional relations for all pairs of variables.

6. Testing of causality for pre-crisis and crisis, and pre-pandemic and pandemic periods

An interesting issue is the impact of the crisis or pandemic of coronavirus on possible changes in the direction of the causal relationship. Based on the literature (Olbryś, Majewska, 2014), the following subperiods were selected: 1.2005-9.2007 the period before the financial crisis and 10.2007-2.2009 as the period of the global crisis. This selection of dates allowed for the creation of time series with the same number of observations. The next two subperiods for the coronavirus pandemic include the following dates: pre-pandemic - 2.2018-2.2020; pandemic time - 3.2020-3.2022.

Based on the AIC and BIC information criteria, the selection of the optimal delay order was presented again, determined for the variables covering the periods before and during the financial crisis, as well as before the coronavirus pandemic and during the pandemic. The optimal number of delays for each criterion is shown in parentheses (Table 5).

In Table 6, columns 2 and 3 contain the values of the Granger test statistics for the pre-crisis period and during the crisis, and columns 4 and 5 for the pre-Covid 19 and during the pandemic period. Values for which the hypothesis of no causality has been rejected are marked in bold.

Table 5.
Selection of delays in the the number of VAR model for pairs of variables for the periods: before and during the financial crisis and before the coronavirus pandemic. and during the pandemic

Variable pairs	Before crisis		Crisis		Before pandemic		Pandemic	
	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
CU_F / CL_F	-9.96(1)	-9.89(1)	-8.12(1)	-8.05(1)	-10.56(4)	-10.44(2)	-10,22(5)	-10,17(1)
CU_F / DX_F	-13.20(3)	-13.13(1)	-11.37(1)	-11.30(1)	-14.89(4)	-14.83(1)	-14,02(1)	-13,96(1)
CU_F / WIG20	-10.33(1)	-10.26(1)	-9.08(1)	-9.01(1)	-12.39(3)	-12.34(1)	-11.17(7)	-11.07(1)
CU_F / KGH	-9.31(2)	-9.23(1)	-8.21(1)	-8.14(1)	-11.34(1)	-11.29(1)	-10.17(2)	-10.11(1)
SI_F / CL_F	-10.06(1)	-9.99(1)	-7.97(1)	-7.00(1)	-10.32(3)	-10.22(2)	-9.12(2)	-9.06(1)
SI_F / DX_F	-13.49(1)	-13.42(1)	-11.51(1)	-11.44(1)	-14.75(1)	-14.70(1)	-13.05(3)	-12.98(1)
SI_F / WIG20	-10.43(3)	-10.34(1)	-8.93(1)	-8.86(1)	-12.09(1)	-12.04(1)	-10.09(4)	-10,02(1)
SI_F / KGH	-9.24(3)	-9.15(1)	-7.88(6)	-7.81(1)	-10.87(1)	-10.81(1)	-9.04(4)	-8.99(1)

Source: own study.

Table 6.
Results of the linear Granger test for pairs of financial instruments obtained for the periods: before and during the financial crisis and before the coronavirus pandemic and during the pandemic

Hypothesis H_0	Before crisis	Crisis	Before pandemic	Pandemic
CU_F ⟶ CL_F	1.3564 [0.2450]	0.4540 [0.5009]	0.9113 [0.4571]	1.1741 [0.3208]
CL_F ⟶ CU_F	**4.1486 [0.0424]**	1.2002 [0.2740]	**2.1156 [0.0778]**	**3.3072 [0.0060]**
CU_F ⟶ DX_F	1.8946 [0.1302]	**4.2351 [0.0403]**	1.7886 [0.1298]	**8.4880 [0.0037]**
DX_F ⟶ CU_F	0.5456 [0.6514]	0.0066 [0.9352]	**3.0279 [0.0174]**	2.2999 [0.1300]
CU_F ⟶ WIG20	0.0235 [0.8784]	0.0067 [0.9347]	1.1508 [0.3281]	**6.2972 [0.0000]**
WIG20 ⟶ CU_F	1.4242 [0.2335]	0.3902 [0.5326]	**3.1498 [0.0248]**	0.9827 [0.4430]
CU_F ⟶ KGH	**4.0879 [0.0176]**	0.0150 [0.9025]	0.2289 [0.6325]	1.9217 [0.1474]
KGH ⟶ CU_F	**5.5501 [0.0042]**	**6.5737 [0.0108]**	**6.3926 [0.0118]**	**3.5405 [0.0297]**
SI_F ⟶ CL_F	2.2084 [0.1382]	1.9741 [0.1609]	1.1200 [0.3405]	0.0387 [0.9620]
CL_F ⟶ SI _F	0.0113 [0.9152]	**3.8760 [0.0498]**	0.8248 [0.4806]	**7.0474 [0.0010]**
SI _F ⟶ DX_F	0.8596 [0.3545]	**6.5690 [0.0108]**	**6.4944 [0.0111]**	**2.1064 [0.0985]**
DX_F ⟶ SI _F	0.0632 [0.8016]	0.0580 [0.8098]	0.0776 [0.7806]	**10.104 [0.0000]**
SI _F ⟶ WIG20	**5.3212 [0.0014]**	0.4360 [0.5095]	1.5293 [0.2168]	**8.7057 [0.0000]**
WIG20 ⟶ SI _F	0.8114 [0.4882]	0.3594 [0.5493]	0.8174 [0.3664]	0.9074 [0.4594]
SI _F ⟶ KGH	**5.1524 [0.0017]**	**2.7386 [0.0130]**	0.1502 [0.6986]	**5.3989 [0.0003]**
KGH ⟶ SI_F	0.8224 [0.4822]	**2.5466 [0.0200]**	0.2308 [0.6312]	1.7043 [0.1478]

Source: own study.

Granger's test suggests the presence of two-sided causality in the periods: before the crisis only for the pair {CU_F, KGHM}; crisis - {SI_F, KGH}; pandemic - {SI_F, DX_F}. The results obtained partially confirm the influence of the crude oil, dollar, and WIG20 indexes on the price of copper, but not the other way round. The impact of crude oil can be observed during a crisis, before a pandemic, and during a pandemic. On the other hand, the dollar index and WIG20 only in the period before the pandemic. In the case of silver, the impacts of crude oil in crisis and pandemic periods and the dollar index in pandemic period can be observed.

Then, for the same variables, the nonparametric Diks-Panchenko test was used in the sample covering the pre-crisis and pre-pandemic period and the period of crisis and pandemic (Tables 7-10).

Table 7.
Results of the non-linear Diks-Panchenko test for pairs composed of copper returns and selected financial instruments obtained for the periods before and during the financial crisis

Hypothesis H_0	l	Before crisis	Crisis	Hypothesis H_0	l	Before crisis	Crisis
CU_F ⟶ CL_F	1	-0.763[0.7773]	-1.093[0.1372]	CL_F ⟶ CU_F	1	-1.394[0.9184]	0.958[0.1689]
	2	-1.200[0.8849]	-0.443[0.6711]		2	-0.844[0.8005]	0.373[0.3547]
	3	-0.910[0.8187]	-0.440[0.6699]		3	-0.445[0.6718]	0.812[0.2084]
	4	0.173[0.4313]	0.478[0.3164]		4	-0.691[0.7551]	0.111[0.4558]
CU_F ⟶ DX_F	1	**1.330[0.0917]**	**-2.068[0.0193]**	DX_F ⟶ CU_F	1	0.093[0.4631]	0.113[0.4551]
	2	-0.245[0.5967]	0.938[0.1741]		2	-0.771[0.7797]	-0.086[0.5341]
	3	0.500[0.3087]	0.130[0.4483]		3	-0.403[0.6566]	0.155[0.4385]
	4	-0.789[0.7851]	-0.752[0.7741]		4	-0.128[0.5509]	-0.431[0.6669]
CU_F ⟶ WIG20	1	0.304[0.3807]	**1.794[0.0364]**	WIG20 ⟶ CU_F	1	0.909[0.1816]	-0.443[0.6712]
	2	-0.122[0.5487]	0.130[0.4481]		2	0.690[0.2450]	-0.588[0.7219]
	3	0.557[0.2887]	0.683[0.2474]		3	0.319[0.3748]	-0.647[0.7411]
	4	-0.589[0.7222]	-1.036[0.8499]		4	0.201[0.4202]	-0.103[0.5409]

Cont. table 7.

CU_F → KGH	1	0.295[0.3842]	**2.388[0.0085]**	KGH → CU_F	1	**1.339[0.0903]**	-0.290[0.6142]
	2	0.311[0.3779]	0.624[0.2664]		2	0.441[0.3297]	-0.193[0.5766]
	3	-1.128[0.8703]	-0.019[0.5076]		3	-0.498[0.6907]	-0.604[0.7269]
	4	-0.978[0.8359]	0.511[0.3047]		4	-0.439[0.6696]	-0.042[0.5167]

Source: own study.

Table 8.
Results of the non-linear Diks-Panchenko test for pairs composed of silver returns and selected financial instruments obtained for the periods before and during the financial crisis

Hypothesis H_0	l	Before crisis	Crisis	Hypothesis H_0	l	Before crisis	Crisis
SI_F → CL_F	1	-1.394[0.9183]	0.325[0.3726]	CL_F → SI _F	1	-0.155[0.5616]	0.813[0.2082]
	2	-0.574[0.7169]	0.502[0.3078]		2	-1.086[0.8614]	0.179[0.4289]
	3	-0.687[0.7541]	-0.675[0.7502]		3	-0.425[0.6644]	0.357[0.3605]
	4	0.588[0.2782]	0.739[0.2301]		4	-0.365[0.6426]	0.479[0.3159]
SI _F → DX_F	1	0.390[0.3482]	**72.41[0.0078]**	DX_F → SI _F	1	**1.536[0.0622]**	-0.387[0.6506]
	2	0.287[0.3869]	0.533[0.2971]		2	0.967[0.1667]	0.901[0.1838]
	3	0.169[0.4329]	-0.044[0.5174]		3	0.715[0.2374]	0.556[0.2892]
	4	0.298[0.3830]	0.667[0.2524]		4	1.095[0.1366]	0.685[0.2467]
SI _F → WIG20	1	1.208[0.1135]	1.018[0.1543]	WIG20 → SI _F	1	-0.394[0.6534]	-0.568[0.7149]
	2	-0.336[0.6316]	0.007[0.4973]		2	0.188[0.4256]	0.827[0.2042]
	3	0.854[0.1966]	0.471[0.3189]		3	0.924[0.1777]	-0.248[0.5979]
	4	0.788[0.2155]	**1.459[0.0723]**			0.048[0.4809]	0.374[0.3542]
SI _F → KGH	1	-0.230[0.5909]	-0.238[0.5942]	KGH → SI _F	1	1.147[0.1257]	0.197[0.4217]
	2	-0.401[0.6559]	0.326[0.3723]		2	0.514[0.3035]	0.301[0.3816]
	3	-1.342[0.9102]	-0.931[0.8241]		3	-0.943[0.8272]	-1.359[0.9129]
	4	-0.148[0.5587]	-0.808[0.7905]		4	0.205[0.4187]	-0.688[0.7542]

Source: own study.

Table 9.
Results of the non-linear Diks-Panchenko test for pairs composed of copper returns and selected financial instruments obtained for the periods before the coronavirus pandemic and during the pandemic

Hypothesis H_0	l	Before pandemic	Pandemic	Hypothesis H_0	l	Before pandemic	Pandemic
CU_F → CL_F	1	-0.307[0.6206]	-0.761[0.7766]	CL_F → CU_F	1	0.594[0.2762]	-0.346[0.6354]
	2	-0.109[0.5432]	-1.259[0.8960]		2	-0.211[0.5837]	-1.042[0.8513]
	3	-0.441[0.6706]	-1.698[0.9552]		3	1.047[0.1476]	-0.381[0.6485]
	4	-0.972[0.8344]	-1.290[0.9015]		4	-0.278[0.6094]	0.040[0.4839]
CU_F → DX_F	1	0.410[0.3408]	0.890[0.1868]	DX_F → CU_F	1	**1.434[0.0757]**	-0.884[0.8116]
	2	0.070[0.4720]	0.874[0.1908]		2	0.942[0.1730]	-0.343[0.6343]
	3	0.019[0.4923]	-0.497[0.6904]		3	0.706[0.2401]	-1.007[0.8430]
	4	-1.334[0.9089]	-0.901[0.8163]		4	0.110[0.4561]	-0.040[0.5161]
CU_F → WIG20	1	0.506[0.3063]	-0.691[0.7552]	WIG20 → CU_F	1	0.086[0.4657]	-3.033[0.9988]
	2	0.292[0.3853]	-0.435[0.6682]		2	-0.535[0.7038]	0.542[0.2939]
	3	0.099[0.4604]	0.191[0.4242]		3	-0.706[0.7598]	-1.545[0.9389]
	4	-0.511[0.6954]	0.917[0.1797]		4	0.236[0.4069]	-0.681[0.7519]
CU_F → KGH	1	-0.307[0.6206]	-0.074[0.5296]	KGH → CU_F	1	0.594[0.2762]	-1.525[0.9364]
	2	-0.109[0.5432]	-0.605[0.7273]		2	-0.211[0.5837]	0.286[0.3875]
	3	-0.441[0.6706]	0.202[0.4201]		3	1.048[0.1476]	-0.223[0.5881]
	4	-0.972[0.8344]	-0.658[0.7446]		4	-0.278[0.6094]	0.048[0.4809]

Source: own study.

Table 10.
Results of the non-linear Diks-Panchenko test for pairs composed of silver returns and selected financial instruments obtained for the periods before the coronavirus pandemic and during the pandemic

Hypothesis H_0	l	Before pandemic	Pandemic	Hypothesis H_0	l	Before pandemic	Pandemic
SI_F ⟶ CL_F	1	0.753[0.2258]	**1.477[0.0699]**	CL_F ⟶ SI _F	1	**2.737[0.0031]**	-0.643[0.7398]
	2	0.750[0.2266]	0.602[0.2735]		2	**1.357[0.0874]**	0.336[0.3684]
	3	1.109[0.1338]	0.582[0.2804]		3	0.566[0.2857]	-1.287[0.9010]
	4	1.192[0.1167]	-0.580[0.7189]		4	0.079[0.4684]	-1.145[0.8739]
SI _F ⟶ DX_F	1	0.137[0.4454]	1.202[0.1146]	DX_F ⟶ SI _F	1	0.545[0.2929]	**1.546[0.0609]**
	2	0.000[0.4999]	0.684[0.2469]		2	-0.182[0.5721]	0.869[0.1924]
	3	0.726[0.2339]	0.275[0.3916]		3	-1.070[0.8577]	0.679[0.2485]
	4	0.240[0.4052]	-0.667[0.7476]		4	-0.304[0.6194]	0.264[0.3959]
SI _F ⟶ WIG20	1	0.468[0.3199]	0.148[0.4411]	WIG20 ⟶ SI _F	1	0.472[0.3185]	0.816[0.2074]
	2	0.524[0.3000]	-0.084[0.5335]		2	0.466[0.3205]	0.700[0.2418]
	3	0.356[0.3607]	0.490[0.3119]		3	-0.455[0.6756]	-0.393[0.6528]
	4	-0.463[0.6781]	0.067[0.4732]		4	-0.097[0.5388]	-1.299[0.9029]
SI _F ⟶ KGH	1	0.753[0.2258]	0.523[0.3006]	KGH ⟶ SI _F	1	**2.737[0.0031]**	0.292[0.3853]
	2	0.750[0.2266]	0.591[0.2771]		2	**1.357[0.0874]**	0.279[0.3900]
	3	1.109[0.1338]	0.593[0.2767]		3	0.566[0.2857]	-0.284[0.6118]
	4	1.192[0.1167]	0.314[0.3768]		4	0.079[0.4684]	0.435[0.3318]

Source: own study.

When comparing the results of the Diks-Panchenko test for l = 1 with the results of the linear Granger test, the following conclusions can be drawn. The results of both tests turned out to be similar only for pairs of variables: {KGH and CU_F} in the pre-crisis period; {CU_F, DX_F}, {CU_F, KGH} and {SI_F, DX_F} in crisis; {DX_F, CU_F} before the pandemic; {DX_F, SI_F} during the pandemic. During the crisis and pandemic, the null hypothesis of no causality was more often rejected. In the pre-crisis and pre-pandemic periods, the causal relationships were weaker. Contrary to the author's expectations, events of global importance (financial crisis and pandemic) did not affect the causal relationships between the variables studied in a similar way.

7. Summary

The industrial metals market is sensitive to the impact of many market and non-market determinants, which are short or long term. As mentioned earlier, these may include supply and demand, inventories, the prices of some commodities, including crude oil, fluctuations in the dollar exchange rate, financial crises and those related to global events (e.g. the Covid-19 pandemic). These factors also include investor sentiment in capital markets and the state of the economy, which are best reflected by stock indices. Due to such a large group of variables influencing the prices of copper and silver, the study focuses only on the causal relations with the prices of crude oil, the stock index, and the dollar index. The research was carried out first for the entire period, i.e. from January 2005 to May 2022, and divided into four sub-periods, i.e. before the financial crisis and for the crisis, and before the Covid -19 pandemic and during the pandemic period.

The presented test results indicate the presence of causality between the tested instruments for the entire sample. The use of the non-linear Diks-Panchenko test allowed the detection of two-way dependencies in most cases. This is important information from the point of view of market participants investing in the copper and silver market, investors conducting currency transactions, or decisions related to KGHM. Knowing about this type of relationship can help to get better forecasts for both the metals and stock markets.

Due to the impact of the global financial crisis on changes in the relationship of returns from financial instruments discussed in the literature, the results for the crisis and the previous period were compared, as well as the results obtained for the period before and during the coronavirus pandemic. The causality study conducted for selected periods confirmed this change. The null hypothesis of no causality in most cases has not been rejected.

The indications of the Diks-Panchenko test depend on the number of variables. At a later stage of the research, one should, inter alia, check in more detail the influence of the delays adopted for the variables in this test.

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