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Volatility of Rapeseed and Oil Prices Amid War in Ukraine

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Abstract:

Purpose: *The purpose of this article is to examine the impact of the war on the volatility of rapeseed and oil prices in the EU and to determine the impact of oil prices on rapeseed prices during the war.*
Design/Methodology/Approach: *Price changes were determined using the volatility index and coefficient of variation, and the impact of oil prices on rapeseed prices was assessed using the VAR (vector autoregression) model.*
Findings: *The study showed that (1) rapeseed prices reacted with stronger increases than oil prices to Russia's invasion of Ukraine; (2) the volatility of rapeseed prices was significantly higher after the outbreak of war than before it, while the volatility of oil prices decreased during the same period. The limited impact of oil prices on rapeseed prices was also demonstrated.*
Practical Implications: *The Russian invasion of Ukraine was a shock to the global economy in terms of geo-politics, food, and energy. Both countries are world leaders in grain and oilseed exports, and Russia is also a major oil producer. The EU is a net importer of rapeseed, which is largely used for energy purposes (biodiesel production). Ukraine is a major supplier of rapeseed to the EU.*
Originality/Value: *Geo-political, environmental, and economic issues have led to an increase in the use of cereals, oilseeds, and sugar crops, mainly for biofuel production. Rapeseed is the primary feed-stock for the production of esters used in the EU to make biodiesel.*

Keywords: *War in Ukraine, rapeseed and crude oil prices, price volatility.*

JEL codes: *C10, D40, D20.*

Paper type: *Research article.*

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1. Introduction

The full-scale war in Ukraine in February 2022 was a shock that threatened political, food, and energy security not only in the region. Several factors contributed to this situation. Russia and Ukraine are the world's leading producers and exporters of grains and oilseeds. The war called into question their supply from these regions, especially since the Russians took control of Ukraine's Black Sea ports, which were major shipping channels.

The EU and the US also imposed various sanctions on Russia, and in December 2022, the G-7 and Australia decided to introduce a mechanism for buying oil from Russia at a price not exceeding $60 per barrel. At the same time, the EU allowed duty-free imports from Ukraine, and Ukrainian exports moved initially mainly by rail through neighboring EU countries, which led to oversupply in so-called frontier countries like Poland, Hungary, and Slovakia, causing a drop in prices.

As a result, the EU imposed a temporary ban on grain, rapeseed, and sunflower imports to Poland, Slovakia, Hungary, Romania, and Bulgaria (European Commission, 2023). In addition, Russia is a leading oil producer, with a share of 11% of world production. The war between these two leading exporters of agri-food commodities, one of which is also a major oil producer, suggests various repercussions for the markets, including prices. Especially since the modern economy is based on oil as one of the main energy resources, and plastics are also produced from it.

Prices of agri-food raw materials are naturally linked to oil prices due to production, transportation, or storage costs. Geo-political, environmental, and economic issues have led to an increase in the use of cereals, oilseeds, and sugar crops, mainly for biofuel production. Rapeseed is the primary feed-stock for the production of esters used in the EU to make biodiesel.

The EU rapeseed sector is not self-sufficient, with Ukraine being its leading supplier. In such a situation, it is interesting and research-relevant to investigate the impact of the outbreak of war in Ukraine on the volatility of rapeseed and oil prices and the impact of oil prices on rapeseed prices. This will help to show the role of market shocks in the development of price levels.

2. Literature Review

At the beginning of the 21st century, biofuels were seen as a solution to oil energy crises and as pro-environmental measures to reduce greenhouse gas emissions. However, the 2008 food crisis changed this perspective, highlighting the negative social and environmental consequences of their use of energy. The ethical discussion about the legitimacy of using food raw materials for energy resurfaced with the outbreak of war in Ukraine and the resulting disruption of the country's rapeseed and grain supply chain (Transport & Environment, 2022; Thompson, 2024).

The OECD-FAO estimated that between 2008 and 2010, the consumption of vegetable oils for fuel purposes in the world accounted for 9.6% of their total consumption, increasing to 14.9% between 2018 and 2020. For the EU, this share was 45.3% and 45.4%, respectively. The organization projected that the share of oil consumption for fuel purposes will fall to 13.5% in 2030 and to 41.2% in the EU, which is largely related to the expected decline in total fuel consumption and relatively rigid blending thresholds (OECD-FAO, 2021).

Rapeseed is the second most popular oilseed crop in the world, next to soybeans. The increase in the cultivation and processing of seeds into oil in Europe in the 21st century was largely driven by demand from the energy sector (biodiesel production). The demand for biocomponents and biofuels is the result of EU regulations stimulating energy crops (Carré and Pouzet, 2014).

EU energy policies to promote biofuels have boosted their production and led to the creation of new price linkages between rapeseed oil and diesel, with the dynamics of rapeseed oil price changes no longer reflecting previous sectoral volatility and beginning to mimic changes observed in the diesel sector (Peri and Baldi, 2013). Between 2008 and 2013 in the EU, crude prices were a key influence on biodiesel prices, but changes in biodiesel prices have not been shown to significantly affect food prices (Bentivoglio, Finco, Bacchi, and Spedicato, 2015).

Instead, the use of rapeseed as an energy crop in the EU contributed to reducing the risk of volatility in the profitability of its cultivation (Zafeiriou and Karelakis, 2016). During 2008-2018, direct and indirect integration of the Ukrainian and EU rapeseed markets was observed through physical trade flows of rapeseed, rapeseed meal, and rapeseed oil. This made it possible to assume that rapeseed prices in Ukraine and the European Union are cointegrated and that adjustments of the long-term equilibrium relationship are asymmetric and seasonal (Hamulczuk, Makarchuk, and Sicafor, 2019).

The EU Directive on the Promotion of Energy from Renewable Sources (the so-called RED III), revised in 2023, maintained the maximum share of biofuels from food and fodder feedstocks at 7% in transport. The new law stipulates that if the share of first-generation biofuels is lower than this limit, a member country can reduce its mini-mum share of renewable energy (at least 29% in 2030) or its greenhouse gas emissions reduction (at least 14.5% in 2030) by this difference (European Parliament, 2023).

Once again, the EU is consistently betting on wind and solar power and non-biological renewable fuels like hydrogen while reducing the use of canola or corn-based fuels. The OECD-FAO forecasts that EU biofuel production will reach 756.5

petajoules (PJ) in 2033, down 0.7% from the 2021-2023 aver-age. The share of advanced fuels will increase at the expense of conventional fuels from 31% to 37% (OECD-FAO, 2024). Increasing competition for raw materials between the food and energy sectors raises questions about the drivers of inflation and price linkages between the sectors.

In the 20th century, commodity prices were mainly influenced by the business cycle and economic growth, suggesting a strong connection to the demand side, while the 21st century has seen an increased influence of oil prices (Borensztein, Wickham, Khan, Reinhart, 1994, Delle Chiaie, Ferrara, Giannone, 2017). Studies on the price elasticity of commodity markets have shown that, over the long horizon, agri-food commodity prices tend to change more under the influence of supply than energy commodities and metals, and lower price elasticity was observed in perennial crops compared to annual crops (Bogmans, Pescatori, Petrella, Prifti, and Stuermer, 2024).

Some studies point to an increase in price volatility in the agri-food sector in the 21st century, with periods of increased volatility possibly related to low inventory levels (Tothova, 2011). However, a cross-sectional study covering the 50 years up to the food crisis at the end of the first decade of the 21st century found no significant divergence in price volatility over the period analyzed, with the exception of cereals and rice, where volatility increased (Huchet-Bourdon, 2011). It is also pointed out that historically, periods of high volatility have already been observed and were transient phenomena (Gilbert and Morgan, 2010).

The level of food prices is the result of the complex interaction of many factors, among which are oil prices, the exchange rate, rising food demand, and slowing agricultural productivity growth, as well as agricultural, energy, and trade policies (Abbott, Hurt, and Tyner, 2008). It is assumed that prices rise faster than they fall. This relationship was observed in two-thirds of the cases studied. The unit response to a price shock at the retail level did not show features of asymmetry, but in the case of a fragmented sales market, above-average asymmetry was already observed (Peltzman, 2000). The analysis of the interaction of oil and food prices in 2000–2015 showed a clear impact of oil prices on food prices, and in the long horizon, signs of feedback were confirmed (Karakotsios, Katrakilidis, and Kroupis, 2021).

From 1991 to 2006, food prices in the U.S. were mainly influenced by agricultural commodity prices and the exchange rate, as well as energy prices, with a significant im-pact observed in the long horizon and none in the short (Baek and Koo, 2010). Also, an analysis of 2000–2016 showed a significant impact of oil prices on food prices in Asia, with food prices responding positively to oil price shocks; as a result, it was found that 64.17% of food price fluctuations could be explained by changes in oil prices (Taghizadeh-Hesary, Rasoulinezhad, and Yoshino, 2019). Oil prices influenced the prices of corn, wheat, and soybeans used for biofuel production, with the impact becoming more pronounced during periods of high oil prices (Chen, Kuo, and Chen, 2010).

From 1997 to 2011, transfers of corn price volatility to ethanol prices were observed in the U.S., but not vice versa, and after 2006, the correlations of corn and ethanol price changes intensified. During the period analyzed, oil price volatility was not observed to affect corn price volatility in the U.S. (Gardebroek and Hernandez, 2013). In contrast, between 1980 and 2017, it was observed that stocks had a stabilizing effect on the prices of wheat and corn in the U.S. (Chavas and Li, 2019).

It was also indicated that supporting corn consumption for energy purposes in the U.S. would lead to an increase in the correlation of corn prices with oil prices (Runge and Senauer, 2007). Between 1999 and 2009, an increasing correlation was found between canola and oil prices. This correlation was stronger during the 2007–2008 food crisis. This allows us to assume that rapeseed prices are increasingly responding to the same information as oil prices. In addition, rapeseed prices are characterized by high sensitivity to shocks and low persistence of volatility and, therefore, carry the risk of overreactions in phases of volatility.

The in-creased correlation creates the possibility of even greater volatility in agricultural commodity prices during the next price boom, as oil prices have historically exhibited higher levels of volatility compared to agricultural commodity prices (Busse, Brümmer, and Ihle, 2010). Between June 11, 2008, and June 14, 2012, price correlations were also found between rapeseed oil, biodiesel, and Brent crude; stocks and the $/€ exchange rate were key to price formation as well (Abdelradi, Serra, 2015). Between 1996 and 2004, the prices of wheat in Poland and Brent crude oil showed no correlation, while between 2005 and 2011, the changes already had similar dynamics, which can be linked to biofuel policy (Hamulczuk and Klimkowski, 2012).

From January 2016 to January 2018, changes in Ukrainian rapeseed prices can be explained by 62% by changes in oil prices (Makarchuk, Skudlarski, 2018). Prices of rapeseed and rapeseed oil reacted more than normal to the outbreak of war in Ukraine and the decrease in the supply of these products from Ukraine. As a result of the Ukrainian war, increased demand for rapeseed and rapeseed oil was also observed, which can be linked to high oil prices and the need to diversify energy sources (Martyshev and Stolnikovych, 2023).

It is worth mentioning that the responses to the 2008-2009 and 2019-2021 crises were different in developing and developed countries: the former reacted similarly to both shocks, the latter more strongly to the COVID-19 pandemic than to the food crisis of the first decade of the 21st century (Tabash, Chalissery, Nishad, and Al-Absy, 2024). Per capita income, on the other hand, is identified as the dominant factor explaining differences in food price transmission across countries, with greater transmission of commodity-level food price shocks to final consumers observed in low-income countries than in affluent societies (Bekkers, Brockmeier, Francois, and Yang, 2017).

Studies of price volatility and price transmission between agri-food commodities and oil point out that the results also depend on the choice of data, such as the length of the period or the selected time intervals, as well as the choice of methodology and theoretical approach (Cheng and Cao, 2019; Mustafa, Vitali, Huffaker, and Canavari, 2024).

3. Methodology

To characterize the supply-demand situation and trade balance of the rapeseed sector, published seasonal data for the period 2017/18–2023/24 (October/September) from European Commission (for the EU) and USDA (for the world) databases expressed in mil-lion tons were used. For prices, published EIA monthly data for Brent crude oil (spot, $/bbl) were used, and for rapeseed, aggregated monthly data from the European Commission (CIF Hamburg, $/t).

Price data were examined for three periods: January 2018–March 2024 (N=75), January 2018–February 2022 (N=50), and March 2022–March 2024 (N=25). The choice of study periods and prices are dictated by the research hypothesis about the potential impact of the outbreak of war in Ukraine on oil and rapeseed prices in the EU and potential changes in mutual relations.

Characterization of the rapeseed market was performed using the volatility index and coefficient of variation, which was calculated according to the formula:

$$V = S / \bar{x} * 100\%$$

where V – symbolizes the coefficient of variation, S – means standard deviation, $\bar{x}$ - arithmetic mean of the variables. Herfindahl-Hirschman Index (HHI) was used to determine concentration of global rapeseed production and trade.

To determine the impact of Brent crude oil prices on EU rapeseed prices, a vector autoregression (VAR) model with the least squares (OLS) method was used. The model used was of the following form:

$$y_t = A_1 \cdot y_{t-1} + \ldots + A_p \cdot y_{t-p} + CD_t + u_t \quad (1)$$

where t is the time point, p is the lag order, y_t is the K×1 vector of endogenous variables, while u_t represents the spherical disturbance component of identical dimension (model fit error). The coefficient matrices $A_1,...,A_p$ are characterised by K×K dimension. In addition, a constant CD_t is included in the model as a deterministic regressor.

The selection of the optimal number of lags p was based on the information criteria: Akaike (AIC), Hannana-Quinn (HQ), Schwarz (SC) and final FPE prediction error. The fit of the vector autoregressive (VAR) model was assessed using R^2 and adjusted

R^2_{adj} determination coefficients. Significance analysis of the effect of multiple factors on the de-pendent variable was carried out using the Wald test. The interdependence and association between rapeseed and oil prices in the VAR model was estimated using a covariance matrix and correlation of residuals. The covariance matrix provides an understanding of the inter-relationship in terms of the co-variance of the residuals of the two variables, while the correlation matrix provides information on the strength and direction of their interdependence.

Heteroskedasticity testing of the fitted VAR model was performed using the ARCH-LM test. The significance of serially correlated errors was determined using the portmanteau test and the Breusch-Godfrey test were applied, which allow a detailed analysis of the autocorrelation of the VAR model residuals.

In the case of heterogeneity, the Granger test result was additionally corrected using the robust covariance matrix estimator. In addition, causality test results were estimated using a bootstrap procedure with 1000 bootstrap replications. Causality was assessed using the Granger F-type and Wald tests. In view of the identified heterogeneity phenomenon, the Granger test results were corrected using a robust covariance matrix estimator. The level of significance in this analysis was set at a threshold of $\alpha = 0.05$.

The VAR analysis was performed in R software (version 4.3.1 R Core Team) using packages: report, urca, vars, MASS, readxl, dplyr, zoo, lmtest, sandwich and strucchange.

4. Research Results and Discussion

The Herfindahl-Hirschman Index (HHI) in the 2017/18 season for global rapeseed crop was 1,946 (N=28), and in the 2023/24 season, it decreased to 1,567 (N=29). HHI score in the 2017/18 season for global rapeseed exports was 4,660 (N=17), and in the 2023/24 season it decreased to 2,789 (N=15). HHI score in the 2017/18 season for rapeseed consumption was 1,924 (N=31), and in the 2023/24 season it decreased to 1,695 (N=30).

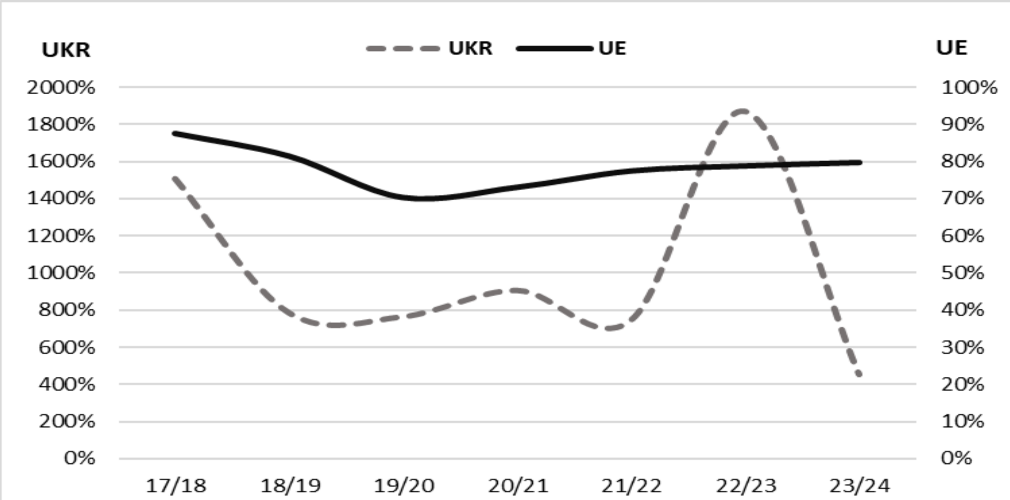
The Herfindahl-Hirschman Index in the 2017/18 season for global rapeseed imports was 1,993 (N=22), and in the 2023/24 season, it decreased slightly to 1,932 (N=22). This means that between 2017/18 and 2022/23, the HHI score for global rapeseed market saw a decline, but the sector remained highly concentrated for exports and imports, and moderately concentrated for production and consumption. The highest HHI score was observed for exports and imports, which means that diversification, especially in a market shock situation, is very difficult for both parties (exporters and importers).

The EU is the world's second-largest rapeseed producer, and Ukraine is the fifth. Their share was 23.8% and 4.0% (median), respectively, in the period under review.

The harvest in the EU decreased minimally (-0.1% to 20.0 mil-lion tons), while in Ukraine, it was higher by 114.3% (to 4.75 million tons). The EU is the world's largest consumer of rapeseed (30.5% share), while Ukraine's share is negligible (0.5%). Self-sufficiency, as measured by the ratio of production to consumption of the global rapeseed sector, averaged 101.4% (median) during the periods studied, showing a tendency to decline.

In the EU, the ratio averaged 79.1%, also showing a decline. For Ukraine, self-sufficiency averaged 784.1%, with a downward trend. This allows us to assume that, in order to balance the EU rapeseed sector, imports are needed to cover about one-fifth of the demand, while the Ukrainian rapeseed sector is characterized by structural overproduction, with surpluses generated for export.

Figure 1. *Rapeseed self-sufficiency in the EU and Ukraine (%)*



Source: *Author's calculations.*

Ukraine is the world's third-largest exporter of rapeseed with a 16,3% (median) share of global exports, during the period under review. In the 2017/18–2023/24 seasons, global rapeseed exports increased by 5.7% to 17.6 million tons, and Ukrainian exports increased by 74.7% to 3.7 million tons. In the 2017/18–2023/24 (October/September) seasons, total EU rapeseed imports increased by 31.3% to 5.5 million tons.

During the same period, Ukraine's rapeseed exports to the EU increased by 68.6% to 2.8 million tons, with an average annual growth rate of 9.1%. Purchases from Ukraine showed moderate volatility (V=22.3%). During the period under review, the average share of rapeseed imports from Ukraine in total EU imports amounted to 36.4% and showed an increasing trend. In the 2022/23 season, which includes the outbreak of the war, imports from Ukraine increased by 43.8% on an annual basis, and in the following season they were higher by 8.2%. In the 2022/23 season, the share of imports from Ukraine in EU imports was 38.2%; in the following season, it was 51.8%.

The above makes it possible to assume that Ukraine is a leading export-oriented rapeseed producer, while the EU is the largest consumer and importer, which has to cover a significant part of its consumption with imports. The EU was the main buyer of Ukrainian rapeseed during the period under review. The impetus for the intensification of Ukraine's rapeseed exports was the war. At the same time, the high concentration in trade, especially on the export side, means that importing countries have very limited opportunities to diversify their purchases. It is worth tracking how EU rapeseed prices reacted to a potential drop in supply from Ukraine as a result of the war.

Prices of rapeseed (CIF Hamburg) and Brent crude oil (spot) reacted to the outbreak of war in Ukraine with increases. In March 2022, rapeseed prices rose 26.9% on a monthly basis, while oil prices rose 20.7%. From the month prior to the price peak, rapeseed prices increased by 37.1% (to an average of $1101/ton in April 2022) and crude oil by 26.3% (to an average of $122.7/bbl in August 2022). The growth dynamics of rapeseed prices were clearly stronger than that of oil; both changes had the same direction and should be considered strong.

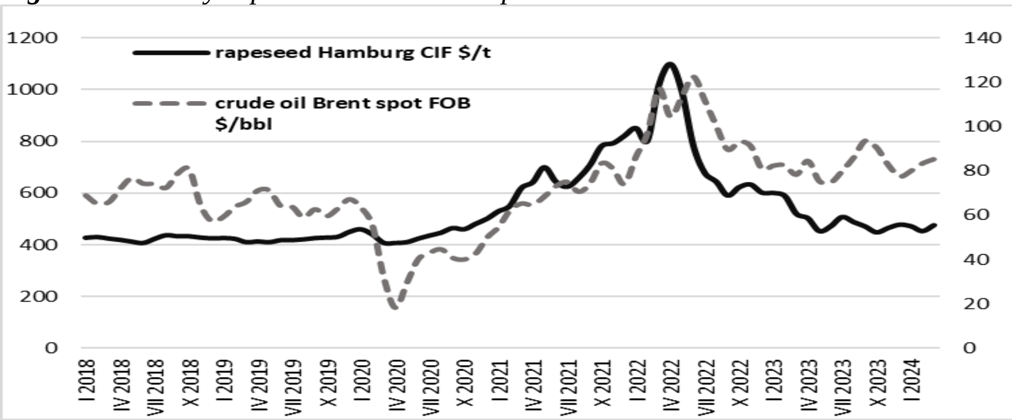
However, the timing of when prices reached a peak was different rapeseed prices peaked after two months, and oil after four. This allows us to assume that the outbreak of war in Ukraine was a supply shock, to which prices responded with strong increases with asymmetric timing characteristics.

In both cases, there was an upward trend in prices even before the outbreak of war, and after the war, peaks came declines, whose dynamics and distribution over time also varied. Rapeseed prices from peak to bottom ($447/ton in October 2023) lost 59.4%, and oil prices lost 39.0% ($74.8/bbl in June 2023). It took 17 months for rapeseed to reach the price bottom and 11 months for crude oil. In both cases, price bottoms were followed by a rebound.

It should be mentioned that the COVID-19 pandemic, the effects of which on the global economy have been widely analyzed, also occurred in the period under study prior to the start of the full-scale armed conflict in Ukraine. Although the pandemic is not the subject of this article's research, it is worth noting that rapeseed and oil prices reacted to this demand shock with declines, with the reaction of oil prices being much stronger (-42.5% month-on-month in March 2020) than rapeseed prices (-7.5% month-on-month).

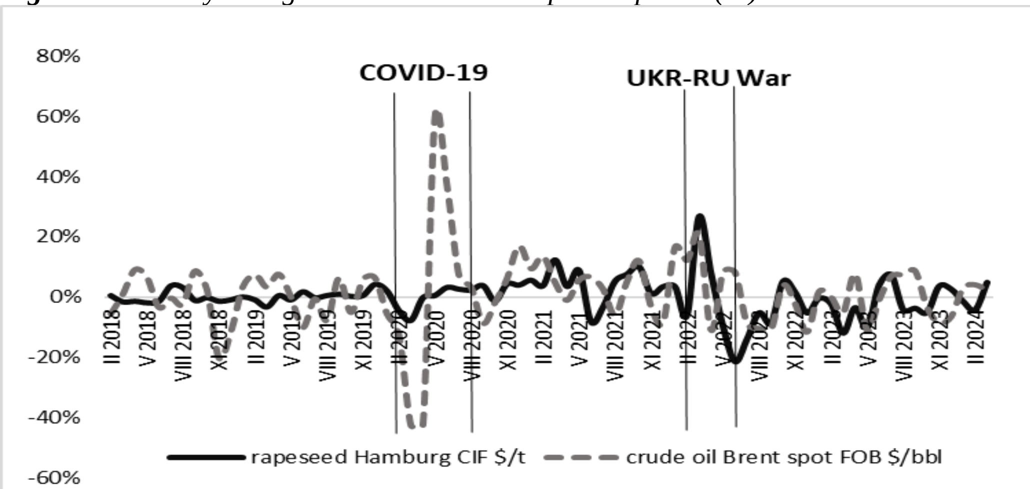
In I.2028-III.2024 period, average Hamburg CIF rapeseed prices were $536/t and Brent spot crude oil was $72.3/bbl. In the period before the outbreak of war (I.2018-II.2022), average rapeseed prices amounted to 504 $/t and oil to 62.3 $/bbl, while in the period after the outbreak of war in Ukraine (III.2022-III.2024), an average of 602 $/t was paid for rapeseed and 90.6 $/bbl for oil.

Figure 2. *Monthly rapeseed and crude oil prices*



Source: *EIA, European Commission.*

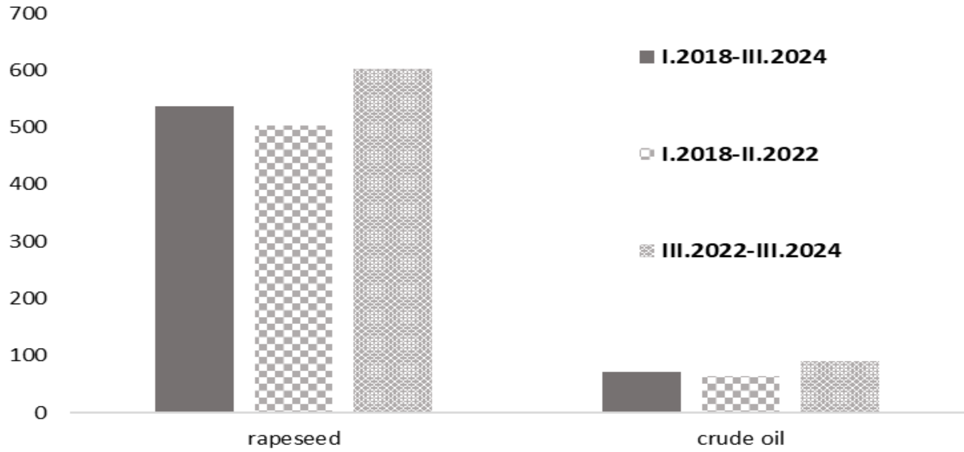
Figure 3. *Monthly changes in crude oil and rapeseed prices (%)*



Source: *Author's calculations.*

This means that prices before the outbreak of war in Ukraine were lower than after the outbreak of war, and the difference was greater for oil (-30.2%) than for rapeseed (-16.3%). This allows us to assume that the outbreak of war in Ukraine had a pro-growth effect on rapeseed and oil prices of a twofold nature. Short-term as a reaction to the outbreak of war (price increase) and long-term as an effect of the outbreak of war (under the increases caused by the outbreak of war, prices had a higher average level and did not return to pre-war levels).

Figure 4. *Monthly average prices of rapeseed (CIF Hamburg, $/t) and crude oil Brent (spot, $/bbl)*



Source: *Author's calculations.*

In January 2018–March 2024, rapeseed prices (spot, CIF Hamburg, $/t) increased by 11.5%, averaging $537 per ton per month, while Brent crude oil gained 23.6% (at an average of $72.3/bbl). The coefficient of variation (V) amounted to 29.5% for rapeseed prices and 27.2% for Brent crude oil prices during the period under review. In both cases, volatility can be considered high on average.

In January 2018–February 2022, the sub-period preceding the outbreak of the war in Ukraine, rapeseed prices increased by 88.5% (aver-aging $504 per month), and Brent crude oil was higher by 40.6% (the average monthly price was $63.2/bbl). In this first sub-period, the coefficient of variation of rapeseed prices was 26.3%, and that of oil was 24.4%. It was, therefore, slightly lower than the entire peri-od under review, while the coefficient for rapeseed can be considered average and for oil low.

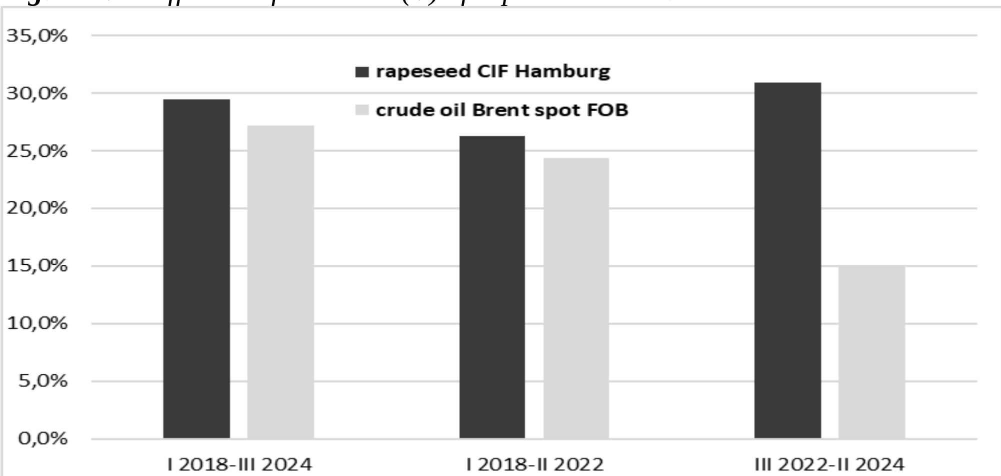
During March 2022–March 2024, the sub-period after the outbreak of the war in Ukraine, rapeseed prices fell by 53.4% (the average monthly price was $602/t), and oil declined by 27.2% (averaging $90.6/bbl). It should be noted that both rapeseed and oil prices had been rising long before the outbreak of the war in Ukraine (since mid-2020), which can be linked to the supply-demand balance in the global oilseed market, the post-COVID rebound of economies and the energy crisis in the EU sparked by gas shortages.

The out-break of war in Ukraine, however, intensified the upward trend in rapeseed prices (the highest monthly growth rate of 26.9% in the period under review occurred in March 2022; the lowest, also linked to the war, was -21.2% in June 2022, when the so-called humanitarian corridor was announced). For oil, such a catalyst was the outbreak of the COVID-19 pandemic (-42.5% and -42.6% in March and April 2020, respectively, and +59.8% in May and +37.1% in June 2020).

Oil prices also reacted more strongly to the war. The coefficient of variation in the post-war sub-period was 30.9% for rapeseed prices and 15.0% for oil prices. These amounts should be considered average and low, respectively.

In the sub-period after the outbreak of the war in Ukraine, the average prices of rapeseed and oil were higher than in the pre-war sub-period (by 19.4% and 43.4%, respectively) and higher than during the entire period studied (by 12.1% and 25.3%, respectively). In the case of rapeseed, an increase in the coefficient of variation was observed in the post-war sub-period, while a decrease was noted for oil. This can be linked to the fact that Ukraine is the world's leading producer and exporter of rapeseed, and the war has put supplies from this direction into question (Russia has blocked Ukrainian shipments by sea through Black Sea ports).

Figure 5. *Coefficient of variation (V) of rapeseed and crude oil*



Source: *Author's calculations.*

The decrease in oil price volatility after the outbreak of war in Ukraine can be linked to two factors: the warfare did not directly affect the petrochemical sector, and as of December 2022, the G-7 countries and Australia introduced a maximum purchase price for Russian oil of $60/bbl. This decision was a direct result of the war (sanctions on the aggressor) and may have helped stabilize oil prices.

The potential impact of Brent crude oil prices (spot FOB, $/bbl) on rapeseed prices (Hamburg CIF, $/t) was verified by applying a VAR (vector autoregression) model using the least squares method. According to the AIC, SC, HQ and FPE criteria, the optimal number of lags is $p = 3$. An additional attempt to include the trend as a deterministic regressor did not significantly improve the model fit, so in the final version of the model, it was decided to keep only the constant as a deterministic variable.

The R^2-value was 0.93 and the adjusted R^2 was 0.93, which confirms that the model is effective despite the adjustment for the number of variables and effectively explains about 93% of the variation in the dependent variable. This allows us to assume that the model is a very good fit for the data. The very high value of the F-statistic (147.5) and the low p-value (< 0.001) indicate that at least one of the predictors in the model significantly determines the price for rapeseed at time t.

Elements of the covariance matrix on the diagonal (40.97 for oil and 1908.0 for oilseed rape) indicate greater variability in the residuals for oilseed rape. The off-diagonal elements (105.1 and 105.12) indicate covariance between the residuals of the two variables, suggesting that there is some interdependence between them.

The correlation matrix provides information on the strength and direction of the relationship between the residuals. A value of 0.38 between oil and rapeseed indicates a moderate positive correlation, meaning that when the values of the residuals of one variable increase, the values of the residuals of the other variable also tend to increase, but the relationship is not very strong.

The constant is also statistically significant ($p = 0.012$), indicating the presence of other exogenous factors that affect rapeseed prices beyond oil prices and their own past values. The results of the ARCH test, $\chi 2(45) = 61.92$, $p = 0.048$, indicate the presence of conditional heteroskedasticity, meaning that the variance of the residuals is not constant but depends on values in previous periods.

This suggests that the VAR model may not fully explain the dynamics of rapeseed and oil price volatility, implying that the volatility of these variables is dependent on their previous values. The results presented should motivate further analysis of the model, which could include the use of GARCH models de-signed to model and forecast the variance variable or other techniques that allow heteroskedasticity to be modelled.

The results of the Portmanteau test, $\chi 2(52) = 45.72$, $p = 0.718$, indicate that there are no significant correlations in the residuals series, which is interpreted as a good sign of the adequacy of the model to the data. This, in turn, means that the model does not show significant omissions in the dynamics of the variables under study, which is important for forecasting and causal analysis. The results of the VAR model estimation are shown in Table 1.

Table 1. *Results of fitting a VAR model with three lags for rapeseed prices (I.2018-III.2024), Nobs = 72.*

Explanatory variable	Rapeseed price (Hamburg cif, $/t) at this time point t			
	A	SE	t	p
Oil price (spot FOB, $/bbl) one-month lag	-0,31	0,79	-0,39	0,699
Oil price (spot FOB, $/bbl)	1,29	1,14	1,13	0,260

two-month lag				
Oil price (spot FOB, $/bbl) three-month lag	-1,69	0,76	-2,21	0,030
Constant (CD)	57,19	22,00	2,60	0,012

Source: *Author's calculations.*

The effect of the oil price on the rapeseed price at the first lag is statistically insignificant (p = 0.699), indicating that short-term changes in the oil price do not directly affect the rapeseed price in the model. For the second lag, the oil price was similarly not significant (p = 0.260).

Analysis of the results with the third lag shows that the effect of oil prices is statistically significant and negative (p = 0.030), which may suggest that long-term changes in oil prices have an inverse correlation with rapeseed prices. The constant term of the model is also statistically significant (p = 0.012), indicating the presence of other exogenous factors that affect rapeseed prices beyond oil prices and their own past values.

Granger causality analysis and tests for the existence of instantaneous causality conducted on data from the VAR model for the oil and rapeseed variables provide mixed results regarding the dynamics of the effect of oil prices on rapeseed prices. The results of the Granger test indicate that it cannot be conclusively concluded that oil prices contribute to changes in rapeseed prices (F-Test = 1.87, p = 0.139). The lack of significant causality in the Granger sense suggests that long-term forecasts of rapeseed prices may not be strongly influenced by oil price predictions.

On the other hand, the instantaneous causality test, which assesses the interdependence of oil and rapeseed prices over the same time period, showed statistically significant results: $\chi^2 = 8.92$, p = 0.003. This indicates that changes in the price of one commodity can be linked to simultaneous changes in the price of the other, suggesting the existence of ongoing market interactions between these markets. Similar causality results for both tests were also obtained using the bootstrap procedure.

In the sub-periods analyzed (i.e., before and after the outbreak of war), no clear indication of the optimal number of lags (p) in the VAR model was observed. For the first pe-riod (January 2018–February 2022), different information criteria suggested different p-values: HQ and SC indicated p = 1, while AIC and FPE indicated p = 3.

For the second period (March 2022–March 2024), the recommended p-values showed even greater divergence, with AIC and HQ suggesting p = 6 and Scand FPE indicating p = 4. It was decided to adopt p = 3 for the period 01.2018–02.2022 and p = 4 for the period 03.2022–03.2024. This choice takes into account the balance between the complexity of the model and its ability to adequately reflect the dynamics of changes in rapeseed prices. In both examined periods, the model demonstrates a high coefficient of determination (R^2), which suggests that the model effectively explains the variability of the rapeseed price based on the included variables.

In the period from January 2018 to February 2022, the impact of oil prices on rapeseed prices is negligible. This indicates that during this period, rapeseed prices were more self-sustaining and less dependent on changes in oil prices. The results of the VAR model estimation are shown in Table 2.

Table 2. *Results of fitting a VAR model with three lags for rapeseed prices before the outbreak of the war in Ukraine (I.2018-II.2022)*

Explanatory variable	Rapeseed price (Hamburg cif, $/t) at this time point t			
	A	SE	t	p
Oil price (spot FOB, $/bbl) one-month lag	-0,31	0,79	-0,39	0,699
Oil price (spot FOB, $/bbl) two-month lag	1,01	0,93	1,08	0,286
Oil price (spot FOB, $/bbl) three-month lag	-0,84	0,62	-1,35	0,184
Constant (CD)	12,31	20,67	0,60	0,555
Model statistics:				
Nobs	47			
R^2	0,97			
R^2_{adj}	0,97			
Wald test results	$F(6,40) = 220,9$, $p < 0,001$			

Source: *Author's calculations.*

In the period from March 2022 to March 2024, a significantly higher impact of oil prices with a one-month lag on rapeseed prices was observed, as reflected by the p-value at the significance limit. The increase in the significance of the impact of oil prices can be linked to the war in Ukraine as a determinant of supply-demand and price changes, which made the rapeseed market more susceptible to external influences. The results of the VAR model estimation are shown in Table 3.

Table 3. *Results of fitting a VAR model with three lags for rapeseed prices after the outbreak of the war in Ukraine (III.2022-III.2024)*

Explanatory variable	Rapeseed price (Hamburg cif, $/t) at this time point t			
	A	SE	t	p
Oil price (spot FOB, $/bbl) one-month lag	-3,09	1,42	-2,17	0,050
Oil price (spot FOB, $/bbl) two-month lag	3,24	1,87	1,73	0,109
Oil price (spot FOB, $/bbl) three-month lag	-0,75	1,70	-0,44	0,668
Oil price (spot FOB, $/bbl) four-month lag	1,83	1,18	1,55	0,148

Constant (CD)	66,60	76,79	0,87	0,403
Model statistics:				
Nobs	21			
R^2	0,93			
R^2_{adj}	0,89			
Wald test results	F (8,12) = 21,02, p < 0,001			

Source: *Author's calculations.*

The insignificance of the multi-month lags in the oil price, with the exception of the one-month lag in the second period, which shows some impact, although it is at the significance limit, may indicate a lagged response of the rapeseed market to oil price changes. This is consistent with the hypothesis of dependence on broader global economic fac-tors.

Another interesting aspect is the high value of the constant (CD) in the second period, which may suggest a change in the level of price equilibrium or the influence of other fac-tors not included in the model that may have significantly increased the average price lev-el.

Both time series were characterized by the absence of heteroskedasticity ($p = 0.616$ and $p = 0.352$, respectively) and the absence of serial autocorrelation ($p = 0.799$ and $p = 0.109$, respectively). However, the causality test conducted showed different results for the two periods. The data from the earlier period (January 2018–February 2022) showed both the absence of Granger causality ($p = 0.180$) and instantaneous causality ($p = 0.134$). This means that past values of oil prices did not provide useful information for predicting future values of canola prices in the context of the VAR model. Also, changes in oil and rapeseed prices were not observed to be interdependent at any given point in time within the model under study.

In testing Granger causality and instantaneous causality in the context of the impact of oil prices on rapeseed prices from March 2022 to March 2024, the results obtained indicate the absence of Granger causality but show significance in terms of instantaneous causality. The p-value for Granger causality was $p = 0.101$, which again suggests that past values of oil prices do not systematically predict future changes in rapeseed prices.

In contrast, the p-value for instantaneous causality reached $p = 0.029$, indicating statistical significance and suggesting that oil and rapeseed price changes are interdependent over the same time period. The significance of instantaneous causality may indicate a dynamic interaction between the two markets that manifests itself in synchronous price responses, which may be the result of common external factors or simultaneous market responses to global economic, political, or climatic events. It is worth noting that this observation may indicate the presence of complex transmission mechanisms in the economy, which are recorded almost simultaneously in both series analyzed.

5. Conclusions, Proposals, Recommendations

The outbreak of a full-scale war in Ukraine in early 2022 was a shock that affected the Brent crude oil and rapeseed (CIF Hamburg) markets in Europe. The impact, however, varied: the direction of change was the same, but the magnitude was different.

Rapeseed prices reacted with stronger increases than Brent crude oil prices, which should be linked to the fact that Ukraine is a key exporter of rapeseed, and the EU is its main buyer. In addition, the strong concentration of global exports makes diversification of supply very difficult. At the same time, price declines for rapeseed have been deeper than for oil. The out-break of the war in Ukraine can be considered a supply shock that triggers a price increase.

The second observed effect of the outbreak of war in Ukraine was an increase in the average prices of both oilseed rape and oil, with average prices rising more strongly for oil than for rapeseed.

The third observed effect of the war in Ukraine was an increase in the volatility of rapeseed prices, with a decrease in the volatility of oil prices. In the period January 2018–February 2022, i.e., before the outbreak of war, the volatility of rapeseed prices was significantly lower than in the period March 2022–March 2024, i.e., after the outbreak of war, and also lower in relation to the entire period under study (January 2018–March 2024), when the coefficient of volatility was only slightly lower than in the entire period under study.

This allows us to assume that the war in Ukraine has increased the risk of volatility in rapeseed prices in Europe. In contrast, different trends were observed for Brent crude oil. In the period before the outbreak of war, the volatility of Brent crude oil prices was significantly higher than in the period after the outbreak of war, when volatility decreased significantly. In each of the periods studied, rapeseed price volatility was higher than oil price volatility, and the difference intensified after the outbreak of war. The decline in oil price volatility can also be partly explained by the outbreak of war in Ukraine through the mechanism of buying Russian oil at a fixed price by the G-7 and Australia.

The VAR model, on the other hand, gave mixed results regarding the impact of oil prices on rapeseed prices during the period under study. Statistically significant co-movement was observed in the whole analyzed period (January 2018-March 2024), but only with three month lag, which suggests the long-term nature of the potential relation-ship. This may have to do with the fact that rapeseed is grown in the EU not only for food, but also for energy purposes. On the other hand, Granger causality analysis does not find significant long-run causality, while tests for the existence of instantaneous causality suggest such relationships. Whereas in the two sub-periods of the study (before and after the outbreak of war), a different character of covariation was observed. Before the outbreak of war (January 2018-February 2022) no statistically significant effect was observed and after the outbreak of war (March 2022–March 2024) an effect at the limit of statistical significance was observed, but only with one month lag.

The reason for this nature of the relationship may be precisely due to the outbreak of war in Ukraine, which has forced the co-movement or strengthen relationship of prices. This also allows to assume that in general oil prices did not have a decisive impact on rapeseed prices during the period under review, but the war in Ukraine may tightened this relationship.

The findings presented in this article are in line with earlier findings on relationship between oil and agri-food commodity prices, and are in line with the thesis that markets shocks may both increase price volatility and tighten relationship between crude oil and agri-food commodity prices, may also suggests that the results depend on the choice of data and methodology.

It seems to be an interesting research issue to trace the volatility of other agricultural commodities like cereals, of which Ukraine is a significant exporter and their price relationship with oil in the context of the Russian-Ukrainian war. It would also be interesting to investigate the potential links between rapeseed oil and crude oil prices. Additionally, comparing the impact of the COVID-19 pandemic and the full-scale war in Ukraine on price volatility in the agri-food and petrochemical sectors would be valuable. On the methodological side, it seems reasonable to select another model (e.g., GARCH) that al-lows heteroskedasticity to be modelled.

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