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Abstract.

The objective of the paper is to analyse causality between prices of corn, crude oil and ethanol. The analysis conducted in this paper is a dynamic one, and the data used consist of weekly futures prices of crude oil, corn, and ethanol from January 5, 2007 till April 11, 2014. The assessment of causal links between prices of corn, crude oil and ethanol is carried out with the use of rolling regression applied to augmented-VAR framework proposed by Toda and Yamamoto (1995). The application of the rolling regression procedures into the modified Wald (MWALD) causality test allows for the investigation of the persistence of stability in causal relations between analysed prices. The results obtained indicate that the linkages between energy prices and agricultural commodity prices change in the period analysed. The results of Granger causality tests reveal that in the analysed period the price of corn influences the price of energy (crude oil and ethanol). Also crude oil prices influence corn prices and ethanol prices. However, the influence of ethanol prices on crude oil prices and corn prices has not been observed.

Keywords: Granger causality, rolling regression, Toda -Yamamoto tests, commodity prices.

JEL Classification: C32, Q13, Q41

1. Introduction

Limited fossil fuel resources and the fact that the demand for them is growing continuously coupled with the economic development and excessive pollution of the environment lead to the increase in the significance of renewable energy source. Additionally, the European Commission has set an overall binding target to satisfy 20% of the EU energy needs from renewable sources, such as biomass, hydro, wind and solar power by 2020. As part of the overall target, each member state has to achieve at least 10% of their transport fuel consumption from renewable sources (including biofuels). The factors mentioned above have resulted in the growth in the production of ethanol in the period 2007 - 2013 by about 70%. However, such increased demand for ethanol fuel translates into greater demand for corn, which, in turn, increases the prices of corn. On the other hand, the increase in the production of biofuels changes the structure of energy sources, which affects the prices of fossil fuel, including crude oil prices. What is more, Kilian and Park (2009) claim that the price of crude oil has the greatest influence on food prices because its increasing price raises both transport costs and food production costs through the growth of fuel costs for mechanized farming. Additionally, growing prices of crude oil increase the economic motivation for the production of biofuels (corn, soybean, sugar cane, oil palm, etc.).

Hence, one of the most important effects of the growing biofuel production has been the change in the nature of the linkages between agricultural commodity markets and energy markets. Thus, it is interesting to investigate how the prices of biofuels affect fossil fuel prices and food prices and vice versa. In this study we analyse causality between corn prices representing the food prices, crude oil prices representing the fossil fuel prices, and ethanol prices representing the biofuel prices.

The investigation of related issues can be seen in numerous recent studies, although their conclusions are inconclusive. Some researchers analyse only the relations between food and fossil fuel prices generally ignoring biofuel prices. Some studies confirm the linkages between food prices and crude oil prices (e.g: Chen et al., 2010; Ciaian and Kancs, 2011a; Ciaian and Kancs, 2011b; Harii et al., 2009; Natanelov et al., 2011; Nazlioglu and Soytas, 2011; Nazlioglu, 2011; Papież and Śmiech, 2012). Other empirical studies report no evidence regarding the oil–food price nexus, thereby supporting the neutrality hypothesis. Nazlioglu and Soytas [2012] and Zhang et al. [2010] find agricultural commodity prices to be neutral to the effects of oil price changes in the long run.

Subject literature contains a large number of studies on the linkages between the prices of energy sources (fossil fuel and biofuels) and the prices of food. Many of these studies use time-series econometric techniques to quantify the relations between oil, ethanol, and food prices in levels (e.g., Kristoufek et al., 2012; McPhail, 2011; Natanelov et al., 2013; Qiu et al., 2012; Saghaian, 2010; Serra et al., 2011; Wixson and Katchova, 2012; Zhang et al., 2009; Zhang et al., 2010) or their volatility interactions (e.g., Gardebroek and Hernandez, 2013; Haixia and Shiping, 2013; Trujillo-Barrera et al., 2012). However, to the best of our knowledge, dynamic causality in the crude oil–corn–ethanol–nexus analysed with the use of the rolling regression procedures applied into the modified Wald (MWALD) causality test has not been addressed in any of them yet.

The objective of this study is to investigate dependencies between prices of corn, crude oil and ethanol, using weekly futures data spanning from January 5, 2007 to April 11, 2014. The analysis of dependencies has a dynamic nature and focuses on Granger causality between the variables. The assessment of causal links between the variables is carried out with the use of rolling regression applied to augmented-VAR framework proposed by Toda and Yamamoto (1995). The application of the rolling regression procedures into the modified Wald (MWALD) causality test allows for the investigation of the persistence of stability in causal relations between analysed prices.

This allows us to address the following questions:

- Are the dependencies between the prices of energy sources and the food prices stable in time?
- Do the prices of biofuels or fossil fuels affect food prices in the short run?
- Do food prices affect the prices of biofuels or fossil fuels in the short run?
- Do the prices of biofuels affect the prices of fossil fuels in the short run?

This paper contributes to the existing literature mostly due to the application of the dynamic analysis, which allows us to assess the stability of the dependencies between the variables. Additionally, incorporating the rolling regression procedure into causality tests provides more information on the issue of the crude oil–corn–ethanol–nexus. What is more, using a rolled window in the analysis makes it possible to indicate breaking points and facilitates their further interpretation.

The paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 presents methodology applied. Section 4 illustrates the data, while

Section 5 contains the empirical results. Finally, the last section presents the main conclusions.

2. Literature review

Dynamic price relationships between commodity and energy markets have been widely discussed in literature. Table 1 presents an overview of studies devoted to linkages between commodity (corn prices) and energy markets (crude oil prices and ethanol prices) in recent years. The table contains the summary of the papers reviewed, their modelling approach, data used and the main research conclusions, that is the relationship between crude oil, corn and ethanol prices. The analysis of the results of previous studies indicates different relationships between crude oil, corn and ethanol prices, which is connected with the period and the frequency of data chosen in a given study.

Table 1

Summary of the literature on biofuel markets.

Reference	Time series modelling approach	Data frequency	Period of study	Short-run Granger causality		
				Crude oil prices (CO) – corn prices (C)	Crude oil prices (CO) – ethanol prices (E)	Corn prices (C) – ethanol prices (E)
Kristoufek et al. [2012]	VAR	Weekly	November 2003-February 2011	CO – C	CO – E	C → E
McPhail [2011]	Structural VAR	Monthly	January 1994 – February 2010	x	CO ↔ E	x
Natanelov et al. [2013]	VECM	Daily	23 March 2005 - 15 December 2011	CO → C	CO → E	C → E
Qiu et al. [2012]	Structural VAR	Monthly	January 1994– October 2010	CO – C	CO – E	C → E
Saghaian [2010]	VECM	Monthly	January 1996– December 2008	CO → C	CO → E	C ↔ E
Wixson and Katchova [2012]	TVECM	Monthly	January 1995– December 2010	CO ← C	CO → E	C → E
Zhang et al. [2009]	VECM	Weekly	March 1989 – December 1999	CO ← C	CO ← E	C – E
			January 2000 - December 2007	CO – C	CO – E	C – E

Note: X → Y denotes Granger causality running from variable X to variable Y, X ← Y denotes Granger causality running from variable Y to variable X, X ↔ Y denotes bidirectional Granger causality between variable X and variable Y. X– Y denotes no Granger causality between variable X and variable Y. Variable X and Y denotes CO – crude oil prices, C – corn prices and E- ethanol prices. Source: author's own calculation.

Kristoufek et al. [2012] use weekly price data for the period between November 2003 and February 2011 to analyserelations between biofuels, their production factors (corn, wheat, soybeans and sugarcane) and fossil fuels. Their analyses are based on autoregressive models (VAR and autoregressive distributed lag models — ARDL), which only allow drawing short-term causality inferences. They find that corn causes changes in ethanol prices, while both elasticity and causality are price-dependent, and they find that biodiesel is caused and elastic to the changes in German diesel prices and the effects are again price-dependent.

McPhail [2011] uses the monthly price data for the period between January 1994 and February 2010. He uses a structural VAR model to analyse the relationship between the US ethanol, crude oil and gasoline and shows that a policy driven increase in demand for ethanol leads to lowering prices of both crude oil and gasoline. McPhail [2011] supports bidirectional causality links between crude oil and ethanol prices.

In their empirical analysis, Natanelov et al. [2013] use daily futures prices of crude oil, corn, and ethanol from 23 March 2005 to 15 December 2011. Their results indicate that crude oil Granger causes corn and ethanol. In case of corn–ethanol relationship, they find that corn precedes ethanol.

Qiu et al. [2012] use monthly time series data from January 1994 to October 2010 to estimate the structural VAR model and determine the directed acyclic graph (DAG) causality among the variables. Their results for contemporaneous causality relationships between the food and fuel markets show that corn prices are not directly caused by any other prices or quantities. Qiu et al. [2012] find that there are no spillover effects on corn prices from the oil, gasoline, or ethanol markets. Thus, this indicates no direct or indirect causes of corn prices, which contradicts the popular food versus fuel assumption. They also find that the corn price is a direct cause of the ethanol price.

Saghaian [2010] analyses pairwise Granger-causality relations by relying on monthly data on oil, ethanol, corn, soybean, and wheat prices for the period from January 1996 to December 2008. Saghaian [2010] shows that corn prices Granger-cause ethanol prices with statistical significance at all conventional levels, but the reversed direction of Granger causality is statistically significant only at 10% significance level. The results also show the existence of unidirectional relationships running from crude oil price series to ethanol and corn prices. Additionally, Saghaian [2010] finds the cointegration relationships between crude oil and corn, soybean and wheat prices with causality running from oil prices to these agricultural commodity prices.

Serra et al. [2011] use an exponential smooth transition VECM to monthly data of ethanol, corn, oil, and gasoline prices from 1990 to 2008. They show that an increase in ethanol prices causes an increase in corn prices. However, they also show that corn price hikes lead to increases in the price of ethanol. Their results indicate the existence of long-term relationship among the prices analysed. They also identify strong links between energy and food prices.

Wixson and Katchova [2012] show on monthly US data from 1995 to 2010 that prices of corn Granger-cause prices of ethanol and prices of crude oil. They find evidence of unidirectional Granger causality running from oil to ethanol.

Zhang et al. [2009] estimate a vector error correction model (VECM) on weekly data for fuel prices and prices of agricultural commodities over the period from March 1989 to December 2007. Their results of Granger causality tests for the pre-ethanol boom period from 1989 to 1999 show the existence of unidirectional Granger causality running from ethanol and corn prices to crude oil prices. However, short-run causality between crude oil, ethanol and corn prices was not observed in the ethanol boom period from 2000 to 2007.

3. Methodology

The assessment of causal dependencies between prices of corn, crude oil and ethanol is carried out with the use of rolling regression applied to augmented-VAR framework proposed by Toda and Yamamoto [1995] and developed by Rambaldi and Doran [1996] and Zapata and Rambaldi [1996]. This procedure avoids the problems of testing for Granger causality with respect to the power and size properties of unit root and co-integration tests (Zapata and Rambaldi [1996]). The approach suggested by Toda and Yamamoto [1995] applies the modified Wald (MWALD) causality test to the model $VAR(k+d_{max})$, where k is the lag length of the system determined by information criteria (Akaike Information Criterion (AIC) or BIC), and d_{max} is the maximal order of integration.

The Toda and Yamamoto methodology involves the following stages.

Firstly, the lag length (k) of the system VAR and the maximal order of integration (d_{max}) are established. To determine whether each series is stationary or not (that is, whether it contains a unit root) traditionally the following unit root tests are used: the Augmented Dickey–Fuller test (ADF) (Dickey and Fuller, 1979), DF-GLS test of Elliott et al. [1996], and the KPSS (Kwiatkowski et al., 1992) unit-root test. However, in recent years structural changes turned out to be a key factor in various economic and financial analyses. Unfortunately, the tests mentioned above do not assume structural breaks in the series, and that is why it is advisable to use tests which take structural changes into account, for example, the Zivot and Andrews [1992] sequential test procedure for unit roots, in which the structural breakpoint is estimated endogenously. Zivot and Andrews [1992] considered three different models: model A allows for one break in the intercept; model B allows for a break in the slope of the trend function; and model C allows for a single break in the intercept and in the slope of the trend function. The Zivot and Andrews [1992] test analyses the null hypothesis of a unit root in a series with no break against the alternative of a trend stationary process which combines one-time changes in the level and in the slope of the trend function of the series.

Secondly, the augmented $VAR(k+d_{max})$s in levels are estimated. Next, for the model $VAR(k+d_{max})$ the Wald test to the first *k* VAR coefficient matrix is performed to test for Granger causality. For testing the null hypothesis, Toda and Yamamoto [1995] confirm that the Wald statistic has the asymptotic χ^2- distribution with *k* degrees of freedom, regardless of whether the generating process is stationary (possibly around a linear trend) or cointegrated.

In our case, Toda and Yamamoto version of $VAR(k+d_{max})$ can be written as:

$$OIL_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} OIL_{t-i} + \sum_{j=k+1}^{d_{max}} \alpha_{2j} OIL_{t-j} + \sum_{i=1}^{k} \beta_{1i} CORN_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} CORN_{t-j} + \sum_{i=1}^{k} \gamma_{1i} ETH_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{2j} ETH_{t-j} + \varepsilon_{1t} \quad (1)$$

$$CORN_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} CORN_{t-i} + \sum_{j=k+1}^{d_{max}} \alpha_{2j} CORN_{t-j} + \sum_{i=1}^{k} \beta_{1i} OIL_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} OIL_{t-j} + \sum_{i=1}^{k} \gamma_{1i} ETH_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{2j} ETH_{t-j} + \varepsilon_{2t} \quad (2)$$

$$ETH_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} ETH_{t-i} + \sum_{j=k+1}^{d_{max}} \alpha_{2j} ETH_{t-j} + \sum_{i=1}^{k} \beta_{1i} CORN_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} CORN_{t-j} + \sum_{i=1}^{k} \gamma_{1i} OIL_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{2j} OIL_{t-j} + \varepsilon_{3t} \quad (3)$$

The directions of Granger causality can be detected by applying standard Wald tests to the first *k* VAR coefficient matrix. For example, for Eq. (1): $H_0: \beta_{11} = \beta_{12} = \dots = \beta_{1k} = 0$ implies that corn prices (CORN) do not Granger cause crude oil prices (OIL), and $H_0: \gamma_1 = \gamma_2 = \dots = \gamma_k = 0$ implies that ethanol prices (ETHANOL) do not Granger cause crude oil prices (OIL).

The changes in dependencies between the variables over time are investigated with the use of rolling analysis (Smiech and Papież, 2013). We apply the fixed window rolling regression to the level VAR model. The first model is built using the data covering observations from 1 to n, the second model covers observations from 2 to n+1, etc. Every time AIC is used to fix the number of lags of VAR model. Next, we estimate the parameters of VAR models, and, finally, we use the MWALD test statistic to test Granger causality. This allows us to observe whether and how the dependencies between the variables change for consecutive rolling windows.

4. Data

The data used in this study consist of weekly prices of crude oil (OIL), corn (CORN), and ethanol (ETHANOL) from the period between 5 January 2007 and 11 April 2014 (380 observations). The data used in the analysis include the prices of futures contracts traded on the New York Mercantile Exchange (NYMEX) and the Chicago Board of Trade (CBOT). The present study uses nominal data because weekly consumer price index is unavailable. The detailed description of variables and descriptive statistics for weekly time series data are presented in Table 2. Figure 1 presents the weekly prices of commodities. Next, for the purpose of the study, all the variables are converted to their natural logarithm form.

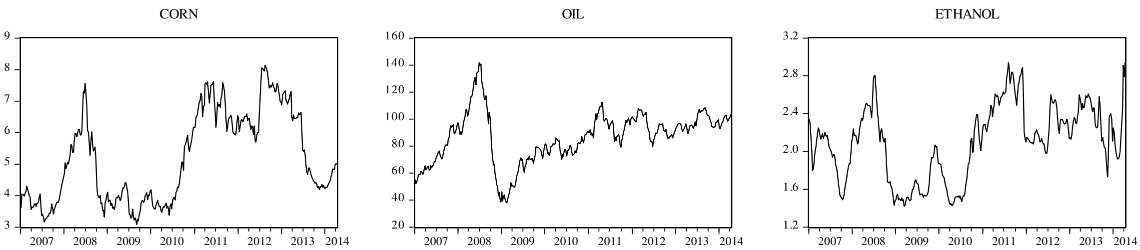

Fig 1. Weekly prices of crude oil (OIL), corn (CORN), and ethanol (ETHANOL) between 5 January 2007 and 11 April 2014.

Source: author's own calculation.

Table 2

Summary statistics for weekly time series

Variable	CORN	OIL	ETHANOL
Symbol	CBOT:C	NYMEX:CL	CBOT:EH
Unit	$/bu	$/bbl	$/gal
Mean	5.20	86.47	2.10
Median	4.87	89.30	2.14
Max	8.14	141.73	2.94
Min	3.09	37.93	1.42
Std. Dev.	1.43	19.01	0.39
Skewness	0.31	-0.21	-0.09
Kurtosis	1.69	3.35	2.09

Source: author's own calculation.

5. Empirical results

To investigate the stationarity issue and the possible presence of unit roots in series, univariate analysis of each of the time series is carried out. We initially investigate the issue of unit root in all time series data by applying the Zivot and Andrews (1992) unit root test. Table 3 shows the results of the Zivot and Andrews (1992) test for three alternative models (one break in the level of the series, a one-time change in the slope of the trend function, one break in the level and the slope of the trend function of the series). The tests statistics indicate that all series are I(1).

Table 3

Zivot–Andrews unit root tests.

	Statistics (level)			Statistics (First differences)		
	A	B	C	A	B	C
CORN	-3.31	-2.49	-3.35	-16.33***	-16.17***	-16.47***
	7/02/2010	7/20/2012	7/30/2010	9/11/2009	10/15/2010	7/04/2008
OIL	-4.33	-2.90	-4.74	-9.49***	-9.28***	-10.45***
	9/26/2008	1/16/2009	7/18/2008	2/20/2009	9/19/2008	1/02/2009
ETHANOL	-3.90	-3.14	-4.12	-11.84***	-11.75***	-11.88***
	8/06/2010	1/30/2009	8/06/2010	8/12/2011	3/01/2013	7/04/2008

Note: A, B, C denote model types and correspond to the three models in Zivot and Andrews (1992). The 1%, 5% and 10% critical values are -5.34 / -4.93 / -4.58; -4.80/-4.42/-4.11 and -5.57/-5.08/-4.82 for models A, B and C, respectively. The numbers in brackets are the estimated structural break dates (mm/dd/year). *** Rejection of the null hypothesis at the 1% level. The null hypothesis states that a series has a unit root with drift and an exogenous structural break. Source: author's own calculation.

As a large number of structural changes has been identified (cf. Table 3), a traditional analysis of causal relations can be distorted by these structural breaks. To avoid this problem, in further analysis we use rolling regression applied to augmented-VAR framework proposed by Toda and Yamamoto [1995]. Conducting the analysis within the rolling regression requires obtaining the window size (VAR models with fixed sample size each time, i.e. a fixed window size). The VAR models are calculated for a rolling 104 observations (approximately 2 calendar years) time window by adding one observation to the end and removing the first observation, and so on. That is, starting with observations 1–104, we calculate the first VAR model. Then, we calculate the VAR model for observations 2–105, 3–106, etc. Using AIC, we determine *k* – the number of lags in VAR models for each window.

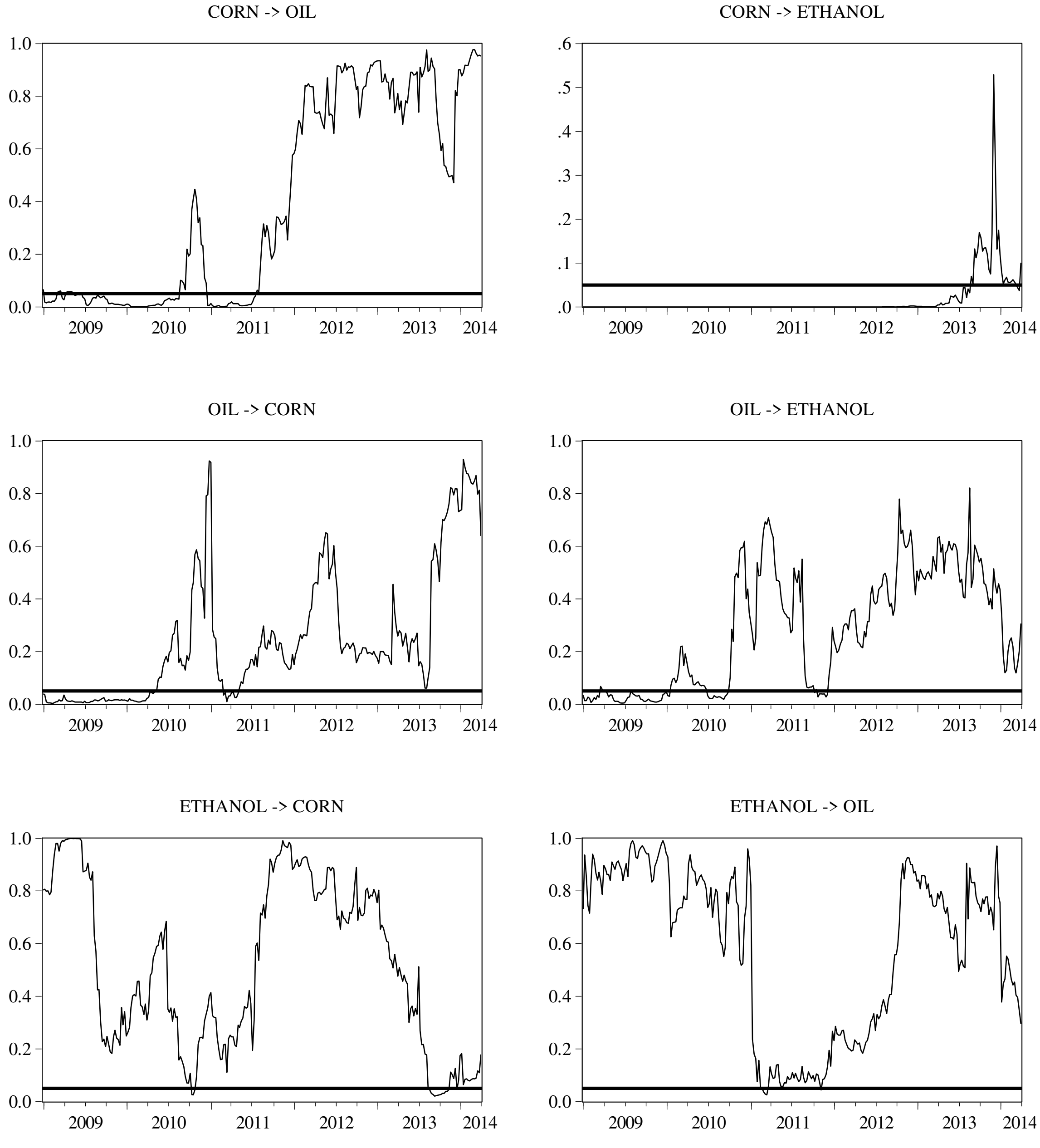

Fig. 2 Rolling Granger causality test - p-value of MWALD test.

Source: author's own calculation.

Granger causality tests can be applied via a MWALD test statistic on the first *k* coefficients. Figure 2 presents p-value for Granger causality tests. The horizontal axis indicates the ending point of the window of analysis. (We report the test statistics on the last day of the rolling sample period from which they are derived.) The first value represents p-value for Granger causality tests for the model estimated for the period from 5 January 2007 to 26 December 2008. The last one represents p-value for Granger causality tests in VAR estimated for the window 20 April 2012 – 11 April 2014. The horizontal line in the chart indicates the significance level of 5%. The values below this line mean that for a given subperiod variable A Granger causes variable B (A → B).

The results presented in Fig. 2 reveal that in the period analysed the variables influencing other variables change. The analysis of the results presented in Fig. 2 indicates that crude oil prices influence corn prices in the subperiods which start at the beginning of the analysis, that is in January 2007 (that is, the subperiod from January 2007 till December 2008) up to the subperiod beginning in April 2008 (that is, the last dependence subperiod lasted from April 2008 till March 2010). It is the period of considerable increases in oil prices and their rapid drops connected with the global financial crisis after the collapse of Lehman Brothers. In the subperiods which begin after April 2008, the influence of crude oil prices on corn prices is not observed. Similarly, corn prices influence crude oil prices in the subperiods beginning in January 2007. Their influence is longer, however, and the last subperiod for which past values of corn prices improve the forecasts of the crude oil prices is observed from September 2009 till August 2011. The results of the analysis indicate mutual dependence between crude oil prices and corn prices from the beginning of the analysis up to the first quarter of 2010. Later corn prices influence crude oil prices. No dependencies between agricultural commodity prices represented by corn prices and crude oil prices are found for the subperiods which begin in the second half of 2011.

Similarly, the results of the analysis presented in Fig. 2. indicate that crude oil prices influence ethanol prices for the subperiods beginning in January 2007 up to the subperiods beginning in October 2008 (that is, the last dependence period lasted from October 2008 to September 2010). However, the impact of ethanol prices on crude oil prices is not observed in the whole period analysed, which means that, within the energy market, Granger causality tests show that changes in the price of oil are an indicator of future changes in the price of ethanol. This relationship is unidirectional with changes in the price of ethanol unable to help predict future changes in the price of oil.

It can also be noticed that past values of corn prices improve the forecasts of ethanol prices from the beginning of the analysis up to the subperiods which begin in the third quarter of 2011 and last up to the third quarter of 2013. Corn prices do not influence ethanol prices in the subperiods which end from the fourth quarter of 2013 on, whereas in the whole period analysed significant causal relationships between the ethanol prices and corn prices are not observed.

6. Conclusion

The objective of the study is a dynamic assessment of dependencies between prices of corn, crude oil and ethanol using weekly data spanning from January 2007 to April 2014. The analysis, which uses the rolling regression to augmented VAR models, allows us to answer the questions posed at the beginning. The results obtained reveal that the dependencies between the prices of energy sources and the food prices change in time.

The results of our analysis indicate that food prices represented by corn prices influence the prices of energy sources. Corn prices affect fossil fuel prices (that is, crude oil prices) only up to the middle of 2010, while they affect biofuel prices (that is, ethanol prices) up to the third quarter of 2013. In the later period the impact of corn prices on energy sources prices is not observed. Similarly, using monthly data from 1995:01 to 2010:12, Wixson and Katchova [2012] show that changes in the prices of corn can be a leading indicator of changes in the prices of oil and ethanol.

The results of Granger causality tests indicate that changes in crude oil prices can be a leading indicator of changes in corn prices only up to the first quarter of 2010 and in ethanol prices up to the third quarter of 2010. In the later period the impact of crude oil prices on corn prices and ethanol prices is not observed.

The price of biofuels represented by ethanol prices does not influence either fossil fuel prices represented by crude oil prices or food prices represented by corn prices.

Additionally, it can be concluded that, from the third quarter of 2010 on, there are no causal relations between fossil fuel prices (represented by crude oil prices) and biofuel prices (represented by ethanol prices). Zhang et al. [2009] find a similar lack of links between ethanol prices and crude oil prices in the period of the ethanol boom

(2000-2007), although McPhail [2011], who uses monthly data from the period 1994:01–2010:02, shows that real ethanol prices Granger cause real oil prices and vice versa.

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