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Price dependence of biofuels and agricultural products on selected examples

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Abstract. The growing demand for raw materials for the production of biofuels may lead to an increase in the prices of these raw materials and, due to the shortage of land, to an increase in the prices of other crops. This is due to the fact that the growing demand for raw materials for the production of methyl esters and bioethanol (the most widely used biofuels), such as rape and corn, is a form of competition on the food and feed markets. It should be mentioned that although the topic is not new, it is still very relevant, taking into account the expansion of energy crops, as well as national, European and world energy policy. Especially due to the fact that, as has already been mentioned, the use of plant products for the production of biofuels has an impact on the regulations of the food market.This study is to analyze the volatility and dependence of ethanol, biodiesel, maize and rapeseed prices in the period of 2016-2019 and aims at assessing the correlation between the agricultural and biofuel markets. In this paper, the investigation regarding co-integration of biofuel and agricultural commodity prices has utilized ethanol and commodity prices with the use of the vector error correction model (VECM). Price dependencies between the prices of biodiesel, rapeseed, maize and ethanol were found, indicating the existence of long-term causality in at least one direction between the analyzed prices. The results indicated that biodiesel prices during the period in question were influenced by the previous week's prices of biofuel and rapeseed. Moreover, biodiesel prices had an impact on the level of ethanol and rapeseed prices. In the case of rapeseed, the correlation between its prices and those of corn is also noticeable, while prices of corn may also affect prices of ethanol.

Keywords: Biofuels, Agricultural market, Biofuel market.
Jel Codes: Q16, Q4.

1. INTRODUCTION

To deal with the unprecedented pace of climate change caused by the accumulation of greenhouse gases in the atmosphere, there is a clear need to shift from an energy dependency on fossil fuels to renewable energy. Now, with environmental policy pushing to reduce greenhouse gas emissions, aided by recent advances in crop engineering and fermentation processes, the production of bioethanol and biodiesel has once again become viable and sustainable substitutes for petroleum-based fuels. Production of biofuels showed a growing tendency in the 1990s when the assumptions of the Com-

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mon Agricultural Policy (CAP) indirectly supported the production of biofuels through guaranteed minimum prices, subsidies per hectare of production and compensation payments for set-aside land that, however, could be used to produce raw materials for biofuel production. Moreover, the 2003 CAP reform introduced a cultivation premium for production of energy crops on primary land (Lamers *et al*., 2011). It should be noted that in the case of the production of pollutants, more than a quarter of the total CO2 emissions are generated by the transport sector (Adams *et al*., 2020). To mitigate the effects of global warming caused by the accumulation of greenhouse gases from climate change, it is imperative to reduce CO2 emissions from fuel combustion in car engines and to switch to alternative and cleaner fuels. It should be noted that the development of road transport in the world has led to a rapid increase in the demand for fuels, especially those derived from crude oil. Increased greenhouse gas emissions are due to the burning of fossil fuels and to changes in land use caused by human activities. Therefore, alternative solutions are sought, especially biofuels that could actually compete with conventional energy sources (Kurowska *et al*., 2020, Klikocka *et al*., 2019). It should be emphasized that the known oil resources are limited resources. Various studies set the date of the world peak in oil production in 1996-2035. That is why it is so important to pay attention to biomass-based energy technologies, which use waste or plant matter to produce energy with lower GHG emissions than fossil fuel sources (Sheehan, 1988). Thus, biofuels entered the market as an option to reduce dependence on crude oil and as a way to pursue social, economic and environmental sustainability (Chavez *et al*., 2010, Kurowska *et al*., 2020). As noted by Janda *et al.* (2012), increased interest in the application of biofuels as an alternative to liquid fossil fuels was observed after the oil crisis that occurred on world markets in the 1970s. In addition, the use of biofuels (compared to fossil fuels) contributes to the mitigation of greenhouse gas emissions (Hallam *et al*., 2006). Moving on to the meaning of biofuels, it should be clarified that the term biofuel refers to liquid and gaseous fuels (bioethanol, biodiesel, biogas) and solids produced mainly from biomass (Demirbas, 2008). Biofuel is a non-polluting, locally available, sustainable and reliable fuel obtained from renewable sources (Vasudevan *et al*., 2005). Liquid biofuels are primarily used to power vehicles, but they can also power engines or fuel cells to generate electricity (Demirbas, 2007). Bioethanol and biodiesel are the two most popular biofuels used as substitutes for regular gasoline and diesel fuel (Clerici and Alimonti, 2015).

As already mentioned the global demand for biofuels such as ethanol and biodiesel is increasing mainly for environmental reasons (Goswamia and Choudhuryb, 2019; Ajanovic, 2011). This is in line with the expansion of this market and the rapid increase in their production worldwide (Banse *et al*., 2008). Biofuels are perceived as an essential element in the development of fuel markets (Ryan *et al*., 2006). In the transport sector, ethanol constitutes the most widely consumed liquid biofuel in the world (McPhail, 2011). It should be noted that the demand for biofuels is driven mainly by the transport sector (Fundira and Henley 2017). Brunschwig *et al.* (2012) as well as Balat (2011) indicated that biodiesel is an attractive alternative to diesel fuel. Sivakumar *et al.* 2010 noted that with population growth, industrial development, and fossil fuel transportation costs soaring, it seems reasonable that countries seek for solutions independent from non-renewable fuels for climatic and economic reasons (Reboredo *et al*., 2016), thus drawing the attention of many stakeholders related to this issue, i.e. decision makers, representatives of the industry, and the scientific community (Timilsina *et al*., 2011).

At the same time, the development of the biofuel market translates into a growing demand for the most important agricultural production factors (van Eijck *et al*., 2014). However, it should be taken into consideration that biofuels compete for renewable and non-renewable resources, and therefore may affect their sustainable growth and the market for agricultural products. Increased cultivation of biofuel crops will affect land utilization (Searchinger, 2007) which will have an impact on global natural resources and environmental sustainability (Zhang *et al*., 2009, Hausman *et al*., 2012), i.e. by generating indirect effects from their exploitation (van Noorden, 2013). Moreover, extending the cultivation area of biofuels with a simultaneous increase in population may lead to higher prices of agricultural raw materials on international markets. Thus, production of biofuels can pose challenges in terms of sustainable food production (Naylor *et al*., 2007). Moreover, in the case of biofuels, a crowding-out effect may appear (Vacha, 2013), redirecting food production to production of biofuel (Baffes, 2013). It should be emphasized that if part of the soil resources is occupied by the fields of energy crops, the potential for food production is weakened, which may result in an increase in food prices. Competition between energy crops and food crops has consequences such as rapidly rising food prices and a food deficit on a global scale (Gomiero, 2010, OECD-FAO). The problem of competition between bioenergy crops and plants intended for consumption, resulting from land use, was also noted by Vasile *et al.* (2016) and Cai *et al.* (2010), Tomei and Heliwell (2016). Therefore, the indirect effects of biofuel production have become the subject of research and discussion among economists, environmentalists, NGOs, and international organizations that call for an additional analysis of the outcomes related to biofuels (Bentivoglio and Rasetti, 2015; Oláh, 2017). It has been observed that the growing demand for raw materials for the production of methyl esters and bioethanol (the most widely used biofuels), such as rapeseed or corn, is a form of competition in the food and feed markets (Koizumi, 2015). It should also be noted that the activities related to the production of biofuels also have indirect negative effects of land use, such as the conversion of food crops into fuel (Humalisto, 2015). This phenomenon is known as indirect land use change, which, in combination with the conversion of carbon-rich lands, can lead to significant greenhouse gas emissions, which counteracts the previously indicated positive environmental importance of biofuels (Britz and Hertel, 2011, EC. Directive (EU) 2015 / 1513, Santeramo and Searle 2019, Kupczyk 2020). As the research by Searchinger *et al.* (2008), emissions of greenhouse gases from corn ethanol in selected locations may even double compared to the continued use of petroleum products. Then, the impact of the biofuel program on greenhouse gas emissions may be unfavorable (Britz and Hertel, 2011). In consequence, it raises doubts as to whether biofuels are a friendlier alternative to petrol (Chakravorty *et al.*, 2017).

The issue of dependence between the agricultural market and the biofuel market plays a significant role, *inter alia*, due to the expansion of biofuels into global agricultural commodity markets (Drabik *et al.*, 2016,Banase *et al.*, 2008). The research conducted so far by, among others, Wright (2011), 2011 de Gorter and Drabik (2015) indicate a sharp increase in biofuel production as well as a strong and direct relationship between prices of energy and agricultural commodit.). The growing demand for raw materials for the production of biofuels may lead to an increase in the prices of these raw materials, and due to the shortage of land, to an increase in the prices of other crops (Searchinger, 2008). The price interdependencies between the food and biofuel market have therefore become an ongoing subject of discussion among energy, environmental and agricultural economists interested in the sustainability of biofuels (Kristoufek, 2012, Oladosu and Msangi, 2013, Kurowska *et al.* 2020). Drabik and *et al.* (2016) also notes that the global agriculture and energy sectors have become more interdependent due to the surge in biofuel production over the past two decades. At the same time, both sectors exhibit high price volatility. In contrast, the transmission of global price shocks to domestic markets, from agricultural commodities to food prices, might have a significant impact on income distribution and welfare for farmers and consumers. As a result, the issue of price transmission between agricultural markets and biofuel markets becomes relevant from the perspective of political economy.

This article analyzes the price relations between the biofuel market and the market of agricultural products. The price transmission between the prices of rapeseed, biodiesel, maize and ethanol was assessed.

The goal was to obtain answers to the following research questions:

1. How were the prices of biodiesel, ethanol, corn and turnip in the analyzed period ?
2. Is there a relationship between the prices of biodiesel, bioethanol, corn and turnip in the analyzed period ?
3. What is the relationship between the prices of biodiesel, bioethanol, corn and turnip in the analyzed period?

It should be mentioned that although the topic is not new, it is still very relevant, taking into account the expansion of energy crops, as well as national, European and world energy policy. Especially due to the fact that, as already mentioned, the use of plant products for the production of biofuels affects the condition of the food market.

2. METHODS AND DATA

The data set includes weekly wholesale prices of ethanol, biodiesel, rapeseed and maize, from the first week of 2016 to the last week of 2019, from global markets, i.e. the stock exchange: The Paris Stock Exchange oraz New York Mercantile Exchange Prices have been averaged and given in EUR. In order to standardize the currency, the average EUR rate in a given trading week was used. A period of no significant disturbances resulting from the COVID-19 pandemic was selected. The mutual integration of all prices was analyzed.

Prior to estimation of model parameters, it is necessary to determine the stationarity of the analyzed time series. For the purpose of this study, the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test was applied (Maddala, 2009; Welfe 2009). The direction of cointegrating relations between the analyzed prices was established based on the vector model of the VECM error correction, which determines the short-term dynamics of each price within long-term relations.

According to the Granger representation theorem, the equation of the VECM error correction model assumed the following form (Gujarati and Porter, 2009; Johansen and Joselius, 1990):

$$\Delta x_t = \Psi_0 D_t + \Pi x_{t-1} + \sum_{i=1}^{k-1} \Pi_i \Delta x_{t-1} + \varepsilon_t \quad (1)$$

where:

$$\Pi = \sum_{i=1}^{k} A_i - I \quad (2)$$

$$\Pi_i = \sum_{j=i+1}^{k} A_j \quad (3)$$

$X_t = [x_{t1} \ldots x_{tk}]^T$ – vector of observations on the current values of all explanatory variables,

D_t – vector of exogenous equation components such as intercept, time change, non-stochastic regression, delayed values of exogenous variables,
A_0 – matrix of parameters with vector variables Dt. (does not contain zero elements),
A_i – matrix of parameters with delayed *xt* vector variables (does not contain zero elements),
k – model row, specifying the maximum length of the delay,
$\varepsilon_t = [e1_t \ldots e_{kt}]^T$ – vectors of stationary random disturbances (residual vectors of the model equations).

In order to assess the response of individual variables to a change in the price level of another component, the Impulse Response Function (IRF) was applied, as presented below (Baillie, Kapetanios, 2013).

$$X_t = \sum_{i=1}^{\infty} \Phi_i \xi_{t-1} \quad (4)$$

where:
B – matrix of parameters standing at non-lagged vector values X_t,
Φ_i – response of the distinguished vector variable Xt to an impulse from another variable.

The choice of the order of variables in the model depends on the AIC information criterion. The length of the model lag has been 1.

The Granger causality test was used to analyse relations between the studied variables. Testing cau-sality in the Granger sense is based on the following system of equations:

$$Y_t = \beta_0 + \sum_{j=1}^{m} \beta_j Y_{t-j} + \sum_{k=l}^{n} \beta_k X_{t-k} + u_t \quad (5)$$

$$X_t = \beta_0 + \sum_{j=1}^{m} \beta_j X_{t-j} + \sum_{k=l}^{n} \beta_k Y_{t-k} + u_t \quad (6)$$

where:
Y_t – values of the variable Y;
X_t – values of the variable X;
β – structural parameters of the model;
u_t– random component of the model (Granger, 1969).

The null hypothesis in the Granger Causality test assumes that all βk coefficients are equal to zero, which means that there is no causality, while the alternative hypothesis assumes the occurrence of causality in the Granger sense.

3. RESULTS

In 2021, the global production of biofuels reached the level of 1,747 thousand. barrels of oil equivalent per day, compared to 187 thousand barrels of oil equivalent per day, produced in 2000. Production of biofuels, given the belief that it can provide energy security and reduce greenhouse gas emissions in the relevant sectors. The global biofuel market is expected to reach over $ 200 billion by 2030 (statista.com, 2022).

As noted, price developments in the four markets in question appear to be correlated. The evolution of rapeseed, maize, biodiesel, ethanol prices and their volatility in years 2016-2019 is depicted in Figure 2. In the analyzed time period, a gradual decline in biodiesel prices was observed. This situation stabilized in the first quarter of 2016. A similar situation occurred in the case of ethanol prices. Throughout years 2016-2019, there were significant fluctuations in the prices of ethanol and biodiesel. In the case of rapeseed and maize, the differences were milder.

Studying the interdependencies of time series requires an examination of their stationarity. The level of integration of the analyzed time series was tested using the KPSS test. The calculated value of the test statistics presented in Table 1 with the included lags at significance level α = 0.01 indicates rejection of the null hypothesis which suggests the stationarity of the tested

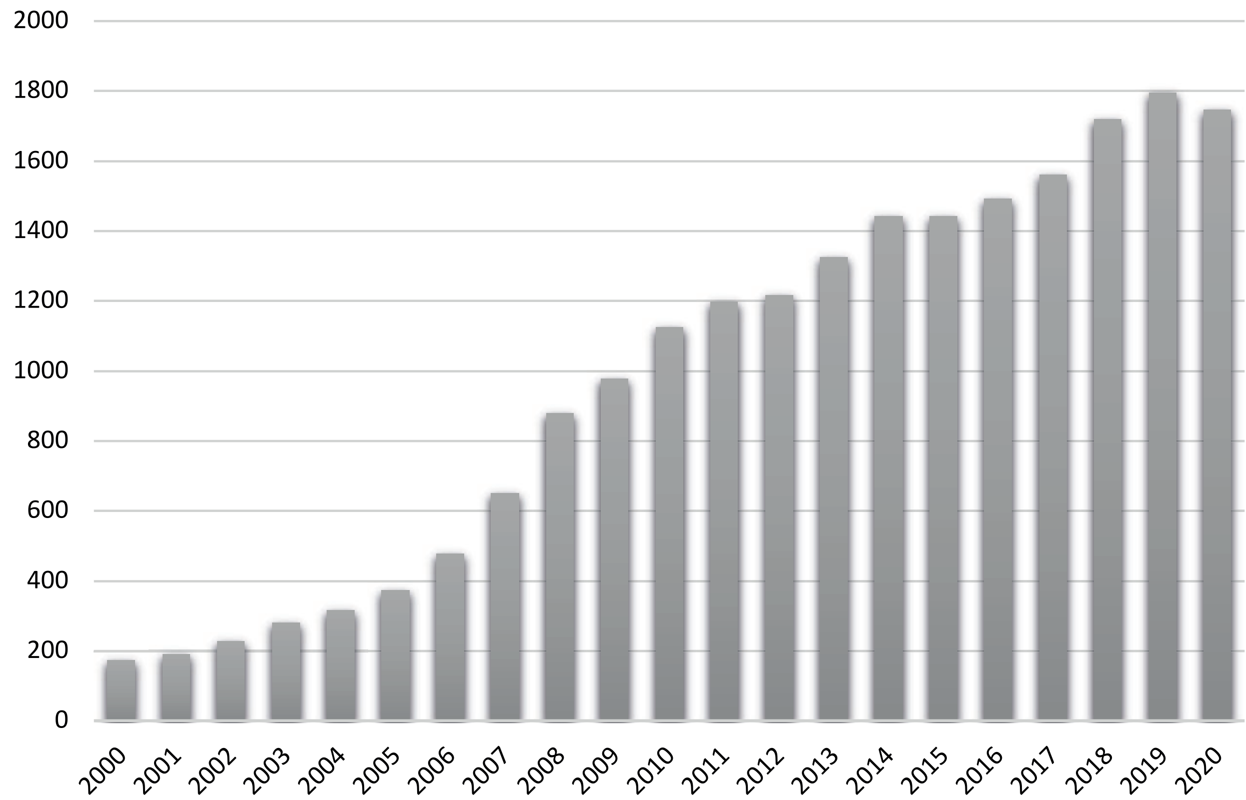

Figure 1. Biofuel production worldwide from 2000 to 2021(in 1,000 barrels of oil equivalent per day). Source: Own elaboration based on statista.com.

time series, proving the non-stationarity of the analyzed prices.

The performed test using the Johansen method shows that at the significance level equal to 0.05, the null hypothesis of no cointegrating relation should be rejected. The test results included in Table 2 indicate the existence of three dependence relations between the examined prices.

The existence of relationships between prices proves the existence of long-term causality in at least one direction between the analyzed prices. However, it does not indicate the direction of causality in price developments. This causality can be determined using the vector model of the VECM error correction (Table 3). The results of the model estimation for the analyzed prices suggested the existence of numerous relationships between the analyzed prices (statistically significant relationships between the price levels have been marked in grey). Namely, the price level of biodiesel in the said period was influenced by prices of this biofuel from the previous week and prices of rapeseed. At the same time, biodiesel prices influenced the price level of ethanol and rapeseed. In the case of rapeseed, the estimation of the

Table 1. Results of stationarity tests with regard to the analyzed time series.

	Biodiesel	Ethanol	Maize	Rapeseed
KPSS test statistics / Critical value	1.724***	1.581***	0.852***	0.965***
p-value = 0,01	0.587	0.587	0.587	0.587
p-value = 0,05	0.399	0.399	0.399	0.399
p-value = 0,1	0.311	0.311	0.311	0.311

Source: Own calculations and analysis with the use of EViews software.

Table 2. Occurrence of correlations between the analyzed time series - Johansen's test.

The number of cointegrating vectors	Test trace	Critical value *p*=0,05
0*	66.05	47.99
1*	36.61	28.99
2*	14.99	13.11
3	3.44	4.74

Source: Own calculations and analysis with the use of EViews software.

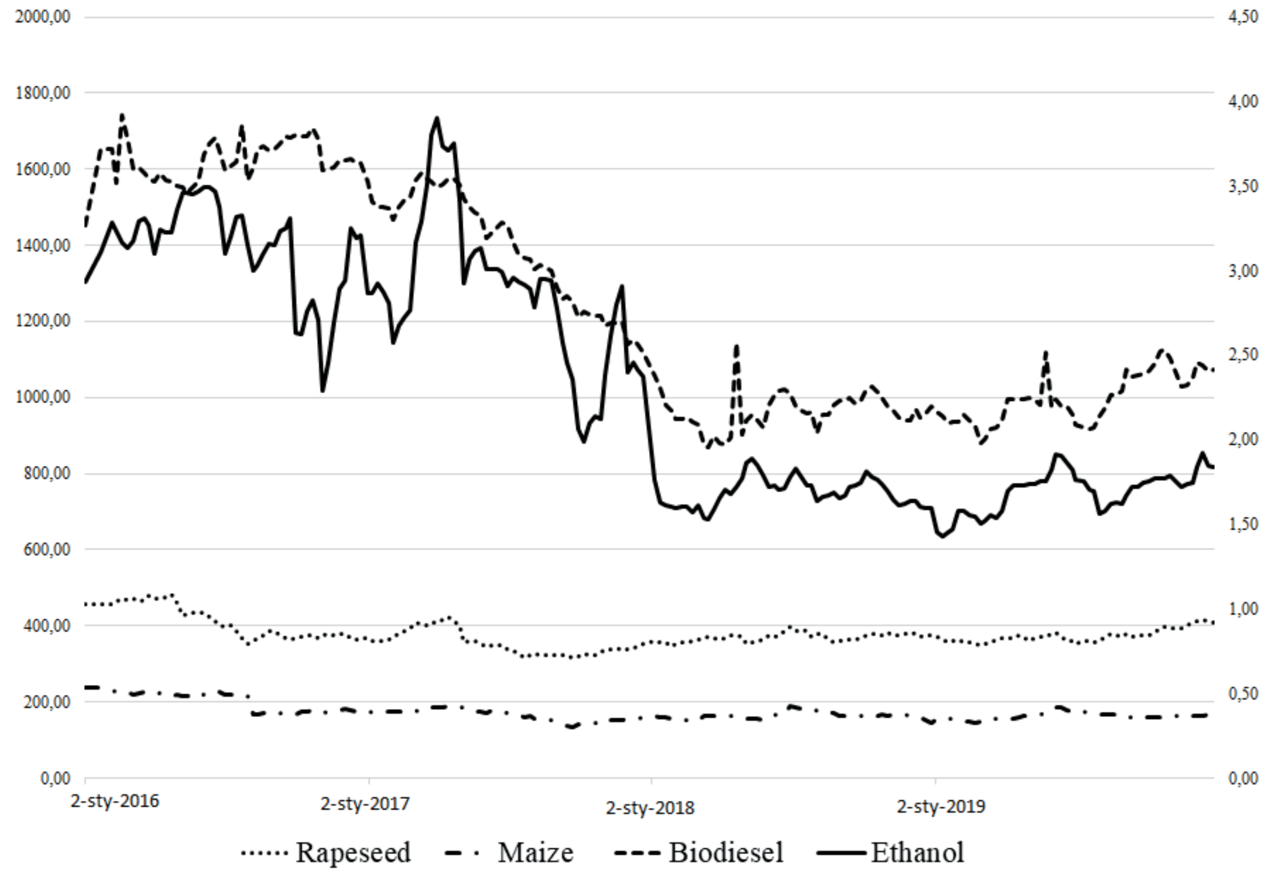

Figure 2. Price level of rapeseed, maize, biodiesel and ethanol prices in the analyzed period in nominal terms (in EUR). Source: Own calculations and analysis with the use of EViews software.

Table 3. The results of the VECM model parameters estimation.

	Biodiesel	Rapeseed	Ethanol	Maize
CointEq1	-32.05	24.25	-0.31	-13.14
	27.24	8.15	0.21	5.88
	[-1.24]	[2.31]	[-2.19]	[-2.74]
Δ_biodiesel	0.41	0.07	0.01	0.01
	0.09	0.04	0.01	0.02
	[2.74]	[2.11]	[1.11]	[0.40]
Δ_rapeseed	0.73	0.31	0.01	0.11
	0.62	0.06	0.01	0.05
	[2.13]	[3.88]	[0.99]	[2.87]
Δ_ethanol	-24.75	-0.20	0.17	-6.412
	18.11	6.01	0.07	3.31
	[-1.74]	[-0.02]	[-1.51]	[-1.74]
Δ_maize	-0.24	-0.27	0.01	-0.07
	0.42	0.14	0.001	0.08
	[-0.81]	[-1.81]	[1.64]	[-1.07]

Source: Own calculations and analysis with the use of EViews software.
Δ – price of given product from previous period.

VECM model showed a connection with maize prices. Nonetheless, it should be noted that maize prices may also cause changes in ethanol prices. In this case, the obtained results indicate the existence of a two-way relationship.

The impulse response function determined on the basis of the estimation of VECM parameters illustrated the occurrence of reactions between individual variables, as depicted in Table 3 (Figure 2). The IRF functions were determined by the results of the VECM model parameter estimation for the levels. The course of the IRF function confirms the interaction of prices, for which the VECM model estimation indicated the presence of interdependencies in their formation.

Based on the analysis of the course of the IRF function, the reaction to the impulse appears up to 2 weeks after its occurrence while individual functions expire within 3-4 weeks, rebalancing the system.

The Granger causality test was used to determine which prices are interdependent in terms of price formation. The test results are presented in Table 4.

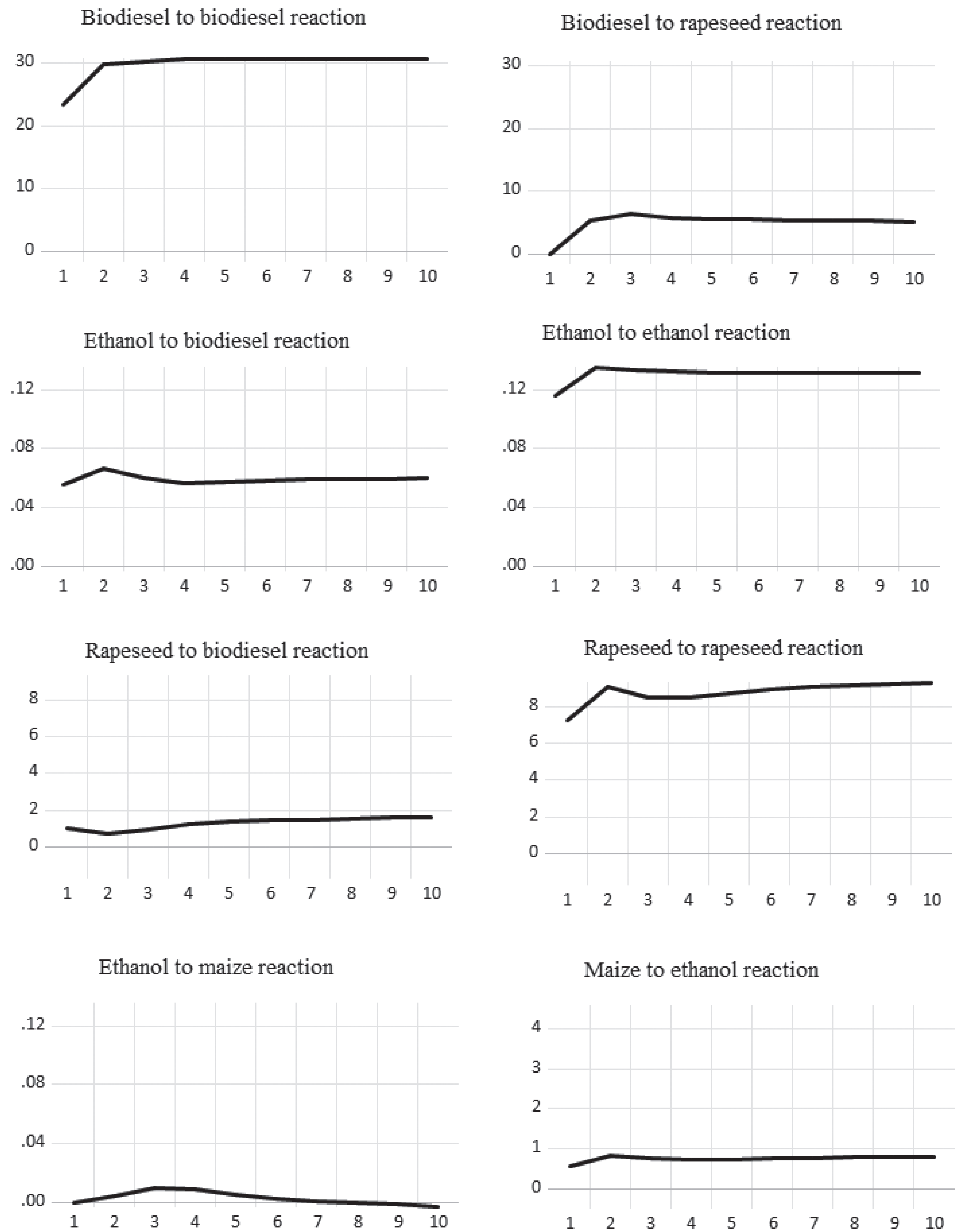

Figure 3. The reaction of individual markets to an impulse in the form price level changes. X axis - days; Y axis - price in EUR. Source: Own calculations and analysis with the use of EViews software.

Table 4. The results of the Granger causality test.

Null Hypothesis:	F-Statistic	Prob.	
Etanol does not Granger Cause Biodiesel	0.154	0.856	Accepted
Biodiesel does not Granger Cause Etanol	**6.285**	**0.002***	**Rejected**
Corn does not Granger Cause Biodiesel	1.358	0.259	Accepted
Biodiesel does not Granger Cause Corn	1.276	0.281	Accepted
Rape does not Granger Cause Biodiesel	**4.769**	**0.009***	**Rejected**
Biodiesel does not Granger Cause Rape	0.880	0.416	Accepted
Corn does not Granger Cause Ethanol	1.467	0.232	Accepted
Ethanol does not Granger Cause Corn	0.955	0.386	Accepted
Rape does not Granger Cause Ethanol	**3.439**	**0.034***	**Rejected**
Ethanol does not Granger Cause **Rape**	1.152	0.317	Accepted
Rape does not Granger Cause Corn	**2.020**	**0.001***	**Rejected**
Corn does not Granger Cause Rape	1.806	0.166	Accepted

*Probability 0.05 then Null Hypothesis is rejected.
Source: Own calculations and analysis with the use of EViews software.

The analyzes of the Granger causality test showed that there was a relationship between the prices of biodiesel and ethanol, the impact of rapeseed prices on biodiesel prices, the price of rapeseed and ethanol prices, as well as the prices of rapeseed and corn prices..

DISCUSSION AND CONCLUSION

The obtained results indicate that further research is necessary in order to provide a detailed description of the multiple dependencies that occur in the biofuel market as well as their connection with fossil fuel and agricultural markets. The presented research results on price volatility and price response of selected biofuels and agricultural products could have been measured more thoroughly with higher frequency data (e.g. daily), as well as taking into account products such as soybean, palm oil, rice or sugar. In addition, it is worthwhile to examine the problem from a broader perspective and to consider to what extent the price interdependence in these markets is a natural phenomenon and how much action is taken to promote the bioeconomy. Literature provides many studies on the relationship between the biofuel market and the agricultural raw materials market, e.g. Ciaian and Kancs, (2011), Janda *et al.* (2012), Serra and Zilberman *et al.* (2013), Kristoufek *et al.* (2014), de Gorter *et al.* (2013), de Gorter *et al.* (2015), Goswami and Choudhury (2019). However, due to the dynamic character of the market, this area should be the subject of continuous study. The conducted analyses indicated relationships between the prices of biodiesel, rapeseed, maize and ethanol, proving the existence of long-term causality in at least one direction between the analyzed prices. Based on the results of the estimation of the VECM model parameters, biodiesel prices in the period in question were influenced by prices of this biofuel from the previous week and prices of rapeseed. Moreover, biodiesel prices influenced the price level of ethanol and rapeseed. In the case of rapeseed, one may also observe the dependence of its prices on the prices of maize, while the prices of maize might be cause changes in ethanol prices. Moreover, in this case, the obtained results indicate the existence of a two-way relationship.

This study may add value to previous studies, showing the relationship between the prices of biofuels and agricultural products, and thus become the basis for further considerations on the analysis of the impact of energy crops and biofuel production on the prices of agricultural and food products. It should also be mentioned that obtaining fuels from bio sources is becoming more and more important. Particular attention in this direction has been paid recently, when there has been a strong increase in the prices of fossil fuels resulting from the pandemic situation in recent years and the ongoing war in Ukraine.

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