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Contagion in Commodity Markets under Financial Stress

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ABSTRACT

The **relevance** of the study is due to the fact that in the conditions of the financialization of the economy, shocks arising in one market can spread rapidly and intensively to other markets, generating the effects of financial contagion. This fully applies to the commodity markets, which occupy a large share of exchange trading. The resulting excess volatility risks should be taken into account both by financial market players when developing optimal portfolio strategies, and by the state when adjusting anti-crisis policy. The **purpose** of the study is to identify financial contagion in commodity markets during periods of financial stress caused by the pandemic and sanctions, to determine the direction and extent of intermarket contagion. The **novelty** of the study lies in the construction of stress indices to separate periods of increased volatility in commodity markets, in the application of statistical tests for the co-moments of the return distribution to identify the financial contagion between the markets of energy (oil and gas), precious and non-ferrous metals during the pandemic and sanctions. The **result** of the study is the identification of a period of increased volatility in commodity markets and its division into two sub-periods based on turning points in the stress index, establishing the direction and extent of financial contagion between commodity markets during these periods. It is **concluded** that stress in commodity markets is accompanied by intense financial contagion. Moreover, volatility contagion turns out to be higher than return contagion and even higher than contagion caused by anomalies in the return distribution. The main sources and receivers of contagion in different periods are the markets of precious and some non-ferrous metals, and in the period from February 2018 to December 2020, also the oil market. At the same time, the gas market before SMO has demonstrated relative independence from other commodity markets, which made it possible to recommend gas futures as a tool for hedging investment portfolios during a period of increased financial stress.
Keywords: commodity markets; stress index; financial contagion; tests; correlation; coskewness; cokurtosis; covolatility

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INTRODUCTION

Exchange commodities directly or indirectly participate in the production of most goods and services. However, their prices are formed not only under the influence of demand and supply in the real sector of the economy, but are also the result of the behavior of stock market players. Commodity futures are actively involved in the formation of investment portfolios, and their returns depend on the expectations, moods and market strategies of stock market players.

Financial globalization and the integration of financial markets are accompanied by the financialization of most exchange commodity markets. Under such circumstances, exchange commodities increasingly acquire the properties of financial assets, which leads to an increase in volatility of their prices and returns [1, 2]. Since the early 1980s, factors such as financial deregulation, the development of new information technologies and financial innovations have contributed to the increased interdependence and interconnectedness of different segments of the financial and commodity markets [3].

Currently, raw materials account for the majority of exchange commodities. In the Bloomberg commodity index 2023 the total share of energy resources (oil, gas and products of their processing) is 29.95% (with maximum share of natural gas — 7.94%), cereals — 22.64%, industrial metals — 15.94%, precious metals — 19.44%, "soft goods" (such as coffee, sugar, cotton) — 6.97%, livestock products— 5.06%.[1] According to the Bank of Russia, in 2022, oil products accounted for 92% of all organized bids in the country, and the share of agricultural products was only 5%.[2]

Prices of exchange commodities exhibit substantial sensitivity to various types of shocks and stressful situations in the economy. These commodities themselves are often a source of shocks in different sectors of the economy. In particular, they can lead to increased costs in related industries, changes in demand for products and alternative sources of energy and other resources, as well as changes in the state economic policy (e.g. raising interest rates in response to rising inflation expectations), which also plays a shock role in the economy [4, 5]. There is empirical evidence that oil price volatility contributes to increased financial stress in the economy [6]. By creating general uncertainty, it affects firms' decision-making and strategic investment [7, 8].

In the context of interconnected financial markets (through trade, investment, information, macroeconomic, political and other channels), shocks in some markets can generate spill-over effects in other markets, causing them to overreact and increasing the overall fragility of the financial system. **Financial contagion** is characterized as a significant increase in the co-movement of the returns of individual markets [9], as opposed to the usual interconnectedness of these markets in calm times. Changing market interconnections and increasing interdependence in the context of financial contagion require a revision of approaches to investment portfolio diversification [10, 11], as well as economic policies in terms of risk management, including risks emanating from global markets [12–14].

Currently there are many scientific papers devoted to financial contagion in exchange commodity markets. They explore the interrelationship of energy, metals, and agricultural commodity markets on a global scale [2, 5, 15, 16], as well as between countries [17] and within the individual country [18]. A lot of research is also devoted to the relationship between the oil market and the stock markets [19,

[1] Bloomberg Commodity Index 2023 Target Weights Announced. Bloomberg, October 27, 2022. URL: https://www.bloomberg.com/company/press/bloomberg-commodity-index-2023-target-weights-announced/ (accessed on 09.06.2023).

[2] Review of the stock exchange and off-the-share commodity market. Information and analytical material. Bank of Russia, 2023, 26 p. P. 8. URL: https://www.tadviser.ru/images/2/21/Reveiw_br_26052023.pdf (accessed on 09.06.2023).

20]. Much fewer studies reveal financial contagion during the pandemic [21, 22] and sanctions [11]. At the same time, most studies look at short-term periods of high volatility in markets, when contagion is actually diagnosed. There are some studies that confirm the spread of contagion over a longer period of time, in particular, after passing the acute phase of the pandemic [23]. An important challenge in all these studies is the clear identification of the contagion period.

This article is devoted to the study of the interrelationship of exchange commodity markets (oil and gas, precious and non-ferrous metals) during the period of impact of sanctions and pandemic shocks 2014–2022 (before Russia announced a special military operation in Ukraine). At the same time, we are looking at contagion for the first time in a fairly long-term interval, identifying it on the basis of the construction of the stress index of the commodity market. The purpose of the paper is to diagnose financial contagion in exchange commodity markets during financial stress, to identify the focus and intensity of contagion, to develop recommendations on risk management in the context of financial contagion. For this purpose, a number of statistical tests are applied to the co-moments of the distribution of futures returns of the investigated commodities.

STUDY DATA AND SEPARATION OF STRESS PERIODS

Our analysis uses daily data for 04.01.2010–23.02.2022 on the price futures of 11 commodities traded on international exchanges[3]:

1. BRENT crude oil ($ per barrel, Intercontinental Exchange = ICE[4]) — OIL[5];
2. Natural gas ($ per million BTE,[6] NYMEX[7]) — GAS;
3. Gold ($ per troy ounce, ICE) — GOLD;
4. Silver ($ per troy ounce, ICE) — SILV;
5. Platinum ($ per ounce, NYMEX) — PLT;
6. Palladium ($ per ounce, NYMEX) — PAL;
7. Copper ($ per pound, COMEX[8]) — COP;
8. Zinc ($ per ton, LME[9]) — ZINC;
9. Nickel ($ per ton, LME) — NICK;
10. Tin ($ per ton, LME) — TIN;
11. Lead ($ per ton, LME) — LEAD.

To separate crisis periods (high market volatility) from periods of relatively calm market we used the construction of stress indices based on a previously proposed and tested methodology [24, 25].

The principal component analysis was used to consolidate all commodity quotations into a single index, eliminating economy of scale and multicollinearity. In this method, the first principal component (PC_1) is the weighted sum of the Z-score of individual market quotations (P_{it} , $i=\overrightarrow{1,n}$ — the number of the individual indicator, $t=\overrightarrow{1,T}$ — the time moment):

$$PC_{1_t} = \sum_{i=1}^{n} a_i \cdot (P_{it} - \mu_i) / \sigma_i . \quad (1)$$

where μ_i — inter-temporal average value of the price of the i-asset; σ_i — inter-temporal standard deviation of the price of the i- asset; a_i — weight or load of the i-asset determined empirically by maximizing the variance of the first principal component.

The stress index (SI_t) was calculated in dynamics as the difference between the moving standard deviation of the first principal component and its moving average:

$$SI_t = \sigma_{PC_t} - \mu_{PC_t} . \quad (2)$$

[3] Source of information: Investing.com. URL: https://ru.investing.com/?text (accessed on 09.06.2023).

[4] Intercontinental Exchange (ICE) — exchange and clearing house network for US, Canadian and European futures markets.

[5] Here and further, we use our own more understandable product designations.

[6] BTU (British thermal unit) — used to measure energy in English-speaking countries.

[7] NYMEX — New York Mercantile Exchange.

[8] COMEX (Commodity Exchange) — NYMEX New York Commodity Exchange Branch.

[9] LME — London Metal Exchange.

Table 1

Comoments of the Return Distribution of Two Assets

Test	Description	Source of indicator calculations and test statistics
Correlation (CR)	Relationship between returns on two assets	[26]
Coskewness (CS_{12}, CS_{21})	Relationship between the return of one asset and the square of return of another asset	[27]
Cokurtosis (CK_{13}, CK_{31})	Relationship between the return of one asset and the cube of the return of another asset	[28]
Covolatility (CV)	Relationship between squares of returns on two assets	[23]

Source: Compiled by the author.

The calculation of the moving average (μ_{PC_t}) and the moving standard deviation (σ_{PC_t}) was based on ten adjacent trading dates, successively shifted by one date. The resulting values were attributed to the middle of the calculation interval.

INTERMARKET CONTAGION TESTS

First, the daily (*t*) returns of each asset (*i*) were determined:

$$r_{i_t} = \ln\left(P_{it}\right) - \ln\left(P_{it-1}\right). \qquad (3)$$

They were used to calculate the co-moments of the return distribution of two assets: *i* (tested contagion transmitter) and *j* (tested contagion receiver) in pre-crisis "*x*" and crisis "*y*" periods. Since during the crisis there is an increase in the asset-transmitter variance, the correlation coefficient in this period is adjusted to take into account the heteroscedasticity [9]:

$$v_{y/x} = \frac{\rho_y}{\sqrt{1+\left(\frac{\sigma^2_{y,i}}{\sigma^2_{x,i}}-1\right)\cdot\left(1-\rho^2_y\right)}}, \qquad (4)$$

where ρ_y — Pearson correlation coefficient for the returns of assets *i* and *j* during the crisis period "*y*"; $\sigma^2_{x,i}$ and $\sigma^2_{y,i}$ — variances of the return of asset *i* in pre-crisis period "*x*" and crisis period "*y*", respectively. An increase in the conditional correlation of the returns of two assets in the crisis period compared to the pre-crisis period ($v_{y/x} > \rho_x$) suggests possible contagion of asset *j* by asset *i*.

Applying the co-moments distribution method provides a more complete picture of contagion (*Table 1*). It includes six tests: one correlation test, two coskewness and cokurtosis tests, and one covolatility test. Test statistics are calculated in all cases. If this statistics is above the critical value at the accepted significance level ($\alpha = 0.05$), possible contagion is inferred.

RESULTS AND DISCUSSION

Fig. 1 demonstrates the dynamics of the moving coefficient of variation for the returns of 11 surveyed commodities. It shows spikes in commodity returns volatility at different points in time, most noticeable during the 2020 pandemic. Meanwhile, this approach makes it difficult to clearly identify the boundaries of high market volatility.

The use of the principal component analysis solved this problem. The parameters of the first principal component, determined using the Gretl package for the quotations of 11 commodities for the period from the

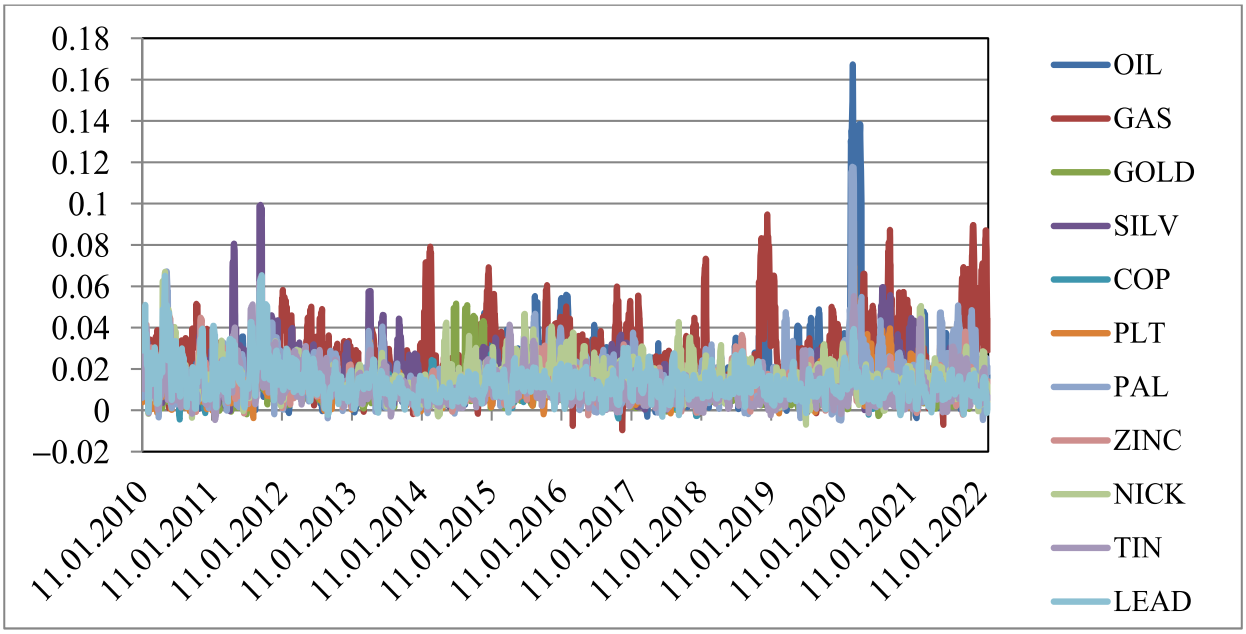

Fig. 1. **Moving Coefficients of Variation of Returns of 11 Studied Commodities**

Source: Completed by the author.

Table 2

Parameters of the First Principal Component (PC 1) of Commodity Quotes

Commodities	Eigenvector (component loading)	Mean value	Standard deviation	Coefficient of variation
OIL	0.339	76.37	25.76	0.337
GAS	0.283	3.26	0.89	0.272
GOLD	0.214	1433.64	238.51	0.166
SILV	0.353	21.48	6.65	0.310
PLT	0.322	1206.10	318.95	0.264
PAL	0.027	1073.76	628.57	0.585
COP	0.409	3.18	0.63	0.197
ZINC	0.091	2349.28	464.95	0.198
NICK	0.380	15564.57	4469.68	0.287
TIN	0.344	21287.98	5284.70	0.248
LEAD	0.302	2098.47	248.41	0.118
Eigenvalue for the correlation matrix			5.3024	
Percentage of variation explained			0.4820	

Source: Calculated by the author.

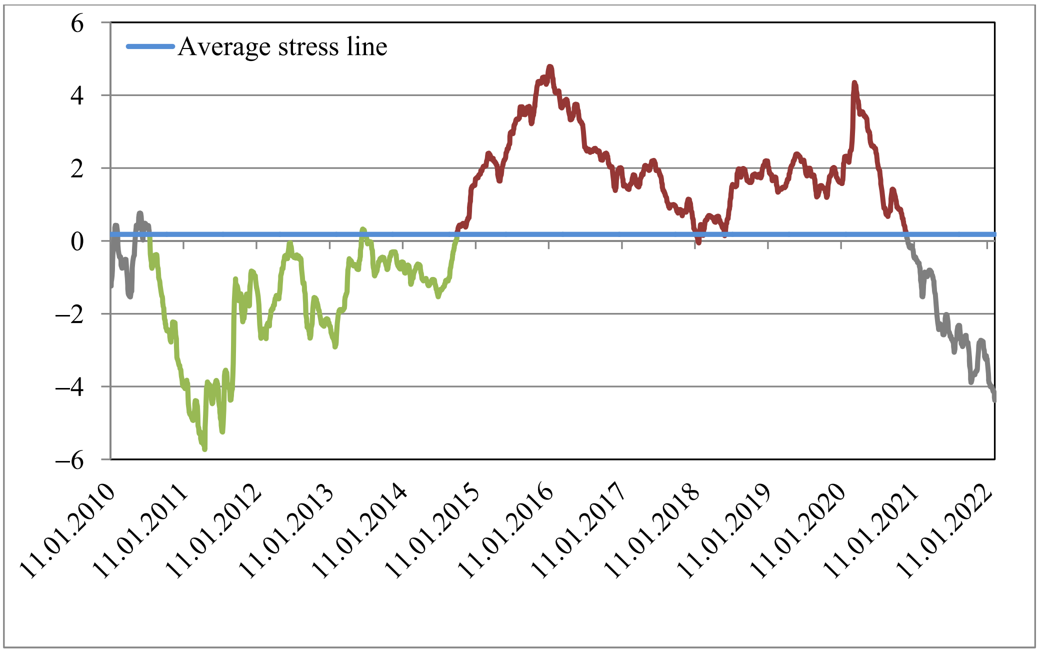

Fig. 2. **Commodity Market Stress Index on the First Principal Component**

Source: Designed by the author.

beginning of 2010 to 23.02.2022, are presented in *Table 2*.

Based on them, the time series values of the first principal component were calculated using the formula (1). Next, the commodity market stress index was determined according to formula (2), the dynamics of this index are presented in *Fig. 2*. Its comparison with the average stress level in the considered interval allows two periods of the study to be identified:

1. Period of relatively calm market (pre-crisis period): 26.07.2010–09.10.2014 (green line on *Fig. 2*).

2. Period of high volatility market (crisis period): 10.10.2014–01.12.2020 (red line on *Fig. 2*). Note that this period covers both several waves of sanctions against the Russian economy and the period of the first and second wave of the 2020 pandemic.

Two visible waves of growth and reduction of stress during the crisis period make it possible to distinguish two sub-crisis periods:

1) 10.10.2014–30.01.2018;

2) 31.01.2018–01.12.2020.

Table 3 contains data on average returns and their standard deviations for the commodities under study in the four periods considered. During the stress period, the average daily return of commodities increased slightly (+0.001%), which may be due to the influence of the inflationary component, but the standard deviation of return increased much more (+0.071%). In the first stress sub-period, both the average return and its standard deviation were significantly reduced compared to the pre-stress period (–0.001% and –0.025%, respectively). In the second stress sub-period, average return and its standard deviation, on the contrary, increased (+0.004% and +0.160%, respectively).

Table 3 results confirm that crisis periods are mainly accompanied by falling oil prices and rising volatility in oil futures returns. For other exchange commodities, the average return does not decrease, but the volatility of the return on futures for natural gas, platinum, palladium, nickel increases.

Table 4 presents the correlation matrix of returns of exchange commodities in the pre-stress and stress periods. The impact is assessed by line i→j. The correlations in the pre-stress period “x” are represented in the upper left corner of each cell, and the adjusted

Table 3

Descriptive Statistics of Commodity Returns in the Pre-Stress and Stress Periods

Commodities	Pre-stress period		Stress period					
			joint		1st sub-period		2nd sub-period	
	μ	σ	μ	σ	μ	σ	μ	σ
OIL	0.02	1.40	−0.04	2.72	−0.03	2.38	−0.05	3.07
GAS	−0.02	2.62	−0.02	3.07	−0.02	2.84	−0.02	3.31
GOLD	0.01	1.36	0.02	1.05	0.00	1.11	0.04	0.97
SILV	0.00	2.18	0.02	1.73	0.00	1.54	0.04	1.93
PLT	−0.02	1.14	−0.02	1.52	−0.03	1.17	0.00	1.84
PAL	0.05	1.71	0.07	2.01	0.03	1.69	0.11	2.32
COP	0.00	1.41	0.01	1.22	0.01	1.22	0.01	1.22
ZINC	0.02	1.55	0.01	1.47	0.05	1.52	−0.03	1.40
NICK	−0.02	1.70	0.00	1.77	−0.02	1.91	0.03	1.60
TIN	0.01	1.58	−0.01	1.18	0.01	1.24	−0.02	1.12
LEAD	0.01	1.71	0.00	1.40	0.03	1.45	−0.03	1.34

Source: Calculated by the author.

correlations in the stress period "y" are in the lower right corner. Cells with higher conditional correlations in the crisis period than in the pre-crisis period are colored gray; they raise suspicion of contagion on the line i→j.

Analysis of the data in Table 4 makes it possible to draw a number of conclusions. Firstly, there are significant correlations between the returns of precious metals (gold, silver, platinum and palladium) in both periods. In the pre-stress period, their returns are also significantly correlated with the return of copper. Secondly, there is a strong correlation between the returns of non-ferrous metals (copper, zinc, nickel, lead and lead). Thirdly, oil returns in the pre-stress period are weakly correlated with those in silver, platinum, palladium, copper, tin and lead. Finally, there is virtually no correlation between natural gas and other commodity returns.

A comparison of pre-stress correlations with adjusted stress correlations suggests that during stress the natural gas market may begin to transmit and receive contagion from other exchange commodity markets. Exceptions are the platinum and palladium markets, which have little interaction with the gas market. However, the correlations of commodity markets with the gas market are weak in themselves, and their significance should be clarified by the Forbes-Rigobon contagion test on the first co-moment of the return distribution. It is also worth noting the possible transmission of contagion between the gold and silver markets and their combined impact on the platinum market. At the correlation level, other effects of contagion are not diagnosed.

The results of the contagion tests for different co-moments of the return distribution, based on the sources listed in *Table 1*, are presented below. They testify that as the co-moment of distribution increases, the number of confirmed contagions increases. Thus, for the entire stress period, at the level of

Table 4

Conditional Correlations of Commodities Returns in the Pre-Stress (ρ_x) and Stress ($v_{y/x}$) Periods

OIL	0.071 0.058	0.203 0.026	0.359 0.090	0.363 0.112	0.391 0.122	0.423 0.142	0.274 0.107	0.295 0.114	0.335 0.082	0.339 0.054
0.071 0.096	GAS	−0.001 0.014	0.046 0.038	0.052 0.039	0.069 0.038	0.031 0.047	0.002 0.056	0.024 0.070	0.030 0.065	0.022 0.059
0.203 0.065	−0.001 0.022	GOLD	0.672 0.757	0.572 0.576	0.405 0.355	0.357 0.108	0.264 0.094	0.224 0.108	0.223 0.083	0.260 0.043
0.359 0.217	0.046 0.056	0.672 0.748	SILV	0.653 0.710	0.550 0.502	0.528 0.342	0.387 0.261	0.349 0.283	0.340 0.253	0.392 0.192
0.363 0.163	0.052 0.035	0.572 0.378	0.653 0.516	PLT	0.717 0.409	0.511 0.208	0.398 0.178	0.357 0.209	0.379 0.131	0.377 0.117
0.391 0.200	0.069 0.038	0.405 0.242	0.550 0.365	0.717 0.453	PAL	0.562 0.247	0.418 0.225	0.390 0.223	0.398 0.199	0.431 0.175
0.423 0.305	0.031 0.063	0.357 0.096	0.528 0.315	0.511 0.309	0.562 0.325	COP	0.668 0.601	0.597 0.565	0.583 0.371	0.672 0.513
0.274 0.216	0.002 0.069	0.264 0.076	0.387 0.220	0.398 0.245	0.418 0.274	0.668 0.566	ZINC	0.585 0.508	0.549 0.308	0.788 0.620
0.295 0.210	0.024 0.079	0.224 0.080	0.349 0.219	0.357 0.263	0.390 0.249	0.597 0.496	0.585 0.474	NICK	0.556 0.323	0.571 0.376
0.335 0.207	0.030 0.101	0.223 0.085	0.340 0.266	0.379 0.227	0.398 0.302	0.583 0.419	0.549 0.380	0.556 0.428	TIN	0.573 0.344
0.339 0.127	0.022 0.084	0.260 0.041	0.392 0.186	0.377 0.188	0.431 0.246	0.672 0.535	0.788 0.676	0.571 0.458	0.573 0.319	LEAD

Source: Calculated by the author.

the first co-moment of the return distribution (correlation), contagion is observed in 4.1% of the pairs studied, at a level of coskewness — 55.8% of pairs, cokurtosis — 71.9% of pairs, covolatility — 72.7% of pairs.

Table 5 shows the results of tests for contagion in both the long stress period and its two sub-periods. In general, they indicate that contagion is confirmed for 57.3% of tests. Such confirmations were higher (61.0%) in the first sub-period than in the second (55.9%). The markets most affected by contagion were silver (66.2%), gold (63.1%), palladium (63.1%), lead (62.6%) and tin (60.6%). These same markets became the main transmitters of contagion (in particular, for the lead market, 77.6% positive tests were received, silver — 77.0%, gold — 75.2%, palladium — 73.9%, tin — 73.9%). The gas market turned out to be autonomous and little connected with other markets. Only 34.8% of tests confirmed that gas was the source of contagion, and 44.2% of tests confirmed that it as a receiver of contagion.

Table 5

Number of Confirmed Contagions in the Overall Stress Period and Its Two Sub-Periods

i→j	Contagion reception											N
Contagion transmission	OIL	3 2 2	1 3 4	3 5 4	5 5 5	5 5 5	3 4 5	3 3 4	3 5 4	5 5 3	3 4 5	34 41 41
	3 2 2	GAS	2 2 4	1 2 2	3 1 3	2 4 2	2 3 2	2 5 2	1 3 2	1 2 2	3 3 2	20 27 23
	1 3 4	2 2 4	GOLD	5 5 6	5 5 6	5 5 5	4 5 4	4 4 3	4 3 4	5 5 4	5 4 4	40 41 44
	3 5 4	1 2 2	5 6 6	SILV	5 6 4	4 5 3	5 5 4	5 5 4	5 4 5	4 5 3	5 5 5	42 48 40
	5 5 5	3 1 3	4 5 5	4 5 4	PLT	5 5 5	1 4 2	2 3 2	2 3 4	4 5 5	4 5 3	34 41 38
	5 5 5	2 4 2	5 5 5	4 5 3	5 5 5	PAL	3 4 4	3 4 3	4 3 4	5 5 4	5 5 4	41 45 39
	3 4 5	2 3 2	4 5 4	5 5 4	2 4 2	3 4 4	COP	3 3 3	3 3 4	4 4 3	5 5 3	34 40 34
	3 3 4	3 5 2	4 4 3	5 5 4	2 3 2	3 4 3	3 3 3	ZINC	4 3 4	4 4 3	5 4 3	36 38 31
	3 5 4	1 3 2	4 3 4	5 4 5	2 3 4	4 3 4	3 2 4	4 3 4	NICK	5 5 5	5 5 5	36 36 41
	4 4 5	4 2 3	5 5 4	5 5 4	2 3 3	4 4 3	4 4 6	5 5 3	3 4 3	TIN	5 5 4	41 41 38
	5 5 3	2 2 3	5 5 4	4 5 3	4 5 5	5 5 4	4 4 3	4 4 3	5 5 5	4 5 4	LEAD	42 45 37
N	35 41 41	23 26 25	39 43 43	41 46 39	35 40 39	40 44 38	32 38 37	35 39 31	34 36 39	41 45 36	45 45 38	400 443 406

Source: Calculated by the author.

Note: The first row of data for each asset refers to the joint stress period, the second row – to the 1st sub-period, the third row – to the 2nd sub-period.

Copper and zinc markets were also less related to other markets. The involvement of the oil market in the processes of intermarket contagion was average (58.1% of positive tests for the transmission of the contagion and the same — for its reception).

As regards the transmission of contagion between specific commodity markets, the maximum number of positive tests (95.8%) is observed in the interaction of the silver and gold markets. The gold, platinum and palladium markets took the second place in terms of the level of intermarket contagion (85.4% positive tests). The nickel and lead markets also show a high degree of cross-contagion (83.3%). Oil and platinum, oil and palladium also account for 83.3% of confirmed cases.

With this, there is a moderate spread of contagion between the gas market and the oil, silver, and platinum markets (only one-third of positive tests). The contagion spread weakly between the gas and lead markets (37.5% of positive tests).

It is also interesting to compare two sub-periods of contagion: 10.10.2014–30.01.2018 and 31.01.2018–01.12.2020. In the first sub-period, the markets for silver, palladium, tin and lead were the main transmitters and receivers of the contagion. In the second period, these were the markets for gold, oil, nickel and silver.

CONCLUSION

In the context of financial globalization and integration, exchange commodities are increasingly acquiring the properties of financial assets. The result is a rise in their returns and volatility, as well as greater sensitivity to economic shocks and the news background that accompanies them. Commodity futures have become an active tool of stock portfolios, and transactions with them are involved in the implementation of stock market strategies. In the context of interconnected financial and stock markets, commodities become both a source and a transmitter of financial contagion.

The study examined the spread of contagion between exchange commodities, including oil and gas, precious and nonferrous metals. The author's stress index was used to identify periods of increased volatility in commodity markets. With its help, two stress waves were detected (10.10.2014–30.01.2018 and 31.01.2018–01.12.2020). Contagion testing was carried out on the basis of four co-moments of the return distribution: correlation (adjusted for heteroscedasticity), coskewness, cokurtosis and covolatility. As the co-moment of the return distribution increased, the number of confirmed cases of contagion increased. The largest relationship was found in the "gold-silver" pair. The transmission of contagion between all precious metals has proved to be one of the most intense, but there is also high contagion in individual pairs of non-ferrous metals (nickel and lead) and in the relationship of the oil market with the platinum and palladium markets. Oil markets showed greater involvement in contagion processes in the second period covering the pandemic.

The gas market in the period under review was the least affected by contagion and least likely to transfer it. The correlation of its returns with returns of other commodities was negligible both in calm and stressful periods. This means that until February 2022, gas futures could serve as a reliable tool for hedging investment portfolios. However, it was during the Special Military Operation (SMO) that the gas market was most negatively affected and could well have become a source of intermarket contagion after 24 February 2022. Analysis of changes in financial contagion in exchange commodity markets during the SMO period could be the subject of future research.

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