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Empirical investigation of the dynamic linkages between crude oil and maize prices: Dating the structural breaks

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The main purpose of this paper is to analyze the long- and short-run effects of crude oil prices on maize prices, taking into consideration the possible structural breaks in the relationship between them. Time-series analysis was used to estimate the dynamic linkages between variables under examination, while the Bai and Perron procedure was applied to endogenously identify the turning points. Data employed were collected from the World Bank's database Global Economic Monitors (GEM) for commodities, covering the time period from January 1960 to December 2012. The structural break was dated in early 2005, when the ethanol mandate in the US Energy Policy Act became effective. Empirical results from cointegration analysis support the hypothesis that crude oil prices consistently affect maize prices and this relationship has strengthen after the biofuel mandate in 2005 was issued in the US. Furthermore, the estimation of the ECM suggests that any deviation from equilibrium is corrected with nearly 48% over the following year. The results may call for serious policy implications. Directives and legal framework supporting the production and use of bioethanol should take into consideration the possible effect on food prices and especially grains, usually used for biofuel production.

Key words: Crude oil, maize, cointegration, Bai and Perron, structural breaks.

INTRODUCTION

During 2006-2008 the world experienced unprecedented increases in basic food prices, raising concerns about world food security, hunger and poverty around the world. One factor highlighted as the main cause of increased food prices was the steep rise in crude oil prices. Agriculture, historically, has been an energy intensive sector. From fertilizers to long distance transportation, agricultural sector includes many energy-dependent procedures, through which the price transmission from one sector to other occurs. According to Hanson et al. (1993), increases in crude oil prices are followed by higher costs, resulting in rising agricultural prices.

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Moreover, spikes in crude oil prices offered the motivation for the production of biofuels contributing to the further rise of food prices and also to a closer link between energy and agriculture (Cooke and Robles, 2009). Biofuel industry uses staple food, such as grains, rice, sugar and vegetable oils, as a basic input in the production procedure. Subsequently, the increased demand for grains contributed to soaring food prices and also to increased integration between energy and agriculture. According to Runge and Senauer (2007), this combined effect of high crude oil prices and large subsidies for supporting bioethanol produced from maize led to the observed expansion of the biofuel sector.

Motivated by the increased integration between energy and agriculture and the following impact on food prices, we investigate the long-run relationship between crude oil and maize prices using time-series analysis. Despite the fact that there is a vast bibliography concluding that a cointegration relationship between energy and agricultural prices exists no one, to our concern, has tested for the long-run stability of these relationships. More specifically, because the development of oil and agricultural prices has not occurred in a completely uniform manner, but rather has experienced important external shocks and increased volatility, previous results for cointegration might have been misleading. For this reason, we apply the Bai and Perron (1998, 2003a) procedure to endogenously identify structural breaks in the relationship between crude oil and maize international prices and, then, the structural breaks are included in the cointegration equation. The cointegration analysis is repeated using the more reliable technique of Fully-Modified OLS (Phillips and Hansen, 1990), while we apply the Hansen (1992) and Phillips and Ouliaris (1990) instability tests to reveal the long-run stability of this relationship. Finally, we investigate the short-run dynamics estimating the error correction model and applying Granger causality tests.

The reason for choosing maize over other grains is very specific. First of all, maize is the basic input in bioethanol production, which represents the largest share of global biofuel supply, nearly 84% of total biofuels production (Currie et al., 2010). Secondly, the ethanol production demonstrated a steep increase during 2000-2008 in the US, while the use of corn in ethanol production rose from 6 to 37% during the same period (RFA, 2009).

Our empirical results provide support for the existence of a stable long-run cointegration relationship between maize and crude oil prices with one structural break, which found to be statistically significant and identified in the beginning of 2005, when the ethanol mandate in the US Energy Policy Act became effective (Krugman, 2008; Mitchell, 2008; de Gorter et al., 2013). These findings support the hypothesis that crude oil prices consistently affect maize prices and this relationship has strengthen after the biofuel mandate in 2005 was issued in the US.

LITERATURE REVIEW

Links between energy and agriculture: Focusing on the 2008 price crisis

Historically, agriculture has been an energy-intensive sector and the investigation of the degree on which changes in energy prices and policies affect agricultural prices or agricultural sector overall has been of primary interest. Since the 1970s, researchers try to examine the certain channels through which agriculture and energy are linked. For example, a study by Chenery (1975) highlighted the distortion in international trade caused by increased energy and food prices and the following negative implications especially for developing countries.

During 2006-2008, dramatic increases in staple food prices raised the world's attention upon a forthcoming food price crisis with devastating implications for food security, hunger and poverty, especially for poorer households in developing and, also, in developed countries. Today nearly 800 million people suffer from chronic hunger and undernourishment, while the rise in basic foodstuff prices is expected to add some more (FAO, 2008). The deprivation of millions of people from the most basic human right, access to food, caused bloody classes and social turmoil globally. According to Bush (2010), the so-called "foodriots" highlighted the social and economic consequences of a dramatic increase in food prices.

More specifically, prices in the three basic commodity groups, energy, metals and agriculture, experienced substantial rises after a long-run downward trend, following a very similar pattern, as illustrated in Figure 1. High energy and metal prices, led by unprecedented rises in crude oil prices, seem to have occurred simultaneously with increases in agricultural prices, especially grains, rice and sugar. To be exact, crude oil prices reached their peak, at nearly \$133/bbl on July 2008 from just \$60.6/bbl on March 2007, while maize prices were more than doubled within a year, between June 2007 and June 2008 (Figures 2 and 3).

Many factors were proposed as causes of soaring food prices, from the demand and also the supply side of agricultural sector. Such factors include the increased demand from emerging markets, such as China and India, and changes in consumer preferences towards meat and dairy products due to rapid growth rates, higher per capita incomes and improved standards of living. Other factors include supply constraints due to extreme weather conditions, such as extended periods of drought in large producer countries, low investment in R&D in agriculture, implementation of restrictive trade policies by governments, such as import tariffs or export restrictions and the increased speculation in commodity markets.

However, the steep rise in energy prices, and especially crude oil prices, highlighted as one of the main reasons behind the drastic food price increases by a

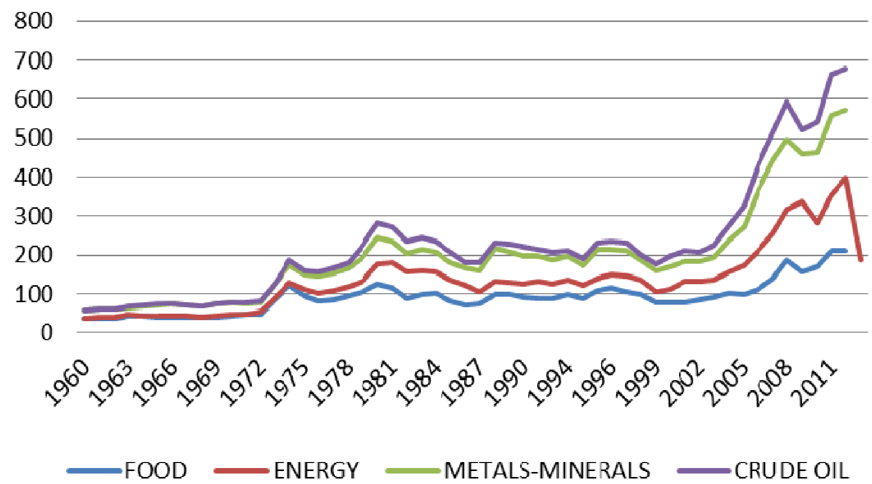

Figure 1. Food, energy, metals-minerals and crude oil prices, 1960-2012, 2005=100, $ nominal.

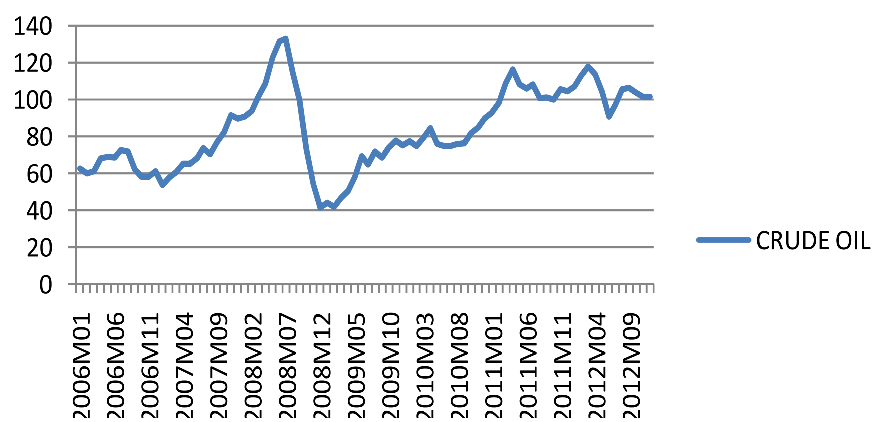

Figure 2. Crude oil, average spot, nominal prices $/bbl, 2006M01-2012M12.

Figure 3. Maize, nominal prices $/mt, 2006M01-2012M12.

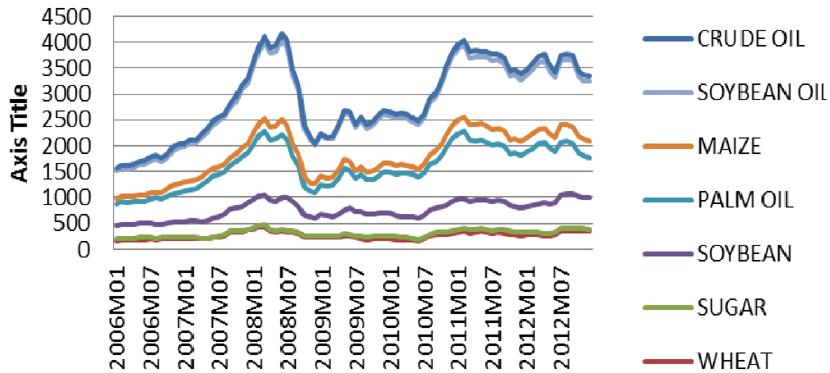

Figure 4. Crude oil, nominal prices $/bbl, maize, palm oil, soybean, sugar, wheat, nominal prices $/mt, 2006M01-2012M12.

large part of the research. According to Piesse and Thirtle (2009), high energy prices was the most crucial factor behind high food prices and, because we expect them to rise more in the future, policy measures should focus on improving the production conditions in global agriculture. It is true to say that energy prices can affect agricultural prices through many channels, while the most apparent one is through production costs. According to Hanson et al. (1993), increases in crude oil prices are followed by higher costs, resulting in rising agricultural prices.

Moreover, this increase is expected to be fairly substantial as agricultural production includes many energy-intensive procedures, from fertilizers to long-distance transportation. For this reason, crude oil prices should be included in the aggregate production function of most agricultural products (Baffes, 2007). Fertilizers, fuels and transportation costs are affected directly by crude in oil prices, and turn, they affect grains production (von Braun et al., 2008). For Chevroulet (2008), the distribution of agricultural production in spatially distributed consumers in urban places will include significant transportation costs, highly dependent on fuel prices.

Moreover, higher prices of conventional energy during the last price crisis provided a strong motivation for the production of alternative fuels, such as biodiesel and bioethanol (Cooke and Robles, 2009). Indeed, this shift in profitability is apparent from older studies; Lunnan (1997) identifies the high biofuel production costs in relation to oil costs as the main prohibitive factor for their expansion. In addition, policy measures and directives in Europe, the US, Japan and Brazil contributed significantly towards this direction by making the production and usage of biofuel obligatory for environmental mainly reasons. According to Runge and Senauer (2007), this combined effect of high crude oil prices and large subsidies for supporting bioethanol produced from maize led to the observed expansion of the biofuel sector.

Figure 4 illustrates the monthly price movement of staple food usually used in biofuel production, like grains, sugar and vegetable oils from 2006-2012, and also crude oil prices per barrel. As it is clear, prices in food commodities and energy followed a very similar pattern, experiencing enormous increases during 2006-2008.

Empirical investigation of the oil-food interdependencies

The investigation of the impact that increased oil prices have on food prices is primarily based on three different methodologies. Firstly, part of the research uses Computable General Equilibrium models (CGE) to simulate the links between energy and agriculture on a macroeconomic level and capture the effects of changes in energy prices on real income and on trade balances. However, despite the fact that such analysis takes into consideration the interdependencies between sectors, it lacks in revealing the short term impacts. In addition, most of the relationships are exogenously determined by economic theory (Zhang et al., 2009).

More recently some researchers tried to assess the impact of energy on agriculture using theoretical models. The most important disadvantage of theoretical models is that the results are highly depended on the assumptions made and the certain structure of the model. More specifically, Gardner (2007) examines the welfare effects of corn and ethanol subsidies in the US by developing a theoretical model of the ethanol, maize and by-products markets, while de Gorter and Just (2009), expand Gardner's model incorporating the ethanol market into the aggregate fuels market and suggest that the price transmission between fuel and maize takes place through the corn demand for ethanol production.

The third methodology that has been used by researchers is cointegration analysis. These studies usually concentrate on the consequences of increased energy prices on certain commodities involved in the biofuel production, such as grains or sugar and vegetable

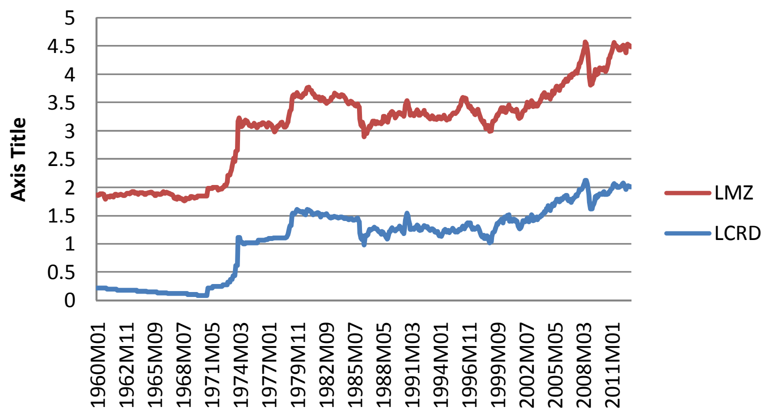

Figure 5. LMZ and LCRD 1960:01-2012:12.

oils using cointegration analysis and also for certain countries or groups of countries. Again, the results vary based on the data and methodology employed, time period and commodities under consideration.

Yu et al. (2006) use weekly data from January 1999 to March 2006 and apply Johansen cointegration methodology to examine the dynamic linkages between international crude oil prices and basic edible vegetable oils, such as soybean oil, sunflower oil, rapeseed oil and palm oil. Their results indicate that shocks in crude oil prices do not affect significantly the agricultural prices. Campiche et al. (2007), also apply the Johansen analysis to investigate the dynamic relationship between crude oil and five agricultural commodities, namely corn, sugar, soybean, palm and soybean oil for the period 2003-2007. They do not find cointegration relationship when the whole time period is taken into account; however, their results reveal that crude oil and agricultural prices are cointegrated for the period 2006-2008. Zhang and Reed (2008) investigate the impact of international crude oil prices on maize, soybean and pork prices in China. Using data for the period January 2000-October 2007, they apply VARMA models, Granger causality tests, variance decomposition and cointegration analysis concluding that the fuel prices did not affect significantly the food prices in China.

On contrary, other studies provide evidence for the existence of a long-run relationship between energy and agricultural prices. Hameed and Arshad (2008), apply the Engle and Granger cointegration methodology to examine the long-run relationship between crude oil prices and four vegetable oils for the time period from January 1983 to March 2008. Their results indicate the existence of a long-run cointegration relationship between crude oil and each vegetable oil, while the estimation of error correction models reveals causal relationships running from crude oil prices to agricultural commodities under examination. Saghaian (2010), uses monthly data for maize, wheat, soybean, crude oil and ethanol prices to test the reaction of agricultural prices in crude oil price changes. The results from the VEC Models indicate a strong correlation between agricultural and energy prices, however, the Granger causality tests provide mixed results. Elmarzougui and Larue (2011), investigate the relationship between international corn and crude oil prices from January 1957 to April 2009 and find three structural breaks using the Bai and Perron procedure (1998, 2003). Their empirical results provide support for the existence of a cointegration relationship only during the third regime, from 1990 to 2009, indicating that the emergence of the biofuel industry contributed to a stronger link between them.

METHODS

Data

The data employed in our analysis are monthly covering the time period 1960M01 to 2012M12 and are collected from the World Bank's database Global Economic Monitors for Commodities. The variables included are international nominal prices for maize (LMZ) and crude oil (LCRD). Moreover, maize prices refer to US, No.2, Yellow, FOB prices, while for crude oil we use the average spot price of Brent, Dubai and West Texas Intermediate, equally weighed. Both variables are used in their physical logarithms (Figure 5).

Stationarity and cointegration analysis

Cointegration refers to the possible comovement among certain variables in the long-run horizon. Furthermore, if maize and crude oil prices are found to be cointegrated means that, despite the fact that they may drift apart temporarily from each other, in the long-run they tend to return to equilibrium. In the context of this paper, we apply the residual-based tests for cointegration proposed by Engle-Granger and Phillips-Ouliaris, which require for variables to be integrated of order one, I(1) in order to avoid a spurious regression (Granger and Newbold, 1974). We apply Dickey and Fuller's (1979, 1981) unit root tests to find out if our variables are stationary of order one, I(1). If this is the case, we can proceed with testing for the possible existence of a long-run equilibrium relationship between maize and crude oil prices with Engle and Granger's (1987) and Phillips and Ouliaris' (1990) single equation cointegration tests. Engle-Granger (1987) and Phillips-Ouliaris (1990) residual-based tests for cointegration are simply unit root tests applied to the residuals obtained from OLS estimation of equations:

$$LMZ_t = \alpha_1 + c_1 LCRD_t + u_t \quad (1)$$

$$LCRD_t = \alpha_2 + c_2 LMZ_t + e_t \quad (2)$$

By obtaining the estimated residuals form the cointegration Equations (1) and (2) $\hat{u}_t = LMZ_t - \hat{a}_1 - \hat{c}_1 LCRD_t$ and $\hat{e}_t = LCRD_t - \hat{a}_2 - \hat{c}_2 LMZ_t$ respectively, we apply unit root tests for stationarity. The null hypothesis of no cointegration against the alternative of cointegration corresponds to a unit root test of the null of no stationarity against the alternative of stationarity.

Bai-Perron procedure for endogenous structural breaks

The previous results might be misleading as the development of prices over the years has not occurred in a completely uniform manner, but rather it has experienced important external shocks. If this is the case, the existence of a cointegration relationship between the variables under examination will not have been a stable one.

Motivated by this observation, in the next step we apply Quandt's (1960) likelihood ratio statistic (QLR) to test parameter's stability and identify possible structural change points in the long-run relationship between LMZ and LCRD. However, because Quandt's statistic has received criticism due to the difficulty in deciding the pre-determined structural turning point, we apply the Bai and Perron (1998, 2003a) procedure to endogenously identify multiple breakpoints. The BP methodology uses statistical inference to date a specific break by calculating thousands of values of SSE (Sum of Squared Residuals) under different assumptions in order to find the minimum one. Each of SSE is calculated by summing up all the squared residuals in all regimes and each residual represents the difference between an observed data series and its corresponding mean in a regime. It is more than apparent that the SSE will be minimized when we date the exact structural breaks for a data series. This concept implies that the breaks are selected by repeatedly testing all possible points according to the relevant significance of certain statistical tests.

For the purposes of this paper we use the sequential $SupF(l+1|l)$ test, where the null hypothesis of l structural changes is tested against the alternative of $l+1$ breaks. If the statistical test $SupF(l+1|l)$ is found to be significant, then we accept the hypothesis for the existence of at least $l+1$ turning points. The procedure is repeated until the number of structural changes is endogenously determined.

Cointegration analysis with structural breaks

Taking into account the structural breaks determined in the previous stage, we test for the existence of a long-run cointegration relationship between maize and crude oil prices, using the more credible Phillips and Hansen's (1990) Fully-Modified OLS (FMOLS) methodology. More specifically, Phillips and Hansen propose an estimator which employs a semi-parametric correlation to eliminate the problems caused by the long run correlation between the cointegrating equation and stochastic regressors innovations. The resulting estimator is asymptotically unbiased and has fully efficient mixture normal asymptotics allowing for standard Wald tests using asymptotic Chi-square statistical inference. Then, we proceed with testing the long-run stability using Hansen's (1992) and Phillips-Ouliaris (1990) instability tests. Hansen (1992), tests the null hypothesis of cointegration against the alternative of no cointegration proposing the L_c statistic which arrives from the theory of Langrage multipliers, in order to assess the stability of the parameters. He notes that under the alternative hypothesis of no cointegration, one should expect evidence of parameter instability. On the contrary, Phillips and Ouliaris (1990) test the reverse null hypothesis of no stable cointegration against the alternative of a stable cointegration using the statistics Phillips-Ouliaris tau and z.

Estimation of error correction models and granger causality tests

In the last step of our analysis, it is appropriate to estimate the error correction models derived from Engle and Granger methodology including the structural breaks in order to investigate the long- and short-run dynamics between our variables. According to Granger's Representation Theorem, in case that cointegration is detected, an Error Correction Model (ECM) exists:

$$\Delta Y_t = \beta_1 \Delta X_t - (1-\gamma_1)(Y_{t-1} - \alpha_0 - \alpha_1 X_{t-1}) + \varepsilon_t \quad (3)$$

$$\Delta Y_t = \beta_1 \Delta X_t - (1 - \gamma_1)\hat{u}_t + \varepsilon_t \quad (4)$$

Where $\hat{u}_t = Y_t - \hat{a}_0 - \hat{a}_1 X$, the estimated residuals derived from the first step of the Engle and Granger methodology. All variables in Equation (4) are stationary, as Y and X are cointegrated. Furthermore, as one can see, changes in Y are dependent on changes in X and also the disequilibrium error of the previous period. This means that the value of Y is being corrected for the disequilibrium error of the previous period, however, the correction is partial and depends on the value of γ_1, for which we assume that $0<\gamma_1<1$. More specifically, we derive the long-run dynamics by estimating the error correction term, γ_1, which represents the speed at which the dependent variable, maize price, returns to equilibrium after a shock experienced in crude oil prices. According to the above, we expect for the coefficient of the error correction term to be negative and statistically significant. Additionally, the dynamic ECM incorporates, also, the short-run effects by including the variables in differences.

With regard to the short-run causality between the variables under examination, we apply the Granger-causality (1969) test based on the previous error correction model. More specifically, we want to reveal how much of the current value of our dependent variable can be explained by the past value of the second variable and to see whether adding lagged value can improve the explanation. This is examined with a simple F-test, where the null hypothesis to be tested is that petroleum price does not Granger-cause maize prices or maize price does not Granger-cause crude oil price.

RESULTS AND DISCUSSION

Stationarity and cointegration tests

Table 1 summarizes the results from the unit root tests on the levels and the first differences of the variables. Both variables are nonstationary in levels (test statistic >critical value), while they turn stationary in first differences (test statistic < critical value). The variables under examination are integrated of order one, I(1), thus we can proceed with cointegration testing. The results from Engle-Granger and Phillips-Ouliaris tests are presented in the

Table 1. Augmented Dickey-Fuller unit root tests.

Series in logarithm	Include an intercept, but not a trend			Include an intercept and a trend		
	Test statistic	**k**	**Critical value**	**Test statistic**	**k**	**Critical value**
LCRD	-0.8419	6	-2.8982	-1,7728	6	-3.5260
LMZ	-1.5676	1	-2.8718	-2.8550	1	-3.4894
Series in first difference	**Test statistic**	**k**	**Critical Value**	**Test statistic**	**k**	**Critical value**
ΔLCRD	-11.0270	5	-2,8545	-11.0181	5	-3.4711
ΔLMZ	-19.3089	0	-2.8551	-19,2990	0	-3.4529

The optimal lag structure of the ADF test is chosen based on the Akaike Information Criterion (AIC), while k denotes lag order. The critical values are 95% simulated critical values using 40 obs. and 1000 replications.

Table 2. Residual-based tests for cointegration.

Dependent variable	Engle-Granger's residuals unit root[1]		Phillips-Ouliaris' residuals unit root[2]	
	t-statistic	**p-value**	**t-statistic**	**p-value**
LMZ	-4.089	0.0057	-3.921	0.0098
LCRD	-3.853	0.0121	-3.685	0.0200

[1]Lag specification based on SIC (maxlag=19), Ho: Series are not cointegrated; [2]Long-run variance estimate (prewhitening with lags = 0 from SIC, maxlags = 1, Bartlett kernel, Newey West fixed bandwidth, Ho: Series are not cointegrated; p-values: based on MacKinnon (1991).

Table 2.

P-values suggest that the null hypothesis of no cointegration is rejected with both methodologies and for both equations; when dependent variable is LMZ and also when dependent is LCRD (p-value < 1 or 5% level of significance). This means that a long-run cointegration relationship exists between our variables. Crude oil and maize prices seem to have followed a similar pattern on the long-run. However, these findings might be misleading if the variables under examination have experienced important external shocks, which means that the relationship between them has not been a stable one. Given the fact that crude oil and agricultural prices are consistently affected by external factors and seasonality, we continue on with dating the structural breaks in the relationship between them.

Endogenous structural breaks with Bai-Perron procedure

Results from QLR test in Table 3 confirm the existence of at least one possible structural turning point in the relationship between variables under consideration (F-statistic>critical value at 1% level of significance). However, because QLR test has received criticism as regards the pre-determination of the turning point, we apply the Bai and Perron procedure to endogenously identify the structural breaks. Table 4 suggests the existence of 5 structural breaks in the relationship between our variables when dependent is LMZ, while the bottom part dates the specific turning points. These can now be taken into consideration in the cointegration analysis with the more reliable Fully-Modified OLS.

Cointegration with structural breaks

Table 5 summarizes the results from the estimations with FMOLS methodology. As one can observe, the variable of LCRD was found to be significant (p-value=0.0000), while most of the dummies used to represent structural breaks were rejected as statistically insignificant, except from S2005. Our results suggest that a 1%rise in international oil prices leads to a 0.27% increase in maize prices. Furthermore, the variable of petroleum price was found to be significant (p-value=0.0000) and with a positive sign, as theory suggests. Table 6 presents the results from instability tests of Hansen and Phillips-Ouliaris. Hansen’s statistic, Lc, reveals a stable long-run cointegration relationship between variables under consideration. This result is supported also with Phillips-Ouliaris tests, z- and t-statistic, both of which reject the null hypothesis of no cointegration.

The analysis provides support of the hypothesis for the existence of a stable cointegration relationship between maize and crude oil prices, when maize is the dependent variable. The structural break with Bai-Perron methodology was dated in early 2005, when Energy Policy Act in the US became effective. More specifically, one important provision of the Act was the increase in the amount of biofuel that must be mixed with gasoline sold in the US. The relationship between variables under consideration seems to have strengthened after 2005.

Table 3. Quandt likelihood ratio for structural break in unknown point.

Dependent variable	Maximum F-statistic	Structural break
LMZ	111,127*	1999:07
OLS, obs. 1960:01-2012:12 (T=636), HAC standard errors, Bartlett kennel 6		
QLR test with 15% trimming, critical value at 1%: 7.78		

Table 4. Bai and Perron test for structural breaks endogenously.

Dependent variable	SupF(l+1)|1)	RSS		
LMZ	SupF(5|4)	RSS_4	16.14899	
		RSS_5	15.28508	
	Dates of structural breaks			
1	**2**	**3**	**4**	**5**
1967M12	1977M04	1988M05	1997M02	2005M01

Table 5. FMOLS cointegration method.

Dependent variable	LCRD	C	S2005
LMZ	0.277553 [0.0000]	3.839[0.0000]	0.050755[0.1088]

Long-run covariance estimate: Prewhitening with lags = 1 from SIC, maxlags = 8, Bartlett kernel, Newey-West fixed bandwidth = 7.0000.

Table 6. Instability tests based on cointegration with FMOLS.

Hansen instabiltity test H_0: Series are cointegrated		Phillips-Ouliaris test H_0: Series are not cointegrated	
Lc statistic	0.144102	Phillips-Ouliaris t-statistic	-4.196[0.0039]
	[> 0.2]	Phillips-Ourialis z-statistic	-36.272[0.0015]

Estimation of error correction and Granger-causality tests

In the last step of our analysis it is appropriate to estimate the error correction models derived from Engle and Granger's methodology, taking into consideration the structural break. Estimations from the EC specification are presented in Table 7. The existence of a long-run causal relationship among the examined variables is confirmed once again since the coefficient of the lagged EC term is found statistically significant (the p-value of the applied t-test is smaller than the 1%) and has the correct sign suggesting that any deviation from the long-term income path is corrected by nearly 48% over the following year.

Regarding the short-run dynamics, as reported in Table 8, there is no evidence of Granger-causality type effects running from crude oil prices to maize prices or the opposite (p-value > 1% or 5% level of significance).

Conclusion

Motivated by the increased interdependence between energy and agriculture during the last years, we used cointegration analysis in order to examine the dynamic linkages between international crude oil and maize prices from January 1960 to December 2012. In addition, we applied the Bai and Perron procedure (1998, 2003a) to endogenously identify the structural breaks in the relationship between variables under consideration.

Our empirical findings revealed a stable long-run cointegration relationship between crude oil and maize prices, when maize is dependent variable and the structural break is included in the cointegration equation. The latest was dated in early 2005, when the ethanol mandate in the US Energy Policy Act became effective and made the gasoline-biofuel mix obligatory (Krugman, 2008; Mitchell, 2008; de Gorter et al., 2013). Moreover, the estimation of the error correction specification

Table 7. VECM estimations.

Cointegrating vector	LMZ = 0.258395LCRD + 3.934764C	
Estimation of error correction term		
Dependent variable	**Coefficient**	**t-student**
ΔLMZ	-0.039830	-3.76065***

***1% significance level.

Table 8. VEC granger causality tests.

Dependent variable	Wald statistic	p-value	Outcome
ΔLMZ	3.590250	0.4643	No causality
ΔCRD	0.748505	0.9452	No causality

revealed that any deviation from the long-run equilibrium, caused by an external shock in crude oil prices, is corrected by 48% over the following year, while there was no evidence of Granger-causality type effects running from crude oil to maize prices or the opposite.

These findings support the hypothesis that crude oil prices consistently affect maize prices and this relationship has strengthen after the biofuel mandate in 2005 was issued in the US. In addition, our results may call for serious policy implications. Directives and legal framework supporting and promoting biofuel use and production should take into consideration any possible impact on food prices, and in particular, grains. Furthermore, there is an urgent need for world agriculture to become sustainable and independent from any non-renewable and conventional energy resources, like fossil fuels. On the contrary, policy should focus on supporting and compensating capital investments for the production of renewable energy and also on encouraging the recycling and reuse of agricultural by-products in order for energy needs to be covered on a natural and self-reliant way.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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