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Spillover Effects and Connectedness between Oil Futures Markets and Commodity Futures Markets

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Abstract. In this study, it was found that the spillover effects between oil futures markets and commodity futures markets. I use the volatility spillover index of Diebold and Yilmaz (2012) to analyze the connectedness between oil futures and commodity futures returns. The main analysis results of this study are as follows. First, I show that spillover effects depend on the period, and especially find that spillover effects are active after the Russian-Ukraine War. Second, I find that the WTI and BRENT futures have a high value in both to spillover effects and From spillover effects. Third, the wheat futures market plays an important role after the COVID-19 outbreak. Finally, I find that the non-ferrous metal futures market is dependent on other markets in most periods. As a result, I find that the WTI and BRENT futures are important information senders in the oil and product asset markets. And the empirical results show that the Russia-Ukraine war increases the linkage of the futures market rather than COVID-19 outbreak.

Keywords: spillover effects, futures, connectedness, Russian-Ukraine war, COVID-19

1. Introduction

The subprime mortgage crisis in the United States, the European financial crisis, and the US-China trade war increase uncertainty and connectedness between the global financial markets. The aforementioned events increase the volatility of individual assets and increase the connectedness between individual assets, assets, and financial markets (Park and Jung 2022).

The occurrence of events such as Coronavirus disease 19 (hereinafter referred to as COVID-19) and the Russia-Ukrainian war affects immediately and simultaneously around the world (Amelya 2022; Izzeldin et al., 2022; Liu et al., 2020). Additionally, the Russian-Ukrainian conflict and the COVID-19 breakout have had a bigger impact on the world economy than the US subprime mortgage crisis, the European economic crisis, and the US-China trade war. The occurrence of COVID-19, which occurred in Wuhan, China on December 1, 2019, has a great economic ripple effect, which can be seen as a case that changes social and economic structures. Since COVID-19, most governments have conducted stimulus measures such as quantitative easing and zero interest rates. After the Pandemic Declaration of Pandemic on COVID-19 in March 2020, the economic stimulus measures continued to rise from April 2020 to the end of 2021. In addition, the increase in private investors has accelerated the rise in asset prices.

On February 24, 2022, Russian President Putin proclaimed the invasion of Ukraine to prohibit Ukraine's entry into NATO and to eliminate the Zelensky government. After the invasion of Ukraine by Russia, the United States and the EU Union immediately began sanctions on Russia. Economic resurrections for Russia have exploded crude oil prices and grain prices, which amplified the volatility and the linkage of the international asset market. Based on the global market share of 2018-2020, Ukraine and Russia are the world's top five grain exports. As a representative grain, sunflower seed oil accounts for 72.7% (Ukraine 49.6%, Russia 23.1%), with 34.1%of wheat (Ukraine 10%, Russia 24.1%), barley 26.8% (Ukraine 12.6%, Russia 14.2 %), Corn accounts for 17.4% (15.3%in Ukraine, 2.1% in Russia). In Russia, the nickel market among the six non-ferrous metals is ranked 3rd in the world and ranks first in the market share. Additionally, the financial market's interconnectedness has a substantial impact on investor sentiment, asset allocation, and portfolio risk management, all of which have a negative impact on investors' wealth and portfolio performance (Jung 2020; Ko and Kang 2016; Naeem et al., 2021; Narayan et al., 2022).

Research on connectedness in financial markets is the most important research topic in the field of finance (Amihud and Wohl 2004; Antonakakis et al., 2016; Kollias et al., 2013; Nikkinen and Vahamaa 2010; Schneider and troeger 2006; Zhou et al., 2012). Representative studies on the connectivity of commodity assets include a study of the relationship between oil and metal (gold, silver, aluminum, copper, and iron) markets using a dynamic connectivity framework (Mokni et al.,

2020) and the spillover effect between the oil market and the commodity asset market (Adekoya and Oliyide 2020; Adekoya and Oliyide 2021). And using the connectedness between the gold price and the spot price of WTI crude oil, gold's hedging ability against oil prices was empirically analyzed (Tiwari et al., 2020).

The previous studies on financial market connectivity used models such as multiple regression analysis, Granger causal analysis, cointegration test, VAR, and VECM. Among them, VAR is the most commonly used, but the order of variables used in the analysis affects the empirical results. The problem is that the alternative SVAR should have a theoretical basis, but variable constraints are possible. In recent studies, the volatility spillover index proposed by Diebold and Yilmaz is used to analyze the connectedness of financial markets (Diebold and Yilmaz 2009; Diebold and Yilmaz 2012; Diebold and Yilmaz 2015). The volatility spillover index has the advantage of being free from the problem of variable order and the theoretical background for variable identification. In addition, the spillover effect can be analyzed by decomposing the direction and size of information.

In this study, the researcher used the volatility spillover index of Diebold and Yilmaz to analyze the linkage between oil assets and commodity asset markets. The 20 commodity futures indices are WTI, BRENT, DUBAI, natural gas, gas oil, gold, aluminum, copper, lead, nickel, tin, zinc, oat, corn, soybean, wheat, cocoa, coffee, cotton, and raw sugar. The total analysis period is 3,104 days from January 4, 2010, to July 29, 2022. To compare the impact of COVID-19 and the outbreak of the Russia-Ukraine war on the transfer effect, I present the results of comparing the transfer effect of three sub-periods based on the outbreak of COVID-19 and the outbreak of the Russia-Ukraine war. And COVID-19 and Russian-Ukrainian wars are not over and are currently ongoing.

This paper is structured as follows. Following the introduction in Chapter 1, Chapter 2 explains the research data and the volatility spillover index, which is a research model. Chapter 3 presents the empirical results of the transfer effect. Finally, Section 4 presents the conclusion.

2. Research Data and Model

2.1. Research data

The influence of the Russia-Ukraine War on commodity asset prices is examined in this study using 20 commodity futures. The 20 commodity indices are WTI, BRENT, DUBAI, natural gas, gas oil, gold, aluminum, copper, lead, nickel, tin, zinc, oats, corn, soybean, wheat, cocoa, coffee, cotton, and raw sugar. The source of the data is FnGuide's DataGiude. The analysis period is a total of 3,104 days from January 4, 2010, to July 29, 2022 (called "ALL" hereafter). The change in the spillover effect between commodities asset prices during the COVID-19 outbreak and the Russia-Ukraine war is then compared over three sub-periods. The first sub-period is the period before the outbreak of COVID-19 from January 4, 2010, to

March 10, 2020 (2,513 days, called "PRE" hereafter). The second subperiod is the period after the outbreak of COVID-19, from March 11, 2020, to February 23, 2022 (484 days, called "COVID19" hereafter). The third lower famine is the period after the outbreak of the Russia-Ukraine War (henceforth War), from February 24, 2022, to July 29, 2022 (107 days, called "WAR" hereafter). Each of the 20 commodity index returns is measured as log returns.

Figure 1 shows the trends of three oil futures prices (WTI, BRENT, DUNAI) and natural gas futures prices. The lowest price of BRENT oil was 19.33 $/bbl on April 21, 2020, and the highest price was 123.7 $/bbl on March 8, 2022. The lowest price for natural gas was 1.482 $/mmBtu on June 25, 2020, and the highest price was 9.293 $/mmBtu on June 7, 2022. In April 2022, according to the Russian Federal Statistical Office Rosstat, Russia produced 10.3 million barrels per day, down 4.5% from the previous year (US 11.87 million barrels, Saudi Arabia 10.441 million barrels), raising crude oil prices.

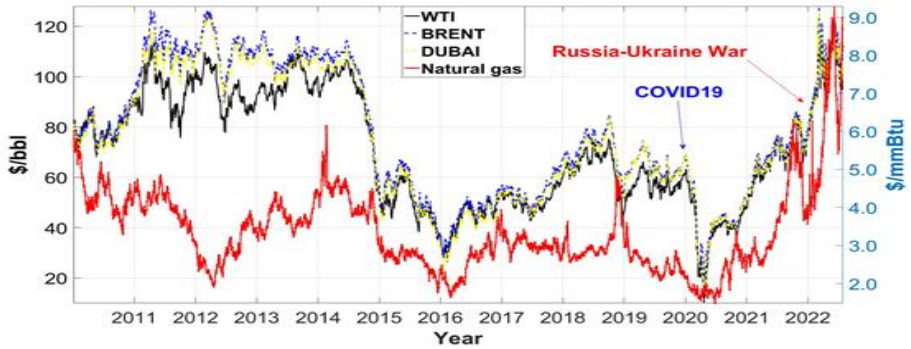


Fig. 1: Oil and natural gas futures price trend.

Fig. 2 shows the trend of the corn futures index and wheat futures index. The corn futures index rose from 2010 to the end of 2012, then showed a downward trend from 2013. However, there is a weak trend from 2013 to 2019. The corn futures index reversed its upward trend after recording the lowest point since the outbreak of COVID-19. The lowest corn futures price is 302 ¢/lb on 29 April 2020, and the highest price is 818 ¢/lb on 29 April 2022.

Next, the wheat futures index shows a similar trend to the corn futures index after the outbreak of COVID-19, and shows greater volatility after the Russia-Ukraine war. The wheat futures index has a high price per lb over the entire period, and shows a similar pattern in its trend. The price of the wheat futures index is high per lb over the entire period, with the lowest price being 474 ¢/lb on June 26, 2020, and the highest price being 1,425.2 ¢/lb on March 7, 2022.

Fig. 2: Corn and wheat futures price trend.

Figure 3 shows the trend of the nickel futures index, and it can be confirmed that the price rose rapidly after the outbreak of the Russia-Ukraine war. Russia accounts for 6% of nickel production in the world, and recently nickel is a raw material for secondary batteries, which is the most important part of electric vehicles along with cobalt and manganese. Nickel futures recorded a peak of 48,241 $/ton on March 10, 2022, a three-fold increase from 16,040 $/ton in the previous year, after which the price of nickel fell sharply.

Fig. 3: Nickel futures price trend.

2.2. Research model

In this study, the volatility spillover index of Diebold and Yilmaz (2012) was used to analyze the connectedness between commodity futures indices, and the measured empirical results are presented as spillover effect to others (SP_i^{to}), the spillover effect from others (SP_i^{from}), net spillover effect (NET), and total spillover effect (TSI).

The total spillover effect is measured by dividing the sum of the off-diagonal elements of the standardized prediction error variance ($\theta_{ij}^G(H)$) by the standardized variance decomposition ($\sum_{j=1}^{N} \theta_{ij}^G(H)$).

$$TSI(H) = \frac{\sum_{i,j=1\ i\neq j}^{N} \tilde{\theta}_{ij,s(H)}^{G}}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij(H)}^{G}} \times 100 \quad (1)$$

Here $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{G}(H)$ is 1. And $\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{G}(H)$ becomes N, and N is 20 because 20 commodity futures indices are analyzed in this study. The closer the total spillover index is to 100%, the higher the connectedness, and the stronger the spillover effect between variables. On the other hand, if the total spillover index has a value close to 0%, the connectedness between variables is low and the spillover effect is not active.

Spillover effect to others (SP_i^{to}) means the spillover effect in which the impact of variable i affects other variables, and can be calculated as follows.

$$SP_i^{to} = \sum_{j=1\ i\neq j}^{N} \tilde{\theta}_{ij,s}^{G}(H) \times 100 \quad (2)$$

The spillover effect from others (SP_i^{from}) represents the spillover effect from another variable j to the variable i and can be calculated as follows.

$$SP_i^{From} = \sum_{j=1\ i\neq j}^{N} \tilde{\theta}_{ij,s}^{G}(H) \times 100 \quad (3)$$

The net spillover effect (NET) means the pure spillover effect of variable i, and is calculated as follows by subtracting the inflow spillover effect from the outflow spillover effect.

$$NET_i = SP_i^{to} - SP_i^{from} \quad (4)$$

If NET has a positive value, the spillover effect to others is greater than the spillover effect from others, which means that the variable plays a leading role in the spillover effect. Conversely, if NET has a negative value, it means that the spillover effect from others is less than the spillover effect to others and is dependent on other variables.

3. Empirical Results

Table 1 is summary of statistics of commodity futures index returns (unit %). And the 20 index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar). The average value of all assets is close to zero, and the highest average return is NA (natural gas). And the returns of oil futures such as WTI, BRENT, and DUBAI are more volatile than other assets. WTI, which shows the lowest rate of return among variables, is -45.21%, and oats, which shows the highest rate of return among variables, is 54.17%. The skewness of the futures return has a mixture of positive and negative values, and the kurtosis all have excess kurtosis higher than 3 of the normal distribution.

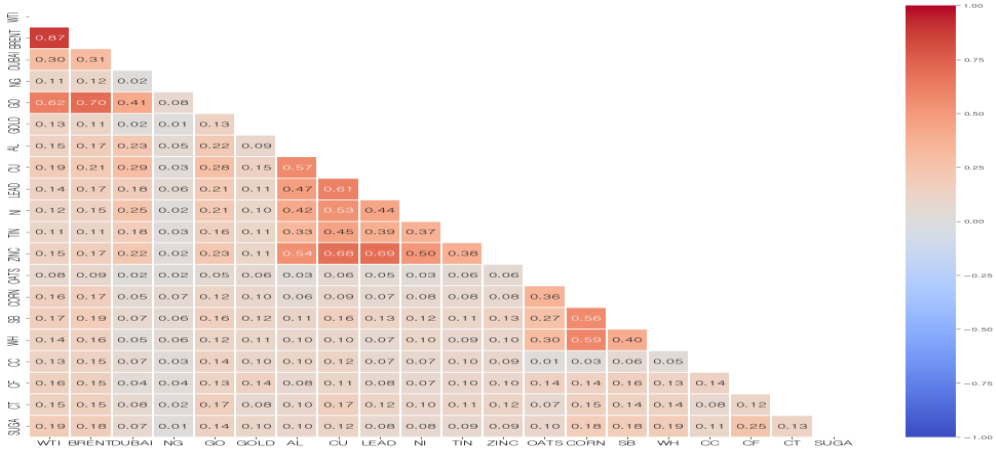
Table 1: Summary statistics (%).

	Min	Median	Mean	Max	Std.	Skew.	Kurt.	No.
WTI	-45.21	0.03	0.05	37.66	2.85	0.07	52.14	3,103
BRENT	-24.40	0.07	0.04	21.02	2.39	-0.12	18.01	3,103
DUBAI	-32.34	0.01	0.04	42.11	2.45	1.51	57.82	3,103
NG	-25.95	0.00	0.06	46.48	3.31	1.08	19.96	3,103
GO	-17.48	0.04	0.04	18.24	1.93	-0.14	12.77	3,103
GOLD	-9.35	0.02	0.02	7.78	1.02	-0.43	9.69	3,103
AL	-12.19	0.00	0.01	14.87	1.35	-0.16	13.54	3,103
CU	-6.98	0.00	0.01	9.25	1.34	-0.14	5.65	3,103
LEAD	-9.47	0.00	0.01	7.47	1.59	-0.14	4.95	3,103
NI	-15.78	0.00	0.03	44.28	2.09	2.77	71.10	3,103
TIN	-14.49	0.00	0.03	14.77	1.73	-0.26	14.01	3,103
ZINC	-7.89	0.00	0.02	11.29	1.58	0.09	5.44	3,103
OATS	-34.06	0.00	0.05	54.17	2.55	1.57	87.35	3,103
CORN	-23.55	0.00	0.03	8.98	1.79	-1.09	18.31	3,103
SB	-16.33	0.04	0.02	6.65	1.39	-1.03	13.45	3,103
WH	-15.66	0.00	0.03	21.79	2.04	0.55	10.34	3,103
CC	-7.85	0.00	0.01	17.04	1.79	0.35	7.66	3,103
CF	-8.63	0.00	0.04	16.10	2.08	0.47	5.83	3,103
CT	-25.23	0.00	0.03	28.60	2.03	-0.25	45.67	3,103
SUGA	-12.45	0.00	0.01	11.42	2.01	0.02	6.48	3,103

**Note : This table presents summary statistics of commodity index returns from January 4, 2010, to July 29, 2022 (ALL). Unit is %. The 20 commodity indices (return) are WTI, BRENT, DUBAI, natural gas (NG), gas oil (GO), gold (GOLD), aluminum (AL), copper (CU), lead (LEAD), nickel (NI), Tin (TIN), Zinc (ZINC), Oat (OATS), Corn (CORN), Soybean (SB), Wheat (WH), Cocoa (CC), Coffee (CF), Cotton (CT), Raw Sugar (SUGA) , and index returns are measured as log returns.*

Table 2 shows the correlation between the returns of 20 futures indices. WTI and BRENT show a significant positive correlation of 0.87, and gas oil has a positive correlation of 0.62. And WTI and DUBAI show a positive correlation of 0.30, which is slightly lower than the correlation between WTI and BRENT. On the other hand, WTI has a weak positive (+) correlation of less than 0.19 with the returns of other futures indices other than those of the oil futures index. Next, the correlations of GOLD, NA (natural gas), and OATS range from 0.01 to 0.14 with relatively lower positive correlations than other variables. The correlation between non-ferrous metals futures (CU, LEAD, NI, TIN, ZINC) shows a relatively high positive correlation of 0.33 or more. And in the correlation of grain futures, the correlation between CORN, SB (soybean), and WH (wheat) is high.

Table 2: Correlation coefficient matrix.



**Note : This table presents summary statistics of commodity index returns from January 4, 2010, to July 29, 2022 (ALL). Unit is %. Positive correlations are shown in red, and negative correlations are shown in blue. In addition, the darker red indicates a value closer to 1, and the darker blue indicates a value closer to -1 index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).*

The results of the volatility spillover index are presented in Tables 3 through 6. Table 3 shows the results measured by the volatility spillover index for the full period (ALL) from January 4, 2010, to July 29, 2022. Table 4 shows the results measured by the volatility spillover index for the period before the outbreak of COVID-19 (PRE) from January 4, 2010, to March 10, 2020. Table 5 shows the results measured by the volatility spillover index for the COVID-19 outbreak period (COVID19) from March 11, 2020, to February 23, 2022. Table 6 shows the results measured by the volatility spillover index for the period after the outbreak of the Russia-Ukraine War (WAR) from February 24, 2022, to July 29, 2022.

The total spillover index (TSI) is calculated by dividing the sum of the spillover effect to others (or spillover effect from others) by the number of variables (N). For example, the total spillover index of the full period is 511.8 when the values in the last row are added, and if the number of variables is divided by 20, the total spillover index (TSI) of the full period is 25.6%. The total spillover index of each subperiod was estimated to be 29.2% (=583.9/20) for the TSI of the period before the COVID-19 outbreak (PRE), and 29.5% (=590.3/20) for the TSI of the period after the COVID-19 outbreak (COVID19), and the total spillover index for the period after the outbreak of the Russia-Ukraine War (WAR) is measured at 69.6% (1392.2/20). The total volatility spillover index is the highest since the outbreak of the Russia-Ukraine War, and the total volatility spillover index has increased by about two times compared to the period before the outbreak of the Russia-Ukraine War (WAR).

Table 3: The Results of the volatility spillover index for the full period (ALL)

	WTI	BRENT	DUBAI	NG	GO	GOLD	AL	CU	LEAD	NI	TIN	ZINC	OATS	CORN	SB	WH	CC	CF	CT	SUGA	SP_i^{From}
WTI	45.9	28.1	9.1	0.1	15.6	0.2	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.1	0.0	0.2	54.1
BRENT	25.7	43.0	13.9	0.0	14.4	0.4	0.0	0.0	0.1	0.8	0.2	0.3	0.0	0.0	0.0	0.6	0.1	0.1	0.0	0.2	57.0
DUBAI	25.1	21.1	42.6	0.0	9.5	0.1	0.0	0.0	0.1	0.5	0.0	0.2	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.3	57.4
NG	0.0	0.1	0.0	98.7	0.1	0.0	0.2	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	1.3
GO	16.4	18.6	3.6	0.3	54.2	0.6	0.0	0.0	0.3	2.8	0.2	0.4	0.0	0.0	0.0	2.0	0.2	0.1	0.0	0.2	45.8
GOLD	0.7	1.0	0.2	0.0	0.9	93.2	0.1	0.1	0.9	0.5	1.2	0.3	0.0	0.0	0.1	0.1	0.1	0.3	0.0	0.2	6.8
AL	0.1	0.1	0.0	0.1	0.2	0.1	48.4	46.9	0.0	1.2	0.9	0.1	0.0	0.0	0.0	1.5	0.0	0.4	0.0	0.1	51.6
CU	0.1	0.2	0.0	0.1	0.2	0.1	48.1	46.8	0.0	1.3	1.0	0.1	0.0	0.0	0.0	1.6	0.0	0.4	0.0	0.1	53.2
LEAD	0.1	0.2	0.2	0.0	0.5	0.9	0.0	0.0	72.4	1.4	2.2	20.2	0.0	0.1	0.1	0.2	0.0	0.1	0.6	0.9	27.6
NI	0.4	0.9	0.7	0.0	0.6	0.3	0.0	0.0	0.8	52.6	0.7	1.3	0.0	0.2	0.0	41.2	0.0	0.0	0.0	0.1	47.4
TIN	0.2	0.3	0.1	0.0	0.2	0.8	0.1	0.1	2.5	6.9	80.6	1.4	0.1	0.1	0.0	4.6	1.5	0.1	0.3	0.1	19.4
ZINC	0.3	0.7	0.4	0.1	0.6	0.3	0.1	0.1	20.2	1.6	1.0	73.1	0.0	0.0	0.1	0.6	0.0	0.1	0.0	0.5	26.9
OATS	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	98.2	0.8	0.6	0.1	0.0	0.1	0.0	0.1	1.8
CORN	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.1	0.0	0.8	88.9	6.2	2.7	0.0	0.1	0.0	0.5	11.1
SB	0.0	0.1	0.0	0.2	0.1	0.1	0.0	0.0	0.1	0.0	0.4	0.1	0.6	6.3	90.1	1.2	0.2	0.3	0.1	0.2	9.9
WH	0.3	1.1	0.5	0.1	0.2	0.1	0.1	0.0	0.1	6.6	0.4	0.9	0.1	2.6	1.1	85.1	0.1	0.0	0.0	0.7	14.9
CC	0.0	0.1	0.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.9	0.1	0.0	0.0	0.2	0.0	97.3	0.5	0.0	0.3	2.7
CF	0.2	0.2	0.1	0.1	0.1	0.3	0.4	0.4	0.1	0.0	0.1	0.1	10.3	0.1	0.2	0.1	0.4	86.3	0.0	0.6	13.7
CT	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.7	0.0	0.3	0.1	0.0	0.1	0.0	0.0	0.0	0.0	97.6	0.7	2.4
SUGA	0.3	0.4	0.4	0.0	0.3	0.1	0.0	0.0	1.2	0.0	0.1	0.9	0.0	0.5	0.2	0.6	0.2	0.6	0.7	93.5	6.5
SP_i^{To}	69.9	73.4	29.4	1.5	43.6	4.5	49.2	47.9	27.6	24.0	9.9	26.5	12.1	11.1	8.9	57.4	3.5	3.4	2.0	5.9	TSI=25.6

**Note : 1. This table shows the results of the volatility spillover index estimated from the daily returns of 20 commodity indices for the overall period from January 4, 2010, to July 29, 2022 (ALL).*

2. Index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).

Table 4: The Results of the volatility spillover index for the previous period of COVID-19 (PRE).

	WTI	BRENT	DUBAI	NG	GO	GOLD	AL	CU	LEAD	NI	TIN	ZINC	OATS	CORN	SB	WH	CC	CF	CT	SUGA	SP_i^{From}
WTI	32.4	29.3	18.4	0.1	17.0	0.8	0.2	0.4	0.3	0.5	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.2	0.0	0.0	67.6
BRENT	29.0	31.5	19.0	0.1	18.2	0.4	0.2	0.3	0.2	0.5	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.2	0.1	0.0	68.5
DUBAI	23.1	24.6	36.0	0.0	14.7	0.1	0.3	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	64.0
NG	1.5	1.7	1.8	92.1	0.8	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.8	0.1	0.0	0.0	0.1	0.4	0.0	0.0	7.9
GO	19.5	21.3	11.7	0.0	44.1	0.6	0.3	0.4	0.3	0.7	0.1	0.4	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	55.9
GOLD	2.2	1.0	0.5	0.0	0.7	83.2	0.2	5.6	0.8	1.9	2.5	0.2	0.0	0.0	0.0	0.2	0.2	0.4	0.1	0.1	16.8
AL	0.9	0.8	0.9	0.1	0.5	0.3	66.4	7.0	6.6	7.1	1.1	6.6	0.0	0.0	0.0	0.0	0.6	0.3	0.0	0.6	33.6
CU	0.7	0.5	0.6	0.0	0.6	3.8	5.4	55.2	11.2	5.8	5.7	9.4	0.0	0.0	0.0	0.3	0.2	0.2	0.1	0.3	44.8
LEAD	0.5	0.5	0.4	0.1	0.6	0.6	5.1	11.3	50.1	7.1	2.8	19.4	0.0	0.0	0.0	0.3	0.1	0.1	0.3	0.6	49.9
NI	1.9	1.7	1.5	0.0	1.5	1.5	6.3	6.6	8.5	63.6	1.6	4.1	0.0	0.0	0.1	0.1	0.0	0.4	0.0	0.4	36.4
TIN	0.3	0.2	0.2	0.0	0.1	1.7	1.3	6.5	4.2	2.3	80.7	1.7	0.0	0.1	0.0	0.2	0.1	0.0	0.2	0.1	19.3
ZINC	1.1	1.3	1.1	0.2	1.0	0.2	5.4	9.8	20.5	3.5	1.3	53.7	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.6	46.3
OATS	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.9	0.1	0.1	0.1	0.1	0.2	0.0	0.0	1.1
CORN	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.4	0.1	0.0	0.1	0.0	0.1	87.3	4.9	5.4	0.1	0.1	0.1	0.7	12.7
SB	0.4	0.5	0.3	0.1	0.3	0.1	0.1	0.0	0.1	0.1	1.3	0.1	0.1	5.0	88.7	2.1	0.1	0.3	0.1	0.2	11.3
WH	0.1	0.0	0.1	0.0	0.0	0.2	0.1	0.2	0.6	0.1	0.4	0.2	0.1	5.2	2.0	87.6	0.4	0.1	0.2	2.2	12.4
CC	0.3	0.3	0.0	0.1	0.2	0.1	0.7	0.3	0.3	0.5	0.1	0.2	0.0	0.0	0.1	0.7	95.3	0.3	0.1	0.3	4.7
CF	0.3	0.2	0.2	0.5	0.0	0.4	0.4	0.2	0.1	0.5	0.0	0.1	12.5	0.1	0.2	0.2	0.2	83.2	0.1	0.7	16.8
CT	0.4	0.5	0.5	0.6	0.4	0.0	0.0	0.2	0.6	0.1	0.2	0.1	0.0	0.1	0.0	0.2	0.0	0.0	95.2	0.7	4.8
SUGA	0.1	0.1	0.1	0.0	0.3	0.1	0.2	0.9	1.2	0.4	0.1	1.4	0.0	0.5	0.2	1.8	0.2	0.8	0.7	90.9	9.1
SP_i^{To}	82.4	84.7	57.5	2.1	57.1	11.1	26.2	50.4	55.9	31.5	17.8	44.6	13.8	11.4	8.0	11.8	2.9	4.2	2.3	7.8	TSI=29.2

**Note : 1. This table shows the results of the volatility spillover index estimated from the daily returns of 20 commodity indices for the previous period of COVID19 from January 4, 2010, to March 10, 2020 (PRE).*

2. Index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).

3. The spillover effect to others (SP^{To}) is calculated as the sum of each column excluding its own effect and presented in the last row. The spillover effect from others (SP^{From}) is calculated as the sum of rows excluding its own effect and presented in the last column. The volatility spillover index (TSI) is calculated by summing the inflow spillover effect of the last row and dividing it by the number of variables (N).

Table 5: The Results of volatility spillovers for the period of COVID-19 outbreak (COVID19).

	WTI	BRENT	DUBAI	NG	GO	GOLD	AL	CU	LEAD	NI	TIN	ZINC	OATS	CORN	SB	WH	CC	CF	CT	SUGA	SP_i^{From}
WTI	40.7	29.5	8.4	0.1	15.3	0.2	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.1	0.3	0.1	1.0	3.7	59.3
BRENT	28.0	42.7	11.1	0.0	9.9	0.4	0.1	0.2	0.2	0.1	0.2	0.2	0.0	0.1	0.1	0.1	0.2	0.1	1.8	4.4	57.3
DUBAI	26.0	19.8	36.0	0.0	9.4	0.3	0.1	0.1	0.1	0.2	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.0	1.6	5.8	64.0
NG	0.0	0.0	0.0	95.2	0.0	0.2	0.4	0.3	0.4	1.6	0.2	0.1	0.1	0.2	0.2	0.4	0.2	0.1	0.1	0.3	4.8
GO	18.1	15.1	1.8	0.5	57.6	0.5	0.1	0.1	0.9	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.4	0.1	0.4	3.6	42.4
GOLD	1.4	2.5	0.8	0.1	1.7	83.3	0.3	0.3	2.0	0.2	1.7	0.4	0.1	0.1	2.6	0.3	0.1	0.6	0.8	0.8	16.7
AL	0.0	0.2	0.1	0.1	0.1	0.2	47.9	45.4	0.1	0.0	0.2	0.0	0.0	0.0	0.1	1.0	0.0	1.7	1.2	1.8	52.1
CU	0.0	0.2	0.1	0.1	0.1	0.2	47.9	45.3	0.1	0.0	0.1	0.0	0.0	0.0	0.1	1.0	0.1	1.7	1.1	1.9	54.7
LEAD	0.4	0.7	0.2	0.7	1.6	2.4	0.4	0.3	79.5	4.2	0.4	5.4	0.1	0.2	0.2	1.2	0.1	0.1	0.1	1.9	20.5
NI	0.4	0.6	0.6	0.2	0.2	0.2	1.1	1.1	3.1	75.8	1.7	2.0	0.0	0.1	0.2	0.5	4.0	0.3	0.6	7.3	24.2
TIN	0.1	0.2	0.2	0.2	0.1	0.2	0.4	0.3	0.8	1.6	84.3	0.8	0.1	0.1	0.7	0.3	3.9	0.6	4.5	0.9	15.7
ZINC	0.6	0.6	0.5	0.1	0.4	0.6	0.1	0.1	5.8	2.2	0.9	85.8	0.1	0.0	0.1	0.2	0.2	0.3	0.9	0.3	14.2
OATS	0.0	0.1	0.0	1.5	0.1	0.0	0.3	0.3	0.2	0.4	0.2	0.2	87.7	0.4	0.1	6.0	0.1	0.2	0.1	2.0	12.3
CORN	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.4	87.1	3.4	7.8	0.0	0.1	0.1	0.4	12.9
SB	0.2	0.1	0.1	2.8	0.4	2.9	0.1	0.1	0.1	0.2	0.3	0.2	0.1	3.2	78.0	8.9	0.7	0.1	1.4	0.3	22.0
WH	0.2	0.2	0.0	1.0	0.2	0.3	1.2	1.1	1.2	0.1	0.1	0.2	4.9	6.5	8.2	71.2	0.2	0.2	1.4	1.5	28.8
CC	0.2	0.2	0.1	0.3	0.2	0.2	0.2	0.2	0.4	4.3	2.6	0.1	0.2	0.0	1.3	0.1	83.9	1.8	0.7	3.1	16.1
CF	0.4	0.6	0.2	0.1	0.3	0.2	1.8	1.7	0.8	0.1	0.5	0.1	0.2	0.1	0.3	0.4	1.7	89.3	0.6	0.6	10.7
CT	5.3	7.0	2.7	0.5	2.8	0.3	1.2	1.2	0.3	0.2	1.4	0.4	0.1	1.3	0.5	0.7	0.2	0.4	69.3	4.1	30.7
SUGA	4.8	4.6	8.6	0.0	1.7	0.1	0.3	0.3	0.7	0.4	0.5	0.3	1.7	0.8	0.3	0.9	1.4	0.1	3.3	69.1	30.9
SP_i^{To}	86.1	82.2	35.5	8.4	44.5	9.4	56.1	53.2	17.1	16.1	11.1	11.3	8.3	13.6	18.5	30.0	13.9	8.5	21.7	44.7	TSI=29.5

**Note : 1. This table shows the results of the volatility spillover index estimated from the daily returns of 20 commodity indices for the period of COVID19 outbreak From March 11, 2020 to February 23, 2022 (COVID19).*

2. Index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).

3. The spillover effect to others (SP^{To}) is calculated as the sum of each column excluding its own effect and presented in the last row. The spillover effect from others (SP^{From}) is calculated as the sum of rows excluding its own effect and presented in the last column. The volatility spillover index (TSI) is calculated by summing the inflow spillover effect of the last row and dividing it by the number of variables (N).

Table 6: The results of volatility spillovers for the period after the outbreak of the Russian-Ukraine War (WAR)

	WTI	BRENT	DUBAI	NG	GO	GOLD	AL	CU	LEAD	NI	TIN	ZINC	OATS	CORN	SB	WH	CC	CF	CT	SUGA	SP_i^{From}
WTI	22.6	21.4	11.0	0.4	9.3	2.6	3.5	2.7	0.5	1.5	1.0	3.0	2.0	0.6	1.2	9.9	0.7	0.5	1.2	4.4	77.4
BRENT	20.6	22.1	11.1	0.8	10.2	2.6	3.4	2.4	0.5	1.5	1.0	3.3	2.1	0.6	1.2	10.2	0.7	0.4	1.0	4.3	77.9
DUBAI	15.0	15.5	27.9	1.0	6.6	2.1	4.5	2.2	0.5	2.4	1.9	2.5	2.8	0.6	1.5	8.6	0.8	0.1	0.4	3.2	72.1
NG	0.7	1.5	1.1	54.7	3.2	4.4	3.6	2.2	2.4	0.6	7.4	4.5	1.1	0.5	0.6	2.0	4.8	1.7	0.9	2.3	45.3
GO	15.8	15.8	11.3	0.8	16.2	1.7	2.7	3.8	0.8	5.3	2.0	2.9	1.9	0.4	1.2	11.6	0.6	0.5	0.8	3.7	83.8
GOLD	3.7	4.2	5.0	1.0	4.7	51.1	5.2	2.2	1.5	1.8	1.8	2.3	1.9	1.2	1.4	5.2	0.7	0.9	1.7	2.6	48.9
AL	15.9	15.0	15.1	0.5	4.8	2.0	10.4	2.4	1.0	5.9	1.8	4.8	1.8	0.4	1.2	11.0	1.4	0.5	0.9	3.1	89.6
CU	9.1	8.0	7.6	1.7	8.0	2.0	4.2	23.1	1.4	1.8	2.0	4.6	4.5	4.3	3.4	4.0	2.6	2.6	2.4	2.8	76.9
LEAD	2.7	3.4	2.9	1.0	2.2	3.6	3.4	5.4	42.9	0.7	4.3	4.4	2.5	1.6	1.3	2.9	1.1	2.4	8.2	2.8	57.1
NI	18.9	17.7	15.3	0.2	5.4	1.4	3.4	1.9	0.8	7.6	1.9	4.0	2.0	0.4	1.1	13.4	0.4	0.2	1.3	2.5	92.4
TIN	11.2	10.9	10.0	2.2	3.8	2.9	3.0	3.9	2.4	3.8	20.8	4.0	1.4	0.7	1.2	9.2	0.8	2.1	3.5	2.0	79.2
ZINC	6.3	7.4	4.3	2.5	3.4	1.2	7.6	6.7	3.9	1.2	1.5	35.6	2.1	1.4	2.3	4.5	2.0	1.9	2.1	1.9	64.4
OATS	3.4	3.0	1.7	1.2	1.5	3.0	1.9	1.7	2.8	1.3	1.3	0.6	24.7	22.5	19.8	3.2	1.1	4.3	0.7	0.6	75.3
CORN	2.6	2.4	1.6	1.6	1.8	2.8	2.1	3.1	2.0	1.4	1.1	0.4	22.3	25.4	20.1	2.8	0.7	3.4	1.4	1.0	74.6
SB	2.9	2.8	2.1	1.1	1.0	2.9	3.3	1.7	1.3	1.2	1.4	0.9	20.9	21.6	27.0	2.3	0.7	3.3	0.4	1.1	73.0
WH	20.0	18.5	13.9	0.4	5.8	1.3	3.0	2.2	0.5	1.3	1.4	3.7	2.4	0.3	0.9	19.8	0.6	0.3	1.2	2.7	80.2
CC	1.3	1.5	3.3	4.6	2.5	2.6	7.9	4.0	1.9	0.4	2.5	1.9	1.3	1.2	0.6	1.5	55.4	2.3	0.8	2.5	44.6
CF	4.1	3.4	2.1	2.2	2.1	2.2	3.8	2.6	6.0	1.2	3.6	1.6	9.7	9.6	9.4	4.3	1.5	28.7	1.2	0.9	71.3
CT	1.4	1.8	1.0	3.0	1.6	1.5	0.4	7.2	4.1	1.2	11.6	2.9	1.4	1.3	2.3	2.4	0.9	0.5	52.8	0.6	47.2
SUGA	4.8	5.1	1.8	9.2	8.9	2.3	3.4	3.6	1.1	0.8	2.3	2.2	1.3	2.4	2.4	6.2	1.3	0.9	0.7	39.2	60.8
SP_i^{To}	160.4	159.3	122.1	35.6	86.8	45.3	70.4	61.8	35.3	35.5	51.9	54.5	85.2	71.6	73.0	115.4	23.4	28.9	30.9	44.8	TSI=69.6

**Note : 1. This table shows the results of the volatility spillover index estimated from the daily returns of 20 commodity indices for the period after the outbreak of the Russian-Ukraine War from February 24, 2022, to July 29, 2022 (WAR)*

2. Index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).

3. The spillover effect to others (SP^{To}) is calculated as the sum of each column excluding its own effect and presented in the last row. The spillover effect from others (SP^{From}) is calculated as the sum of rows excluding its own effect and presented in the last column. The volatility spillover index (TSI) is calculated by summing the inflow spillover effect of the last row and dividing it by the number of variables (N).

Table 7 shows the results of organizing the values in Tables 3 through 6 by size to compare the size of the spillover effect to others (Panel A) and the spillover effect (Panel B) from others of the commodity futures index.

Table 7: Comparison of the spillover effect to others and the spillover effect from others by period.

No.	Panel A. Spillover effect to others				Panel B. Spillover effect from others			
	ALL	PRE	COVID 19	WAR	ALL	PRE	COVID 19	WAR
1	BRENT	BRENT	WTI	WTI	DUBAI	BRENT	DUBAI	NI
2	WTI	WTI	BRENT	BRENT	BRENT	WTI	WTI	AL
3	WH	DUBAI	AL	DUBAI	WTI	DUBAI	BRENT	GO
4	AL	GO	CU	WH	CU	GO	CU	WH
5	CU	LEAD	SUGA	GO	AL	LEAD	AL	TIN
6	GO	CU	GO	OATS	NI	ZINC	GO	BRENT
7	DUBAI	ZINC	DUBAI	SB	GO	CU	SUGA	WTI
8	LEAD	NI	WH	CORN	LEAD	NI	CT	CU
9	ZINC	AL	CT	AL	ZINC	AL	WH	OATS
10	NI	TIN	SB	CU	TIN	TIN	NI	CORN
11	OATS	OATS	LEAD	ZINC	WH	CF	SB	SB
12	CORN	WH	NI	TIN	CF	GOLD	LEAD	DUBAI
13	TIN	CORN	CC	GOLD	CORN	CORN	GOLD	CF
14	SB	GOLD	CORN	SUGA	SB	WH	CC	ZINC
15	SUGA	SB	ZINC	NG	GOLD	SB	TIN	SUGA
16	GOLD	SUGA	TIN	NI	SUGA	SUGA	ZINC	LEAD
17	CC	CF	GOLD	LEAD	CC	NG	CORN	GOLD
18	CF	CC	CF	CT	CT	CT	OATS	CT
19	CT	CT	NG	CF	OATS	CC	CF	NG
20	NG	NG	OATS	CC	NG	OATS	NG	CC

**Note : Panel A summarizes the spillover effect to others by period from Tables 3 to 6 in order of size. Panel B summarizes the spillover effect from others by period from Tables 3 to 6 in order of size. The period consists of the full period (ALL), the period before the outbreak of COVID-19 (PRE), the period after the outbreak of COVID-19 (COVID19), and the period after the outbreak of the Russia-Ukraine War (WAR). Index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).*

BRENT and WTI's spillover effect to others is the highest by period. BRENT's spillover effect on others is highest in the entire period (ALL) and pre-COVID-19 period (PRE), and WTI's spillover effect on others is highest in post-COVID-19

periods (COVID19) and post-Russia-Ukraine war (WAR

). BRENT and WTI's spillover effect to others is the highest by period. BRENT's spillover effect to others is highest in the full period (ALL) and pre-COVID-19 period (PRE), and WTI's spillover effect to others is highest in COVID 19 period (COVID19) and post-Russia-Ukraine war (WAR). As for the spillover effect to others of the period before the outbreak of COVID-19 (PRE), the oil futures index (BRENT, WTI, DUBAI, gas oil) and the non-ferrous metal futures index (lead, copper, zinc, nickel, aluminum, tin) record the top. The spillover effect on others of the COVID-19 period (COVID19) is the highest for aluminum, copper, and sugar after WTI and BRENT. The spillover effect to others of the post-Russian-Ukraine War (WAR) is higher for oil futures indexes (BRENT, WTI, DUBAI, gas oil), and wheat ranks fourth. The spillover effect on others during the period after the outbreak of COVID-19 (COVID19) is highest in the order of WTI, BRENT, aluminum, copper, sugar, gas oil, DUBAI, wheat, cotton, and soybean.

The spillover effect from others shows a similar pattern to the spillover effect to others, but the spillover effect from others shows a very different pattern during the Russia-Ukraine war. Oil futures such as DUBAI, BRENT, and WTI have a high spillover effect from others except during the war period (WAR). In the Russian-Ukraine War (WAR) spillover effect from others is high for nickel, aluminum, gas oil, wheat, and tin.

Table 8 shows the results of measuring the forward spillover effect. The net spillover effect of WTI and BRENT shows a positive (+) net spillover effect in the full period (ALL) and all subperiods (PRE, COVID, WAR). In addition, the figure for the net spillover effect in the period after the outbreak of the Russia-Ukraine War (WAR) is very high compared to other periods.

The net spillover effect (NET) of DUBAI had a negative (-) value and then a positive (+) value after the Russia-Ukraine War. Wheat, oats, and gas oil show a positive net spillover effect after the outbreak of the Russia-Ukraine war. GOLD, zinc, cotton, cocoa, tin, coffee, and nickel have a net spillover effect of negative (-) for the full period and all sub-periods.

Table 8: Net spillover effects.

	WTI	BRENT	DUBAI	WH	OATS	GO	SB	CORN	GOLD	NG
ALL	15.8	16.5	-28.0	42.6	10.3	-2.2	-1.0	0.0	-2.4	0.2
PRE	14.9	16.3	-6.5	-0.7	12.7	1.2	-3.3	-1.3	-5.7	-5.8
COVID19	26.8	24.9	-28.5	1.3	-4.0	2.1	-3.5	0.7	-7.3	3.5
WAR	83.1	81.4	50.0	35.2	9.9	3.0	0.0	-3.0	-3.7	-9.7
	ZINC	CU	SUGA	CT	AL	CC	LEAD	TIN	CF	NI
ALL	-0.4	-5.3	-0.6	-0.3	-2.4	0.7	0.0	-9.5	-10.4	-23.4
PRE	-1.7	5.6	-1.3	-2.5	-7.4	-1.7	6.0	-1.5	-12.6	-4.9
COVID19	-2.9	-1.5	13.7	-8.9	3.9	-2.1	-3.4	-4.6	-2.2	-8.1

WAR	-9.8	-15.1	-16.0	-16.3	-19.2	-21.2	-21.8	-27.3	-42.4	-56.9

**Note : This table shows the results of the net spillover effect (NET) estimated from the daily returns of 20 commodity indices. The net spillover effect is measured by subtracting the spillover effect from others from the spillover effect to others. The period consists of the full period (ALL), the period before the outbreak of COVID-19 (PRE), the period after the outbreak of COVID-19 (COVID19), and the period after the outbreak of the Russia-Ukraine War (WAR). Index returns are WTI, BRENT, DUBAI, NG (natural gas), GO (gas oil), GOLD (gold), AL (aluminum), CU (copper), LEAD (lead), NI (nickel), TIN (tin), ZINC (zinc), OATS (oats), CORN (corn), SB (soybean), WH (wheat), CC (cocoa), CF (coffee), CT (cotton), and SUGA (raw sugar).*

4. Conclusion

This study analyzed the connectivity of 20 commodity futures indices using the volatility spillover index of Diebold and Yilmaz (2012). The main analysis results are as follows. First, the total volatility spillover index was 25.6% in the entire period (ALL), 29.2% in the period before the outbreak of COVID-19 (PRE), 29.5% in the period after the outbreak of COVID-19 (COVID), and 69.6% in the period after the Russia-Ukraine war (WAR) measured in %. In other words, the outbreak of the Russia-Ukraine war increased the total spillover effect between assets by more than 2.3 times. Second, the outflow spillover effect of the returns of the WTI, BRENT, and DUBAI futures indexes appears consistently high regardless of the period. In particular, during the period after the outbreak of COVID-19 (COVID), the outflow spillover effect of aluminum increased. Third, the spillover effect of DUBAI, BRENT, and WTI is consistently high except for the war period (WAR), and after the war (WAR), the spillover effect of assets such as nickel, aluminum, gas oil, wheat, and tin increases. . Fourth, as for the net spillover effect, WTI and BRENT show a positive (+) net spillover effect regardless of the period. In other words, WTI and BRENT play a leading role in the commodity futures market. On the other hand, GOLD, Zinc, Cotton, Cocoa, Tin, Coffee, and Nickel have a net spillover effect of negative (-) for the full period and all sub-periods.

Based on the results of this study, I find that the outbreak of the Russia-Ukraine war is more important than the outbreak of COVID-19 in the spillover effect of the commodity futures market. By taking the lead in the transfer impact between markets, the researcher supports the idea that WTI, BRENT, DUBAI, wheat, oats, gas oil, and lead) in the commodities futures market lead the market. Moreover, future researchers can make better portfolio strategies and cross-hedging between assets using these linkages. Based on the results of this study, it will lead to the next study comparing portfolio performance and hedging using the linkage of commodity futures.

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