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Avril 2016

Les cahiers de l'économie - n° 104

Série Recherche

IFP Energies Nouvelles - IFP School - Centre Économie et Gestion
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I would like to thank Valerie Mignon, Emmanuel Hache and Benoit Cheze for their helpful comments and suggestions.

Abstract

Given the few studies highlighting the existence of an oil-price effect on agricultural commodity prices in the last decade, we sought to demonstrate the role of first-generation biofuel production in such a relationship. Relying on a smooth transition cointegration approach, we show that biofuel development has led to an increase in the long-term price effect of oil on agricultural commodity prices. Thus, the increasing production of biofuels contributes to the price rise of agricultural commodities. This result underlines the importance of accelerating second-generation biofuel production to replace first-generation biofuels.

JEL Classification codes: C22, Q02, Q16

Keywords: Biofuel, Oil price, Agricultural commodity, Nonlinear econometrics

1 Introduction

As seen in Figure 1, the sharp rise in oil prices from 2004-2006 resulted in a small increase in agricultural commodity prices[1] compared with those from 2007-2008.[2] Thereafter, agricultural and oil prices displayed significant co-movements; as illustrated by the strong correlation that exists between the price variations. In addition, this correlation has accentuated during an acceleration phase of US biofuel production development.[3] Biofuels constitute energy sources developed to replace fossil fuels. However, biofuels are produced from agricultural commodities, and this utilization of agricultural commodities competes with their food use. This competition is the main cause of the "food versus fuel" debate, according to which biofuel production accentuates the food insecurity situation in some countries, particularly developing ones. In addition, a main characteristic of the biofuels market is governmental support. Thus, if this new market has indeed contributed to the price rise of agricultural commodities, producer country governments would primarily be responsible.

Insert Figure 1

In the 2000s, the prices of several commodities increased, and many studies sought explanatory factors, particularly in agricultural raw materials. For example, the OECD (2008) attributed the agricultural commodities' price increase to five causes. First, the price increase reflected higher production costs generated by the rise in oil prices. Second, there was weak growth in production due to bad weather conditions in major producing countries, such as Australia and Canada. Third, there was a sharp rise in demand explained largely by biofuel production development. Fourth, low inventories contributed to the price increase by preventing quantity adjustment in the markets. Finally, the investment increase in agricultural derivative markets led to a short-term rise in future prices. This view

[1] This food index includes selected commodities, such as cereals, vegetable oils, meats and tropical products, but it perfectly reflects the evolution of most agricultural commodity prices. In addition, the oil index is the simple average of Dated Brent, West Texas Intermediate and the Dubai Fateh.

[2] Note that in both cases, the oil price has been multiplied by approximately 2.5, whereas the respective multiplication factors of commodity prices are 1.3 and 1.7.

[3] We are referring to first-generation biofuels because new generation biofuels are not in the commercialization phase.

was shared by Mitchell (2008), who added the role of a weak US dollar. Abbott et al. (2011) and Abbott and Borot de Battisti (2011) emphasized these factors and mentioned the economic growth increase in developing countries. These studies, and all of the literature on this subject, can help to improve our understanding of the price formation mechanisms and price volatility of agricultural commodities in the last decade.

Falling into this strand of the literature, the aim of this paper is to study the effect of oil prices on agricultural commodity prices, both in the short- and long-term. We go further than the previous literature by paying particular attention to the effect of biofuel production development on the long-term link. This effect is highly controversial because it has indeed never been proven. To this aim, we use various methods from nonlinear econometrics, including smooth transition cointegration. These methods allowed us to estimate the oil-agricultural commodity price nexus, depending on the level of biofuel production. With a nonlinear approach, we are able to determine the existence of different regimes in the oil-price effect and to verify the role of biofuel development in alternating between these regimes. Therefore, it is possible to estimate this effect both in the absence of biofuel production and when it is at a high level, and to check the widespread intuition that there has been an increase in the oil-price effect caused by biofuel development. The use of a smooth transition approach rather than a model with an instantaneous regime change is justified by the slow development of biofuel production and the time required for changes in market behavior. Our empirical analysis relies on five agricultural commodities. Three are directly linked to biofuel production as input: corn and soybean for US production and rapeseed for European production. Additionally, we use wheat and sunflower to examine whether biofuels affected previous commodities substitutes.

Our contribution to the existing literature is twofold. First, we provide new evidence about the link between oil and agricultural commodity prices using a longer period than much of the literature, including the biofuel production development phase and the last economic crisis. Second, regarding our main contribution concerning the effect of biofuel production on agricultural prices, we provide new evidence in favor of or against an inflationary effect of biofuel production on agricultural commodity prices. Thus, we contribute to the "food versus fuel" debate by showing a positive effect of biofuel production on all of the prices of studied agricultural commodities through an increase in the oil-price effect. This result confirms that biofuel production has been one of the key causes of agricultural price increase in recent years.

This paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the methodology and data used. Section 4 is devoted to our empirical results, and Section 5 draws our main conclusions.

2 Literature review

In the 1990s, studies on the link between commodity prices intensified.[4] The seminal contribution of Pindyck and Rotemberg (1990), although highly debated, opened a new area of research. They studied the correlation matrix of price variations unexplained by macroeconomic variables. The authors showed that macroeconomic variables do not explain the co-movement between commodities. They emphasized the existence of excess co-movement, which is unexplained by macroeconomic shocks, between different unrelated commodities. Palaskas and Varangis (1991), Leybourne et al. (1994), with a cointegration approach, and Deb et al. (1996), through a multivariate GARCH model, then deepened this issue and showed that, although there are excess co-movements, they are of small magnitude and involve few commodities. Several reasons for this co-movement excess were given by the authors, such as the presence of a speculator's liquidity constraint on financial markets, herding behavior or the possibility that agents interpret supply shocks specific to a market as macroeconomic shocks.

Other plausible alternative causes, not mentioned in these papers include the link between energy markets — such as oil — and other commodities. This last point has generated several studies that help to highlight the effect of oil price on

[4] Table 1 summarizes the main studies cited in this section.

commodity prices and the transmission mechanism between energy and other commodity markets. Hanson et al. (1993) studied the cost effect of oil on various commodities using the USDA/ERS[5] Computable General Equilibrium model. Their main finding was the heterogeneity of commodity price responses to an oil shock depending upon assumptions about the exchange rate regime and the trade balance evolution. Thus, the oil-price effect on commodity markets cannot be summarized by the cost effect. However, they did not compare the ability of macroeconomic and oil shocks to explain co-movements. More recently, Gohin and Chantret (2010) studied the effect of an oil shock on agricultural commodity prices using the Computable General Equilibrium model of the GTAP[6] with or without income effect. They showed that the introduction of the income effect can reverse the sign of the relationship between oil and food products for oil-importing countries. They found a decrease in world prices for beef and dairy products. For these markets, the income effect was greater than the cost effect. However, this relationship was not observed in the wheat market with an increase of the world price or in the US and European markets. According to Gohin and Chantret (2010), this absence was due to the lower income elasticity demand for wheat and other grains. The same result should be checked for all cereals. In addition, they mentioned that the production-cost effect was unlikely to exist in the short term due to the quasi-fixity of most production factors. Thus, two shock transmission mechanisms, cost and income effects, can have opposite signs and therefore compensate for one another. Ai et al. (1996) investigated the causes of co-movements with the introduction of competition between two models, one macroeconomic, in which the co-movements are explained by macroeconomic variables, and the second, microeconomic, with supply and demand factors. They emphasized that the most efficient model to explain co-movements was the microeconomic model, showing that the supply factors would be the main causes of price co-movements.

Different approaches have been used to examine the presence of oil-price effects on commodity prices. Relying on the Johansen (1991) cointegration method, Kaltalioglu and Soytas (2009) tested the existence of this effect from

[5] It is the Economic Research Service of the United States Department of Agriculture.
[6] It is the Global Trade Analysis Project.

1980-2008. Finding no long-term relationship between oil and various commodity indices, they estimated a VAR model for the short-term relationship and highlighted weak and transitory responses to an oil shock. Zhang et al. (2010) obtained the same conclusion concerning the nonexistence of a long-term relationship from 1989-2008 using a similar approach with corn, soybeans, wheat, sugar and rice. They also failed to find a short-term relationship. Natanelov et al. (2011) studied several commodity prices, including corn, soybean oil and wheat, and showed that only wheat had a long-term relationship with oil from 1989-2010. However, they found a long-term oil-price effect on these three commodities between 1993 and 2001. Yu et al. (2006) highlighted one vector of cointegration between vegetable oils (soybean, sunflower, rapeseed and palm) and crude oil prices from 1999-2006. However, using an exclusion test, they showed that crude oil and sunflower oil prices did not belong to the cointegration space. In addition, with a causality analysis, they emphasized that oil was not part of the causal relationship. Zhang and Reed (2008) undertook the same work with corn, soybean meal and pork Chinese data from 2000-2007. They did not find long- or short-term relationships. Peri and Baldi (2010) studied the link between three vegetable oils and diesel prices. Unlike soybean and sunflower, a long-term relationship did exist with rapeseed oil from 2005-2007.

A second approach consists of studying cointegration in a panel data framework. The Pedroni (1999) approach was used by Nazlioglu and Soytas (2012) to examine 24 agricultural commodities from 1980-2010. They showed a positive long-term oil-price effect, highlighting the cost effect. Using the Pedroni (1999) and Westerlund (2007) approaches on several commodity prices, Bremond et al. (2014) did not find a long-term relationship between oil and agricultural commodities from 2000-2011. By studying the short-term relationship, they showed a weak causal relationship between oil and commodities.

Another method is to check for the existence of causality from the oil price to a commodity price. Nazlioglu and Soytas (2011) performed the Toda and Yamamoto (1995) long-term causality test in Turkey with corn, cotton, oil, soybean, sunflower and wheat prices from 1994-2010. They showed no long-term causality and therefore no oil-price effect. In addition, they studied the short-term link with a lag augmented-VAR model, identifying a low oil-price effect on corn and cotton prices. With the same test and the Dolado and Lutkepohl (1996) causality test, Kwon and Koo (2009) found a causality relationship from crude energy goods — including oil, natural gas or coal — to agricultural commodities from 1998-2008.

Other studies using various methodologies have been conducted to investigate the existence of a break date in the link between oil and agricultural commodity prices. Campiche et al. (2007) used the Johansen (1991) cointegration approach with different sub-samples for oil, corn, sorghum, soybean oil and palm oil. No long-term relationship was found from 2003-2007, but a link existed between oil and corn and between oil and soybean oil for the sub-sample 2006-2007. With the same cointegration method but with overlapping periods, Harri et al. (2009) looked for a break date on which a long-term relationship appeared between oil and corn prices. They determined April 2006 as the break date. Penaranda and Ruperez-Micola (2011) applied the Bai and Perron (1998, 2003) break tests on the regression between oil and agricultural commodity price growth. They highlighted the existence of a break date with the appearance of the short-term oil-price effect in 2005 for corn and soybean and in 2003 for sugar. In addition, break dates existed for the majority of other commodities, such as 2004 and 2008 for wheat.

Regarding nonlinear cointegration studies, Peri and Baldi (2010) and Natanelov et al. (2011) rely on a TVECM (Threshold Vector Error Correction Model) specification following the Balke and Fomby (1997) and Hansen and Seo (2002) procedures. The authors showed that the adjustment was faster when the deviation from the equilibrium relationship between agricultural commodities and oil prices was greater than a certain threshold. Penaranda and Ruperez-Micola (2011) achieved a threshold regression on price changes, which was interesting for the short-term relationship. The oil-price effect grew when oil prices exceeded a certain threshold. Myers et al. (2014) attempted to explain the cointegration relationship that appeared in 2006, highlighted by Harry et al. (2009). They used the Gonzalo and Piterakis (2002) criterion to verify the presence of non-linearity in the relationships between oil and corn, and oil and soybean spot prices via the existence of several regimes. They assumed that this break could be created by four variables, including the amount of ethanol produced.[7] They showed no change in the relationship. After checking the lack of cointegration relationship from April 2006 through September 2008, they suggested that Harry et al. (2009)'s results may be related to the use of future prices. To our knowledge, no other paper has focused on a long-term oil-price nonlinear effect on agricultural commodity prices used in biofuel production.

Insert Table 1

3 Data and Methods

3.1 Data

We consider daily prices for oil, corn, soybean, sunflower oil, rapeseed oil and wheat. All agricultural data are from the USDA and Thomson Reuters. The oil price series comes from Thomson Reuters, whereas US biofuel production is given by the Energy Information Administration. The oil price that we consider is the spot price for West Texas Intermediate crude oil in dollars per barrel. Concerning agricultural commodities, we use spot price for Illinois No. 2 corn, Soft Red No. 2 wheat and No. 1 yellow soybean. All prices are in US dollars per bushel. In addition, we study the European spot price for sunflower and rapeseed oils with North West Europe Ex-Tank sunflower oil in dollars per metric ton and Rotterdam Ex Mill rapeseed oil in euro per metric ton. This latter price is converted into dollars using the daily EUR/USD exchange rate from Thomson Reuters. For biofuels, we use the US monthly production in thousand barrels, and we turn it into daily data by quadratic interpolation. Unfortunately, to our best knowledge, neither EU nor Brazil biofuels production data are available at a monthly frequency. Moreover, we account for economic activity by integrating the composite Standard & Poor's SP500 index. Due to a lack of data for sunflower and rapeseed oils, we investigate their relationship with oil from 12/04/2001 to 11/28/2014 (i.e., 3389

[7] The other variables were time, oil and coarse-grain stock levels.

observations). For the other commodities, the period under study begins on 01/02/1986 (i.e., 7545 observations). Note that all price series are log-transformed, the corresponding estimated coefficients thus representing elasticity between prices. All series are displayed in Figure 2.

Insert Figure 2

Insert Table 2

Table 2 presents the descriptive statistics for the growth rates of the different variables used for the entire period, and for pre- and post-2006 periods; this date marking a break.[8] Concerning the 1986-2014 period, the prices of corn, wheat and soybean increase on average by 0.01% per day, with standard deviations of 1.91, 1.61 and 2.21, respectively. Note that this growth was lower in the first period, with a zero growth rate, than in the second, in which prices rose by 0.03% for corn and 0.02% for the other two agricultural commodities previously mentioned. In addition, the standard deviations of these growth rates are higher in the second period, reflecting the greater price volatility since 2006. The sunflower oil price evolved similarly. From 2001-2014, it increases by 0.01% per day, against -0.01% and 0.02% for the pre- and post-2006 periods, respectively. The rapeseed oil price has an inverse evolution. It increases faster in the first period, with an average rate of 0.04%, than in the second, at 0.01%. Moreover, these prices have characteristics specific to financial variables with negative skewness and high kurtosis. These characteristics indicate that these prices are subject to more negative, large-scale fluctuations than the normal law would predict. The oil price increases on average by 0.01% per day over the entire period, with a higher growth rate in the pre-2006 period. Its volatility is also higher over this period. Statistics from US biofuels production reflect its development. The production growth was 0.04% per day before 2006 and 0.06% thereafter. For the SP500 index, the crisis affected its evolution. Indeed, its average daily growth rate was 0.03% before 2006 compared to 0.02% thereafter.

[8] Gilbert (2010) used this break date to highlighting the beginning of the increase in food commodity prices.

3.2 Methodology

3.2.1 Preliminary tests

Before performing our study on the role of biofuel production to investigate a possible evolution of the oil-price effect on agricultural commodity prices, it is necessary to (i) determine the series integration order, (ii) test for nonlinearity related to biofuels, and (iii) determine its form.

As a first step, we study the series' integration degree by performing ADF (1981), Phillips-Perron (1988) (hereafter PP), and KPSS (1992) unit root tests. To account for the presence of a break, the Zivot and Andrews (1992) and Perron (1997) tests, hereafter ZA and P, respectively, are also implemented.

Prior to the estimation of our nonlinear specification, we rely on the Terasvirta (1994) procedure to test for the presence of nonlinearity and determined its functional form. To this end, we estimate the following equation using Ordinary Least Squares:[9]

$$AP_{i,t} \approx \theta_{1i} + \theta_{2i}.OP_t + \theta_{3i}.OP_t.B_t + \theta_{4i}.OP_t.B_t^2 + \theta_{5i}.OP_t.B_t^3 \qquad (1)$$

where AP_i denotes the price of agricultural commodity i, OP is the oil price, B stands for the biofuel production, and θ_{ji}, for $j = 3,4,5$, are the parameters related to the nonlinearity. The first step of this procedure consists of testing the joint significance of these parameters via a Fisher-type test of restricted model against no restricted model, i.e., linearity against nonlinearity. If nonlinearity presence is confirmed, the second step allows us to determine its shape by choosing between the exponential and logistic functions.[10] More specifically, we successively test the following hypotheses:

$$H_{01}: \theta_5 = 0 \text{ against } H_{11}: \theta_5 \neq 0 \qquad (2)$$

[9] To simplify this procedure, we remove the SP500 index from the equation. Indeed, only the nonlinearity of the oil-price effect interested us.

[10] For further details on this functions, see Terasvirta (1994).

$$H_{02}: \theta_4 = 0 \mid \theta_5 = 0 \text{ against } H_{12}: \theta_4 \neq 0 \mid \theta_5 = 0 \quad (3)$$

$$H_{03}: \theta_3 = 0 \mid \theta_4 = \theta_5 = 0 \text{ against } H_{13}: \theta_3 \neq 0 \mid \theta_4 = \theta_5 = 0 \quad (4)$$

where the H_{01} rejection induces the use of the logistic function, the H_{02}-only rejection entails the exponential function utilization, and the rejection of H_{03} leads to the choice of the logistic function.

Once the preliminary study was done, we can investigate the oil-price effect on agricultural commodities and the effect of biofuels on the oil-price effect. For this analysis, it is crucial to consider the possibility of different effects in the short- and long-term using a cointegration approach.

3.2.2 Long-term oil-price effect

To investigate the long-term relationship between the oil price and each agricultural commodity price *i*, we consider the smooth transition regression model:

$$AP_{i,t} = (\alpha_{1i} + \alpha_{2i}.OP_t + \alpha_{3i}.SP_t) + (\beta_{1i} + \beta_{2i}.OP_t + \beta_{3i}.SP_t).g(\gamma_i, c_i, B_t) + u_{i,t} \quad (5)$$

To control for the economic activity effect, we include the SP500 index, noted as SP. The first part of the equation represents long-term oil and economic activity effects on agricultural commodity prices, whereas the second part also accounts for the effects related to the quantity of biofuels produced. This last effect depends upon the value taken by the transition function g, ranging between 0 and 1. This function is characterized by the transition speed, γ, and the threshold, c. For the estimation, we use the maximum likelihood estimator of Fisher (1912).

To test for cointegration, we perform the Shin (1994) and Choi and Saikkonen (2010) tests, hereafter S and CS. The S test corresponds to the KPSS test applied on the residuals of the cointegration relationship, whereas the CS test is a modification of the S test to improve its empirical power in the nonlinear framework. The CS test is an implementation of the KPSS test on sub-samples and the choice of the maximum test value.[11]

Next, we perform an exclusion test to check the oil inclusion in the possible cointegration relationship. Indeed, with the use of the SP500 index, we have three variables in the cointegration vector, which is problematic because the latter may include only two variables instead of three. Although the multivariate approach seems to be more adequate in this context, we prefer to use an exclusion test via the likelihood ratio test, which allows us testing the null hypothesis of the oil-price exclusion in the cointegration vector against the inclusion alternative hypothesis.

3.2.3 Short-term oil-price effect

Finally, if cointegration is obtained, we estimate the corresponding Error Correction Model (ECM) by Ordinary Least Squares:[12]

$$\Delta AP_{i,t} = \delta_{1i}.\Delta OP_t + \delta_{2i}.\Delta SP_t + \pi_i.\hat{u}_{i,t-1} + v_{i,t} \tag{6}$$

where $\hat{u}_{i,t-1}$ denotes the cointegration relationship residuals, and $v_{i,t}$ are i.i.d Gaussian errors. In the case of no cointegration relationship, a simple equation of the short-term relationship is estimated. We perform misspecification tests, such as Jarque-Bera (1980), White (1980) and Ljung-Box (1978) tests. In addition, we apply an iterative version of the Chow (1960) test from 06/01/2007 to 12/31/2009 to account for the recent crisis effect. This period corresponds to the economic crisis period defined by the NBER, extended by 6 months before and afterward. This extension allows us to account for the subprime crisis outbreak and the beginning of the post-crisis period. We retain the break date that corresponds to the strongest rejection of the null hypothesis of stability.

[11] For more details on the procedure including the block size choice, see Choi and Saikkonen (2010). The critical values used were calculated by Hong and Wagner (2008).

[12] Note that, as mentioned by Gohin and Chantret (2010), the oil-price effect is unlikely to appear in the short-term. Thus, in the case of a short-term effect, the oil-price effect could hardly be considered a price effect, and it might be a speculation effect for instance. Therefore, we do not include nonlinearity in the short-term relationship.

4 Empirical Results

We now present the results corresponding to the application of the tests and methods previously presented.

4.1 Preliminary tests

The detailed unit root test results are available in Table 3. All of the agricultural commodities prices series are stationary in their first difference, regardless of whether a break date is considered, as well as the SP500 index.[13] Biofuel production and oil price series are integrated of order 1. For the latter, the various tests are in contradiction due to the presence of a break in 2003.

Insert Table 3

The Terasvirta (1994) procedure allows us to verify the relevance of our modeling choice. The first step should confirm our intuition of a biofuel production evolution impact on the oil-price effect. The results, presented in Table 4, confirm the nonlinearity presence for the five equilibrium relationships. Indeed, for each agricultural commodity, the test of linearity against nonlinearity presents a test statistic greater than the 5% critical value. This result confirms the existence of an effect of biofuel production on the link between oil and agricultural commodity prices. With the second step, we could determine the transition function form. Considering that biofuel development could cause the emergence or increase of the link between oil and the studied agricultural commodities, the logistic function seems more appropriate. In successively rejecting the three null hypotheses of Student's t tests, this second step concludes that the logistic function is adequate to represent this nonlinearity, in line with our intuition.

[13] However, this was not true for the 2001-2014 period, in which it was zero order integrated with a rupture in 2008. The ZA and P tests yielded, respectively, statistics of -5.79 and -5.76 for a 5% critical value of -5.08 and -5.59, with a break in intercept and trend for 08/29/2008 and 08/28/2008. These results are surprising. Unfortunately we must consider them to be I(1). Indeed, one known property of financial variables consists of being non-stationary for prices and stationary for returns.

Insert Table 4

4.2 Long-term oil-price effect

Knowing the shape of the function representing the nonlinearity associated with biofuel production, we are able to investigate the long-term relationship. Before interpreting the estimation results, we focus on the test conclusions. Afterwards, we concentrate our analysis on three points: the elasticity of agricultural commodity prices with oil prices with and without biofuel production and the dynamic of the oil-price effect. Recall that the SP500 index allows us to account for the economic environment, but its effect on commodity prices is not the subject of the present study. The value of the biofuel production threshold, $\hat{c}$, indicates when the transition function takes the value of 0.5. We prefer to subsequently interpret the value causing the appearance of the biofuel production effect on the price effect between oil and commodities and the moment when it is maximal.

4.2.1 Cointegration evidence

Existence of the cointegration relationship would allow us to highlight an equilibrium relationship in which we consider that the oil price affects the agricultural commodity prices. Indeed, various studies have already shown that oil prices cause agricultural commodity prices in the long-term relationship.[14]

Table 5 displays the cointegration and exclusion test results. On the one hand, the S test unambiguously confirms the presence of a cointegration relationship between the oil price, the SP500 index and each agricultural commodity price. On the other hand, the CS test is less categorical. The null hypothesis of cointegration is rejected for the corn and wheat relationships. However, it is also possible to interpret this result as a larger persistence of deviations from equilibrium for these commodities. Indeed, this problem is amplified by sub-sample use. Thus, we consider that all relationships are cointegration relationships. Finally, the exclusion test confirms the oil price

[14] See, e.g., Nazlioglu and Soytas (2012).

presence in the cointegration space for each relationship and, therefore, the existence of long-term oil-price effects on agricultural prices.

Insert Table 5

On the whole, our findings show that there is a long-term oil-price effect on the agricultural commodities price for each agricultural product studied.

4.2.2 Oil-price effect without biofuel production

Upon verifying the cointegration relationship between agricultural commodities and oil prices, we focus on the estimated coefficients of equation (5) presented in Table 5. The oil effect column represents the value of the elasticity between the prices of oil and the agricultural commodity, noted as α_{2i}, whereas the oil-biofuel effect column is the additional oil-price effect linked to higher biofuel production, β_{2i}.

In the absence of biofuel production, the commodities studied could be classified into three categories. Soybean, rapeseed and wheat have positive price elasticities with oil price: for a 10% increase in the oil price, the prices of wheat, soybean and rapeseed increased by 0.92%, 0.24% and 4.52%, respectively. Sunflower has price elasticity with oil that is non-significantly different from zero, meaning that its price would be independent from that of oil. Corn provides an interesting case. Its price elasticity is significantly negative, a rise in oil price of 10% would lead to a 1.13% decline in its price.

The difference in the oil-price effect between commodities can have two main causes: the oil products used in the production process and income elasticity. The oil-price effect on commodity prices depends positively upon oil-related production cost share in total costs. Therefore, we study the production cost linked with energy and fertilizers; the latter have strong price elasticity with the oil price.[15] In parallel, the oil-price effect is inversely proportional to agricultural commodity income elasticity. However, because this value is lower for food goods,

[15] According to Baffes (2007) and (2010) the elasticity between fertilizer and oil prices was 0.33 and 0.55 over the periods 1960-2005 and 1960-2008, respectively.

it is necessary to consider the income effect via meat. Indeed, the income elasticity for meat is higher.[16] Thus, the effect of income variation on agricultural commodity prices depends positively upon the portion of animal feed used overall. Finally, the oil-price effect could decrease, or become negative, when the share of animal feed of total demand increased.

We face one problem. To our knowledge, European farm data for sunflower and rapeseed are not available. However, according to our estimation results, it appears that the rapeseed crop requires a higher amount of oil-based product, and/or its animal feed use in the total would be of low importance. To explain this difference, we note that rapeseed requires a large amount of nitrogen during its culture and is a major consumer of fertilizer.[17]

For corn, soybean and wheat, USDA data[18] allow us to interpret the results in detail. We calculate the share of oil-based production costs in total. All of these calculations are presented in Appendix 1. For example, the oil-based cost shares for these commodities in 1990 were 53.01%, 29.20% and 48.85%, respectively. Between 1986 and 2014, the soybean crop is a low consumer of oil-dependent input in comparison to wheat. This fact explains the lower oil-price effect for soybean relative to wheat. However, this cost channel does not explain the negative-price effect for corn given the magnitude of the share of oil dependence. We calculate the share of production allocated to animal feed. Specifically, that share is the ratio of “feed and residual use" to total domestic use. For the 1990-1991 period, soybean and wheat have a small proportion of use in animal feed, apparent in Appendix 2, with various other uses. This share is approximately 7.45% and 35.34%, respectively.[19] In contrast, corn is used at approximately 76.38% of animal feed. Thus, when the oil price increases, economic activity slows or decreases. This effect is accompanied by a decrease in income and meat consumption. In the long term, producers should reduce production to maximize

[16] For example, Gallet (2010) lists 3357 income elasticities for several meats estimated in 393 studies to investigate the estimation method effect and other features of estimated value. The average income elasticities for beef, poultry, pork and lamb were approximately 1, 0.82, 0.8 and 0.74, respectively.
[17] Rapeseed requires between 140 and 200 units per hectare of nitrogen against 80 for sunflower.
[18] Data are available for each agricultural commodity in these two tables: “Commodity Costs and Returns” and “Supply and disappearance”.
[19] In the case of wheat, this share may seem high, but the average is 18.7% over the 1986-2014 period.

profits, causing a drop in corn demand and therefore its price. This process is relatively long, explaining a slower return of corn price to its equilibrium. This slower return corresponds to the CS test results yielding an absence of a cointegration relationship for corn. These data confirm the estimated coefficient and support the assertion that a negative-income effect prevails over the cost effect in the case of corn, unlike for other commodities.

Thus, we provide new evidence of the existence of a long-term positive effect of oil prices on commodity prices for three agricultural products, and a negative price effect for corn.

4.2.3 Oil-price effect with biofuel production

We now focus on the oil-price effect linked to biofuel production. Our results suggest that a 10% increase in oil price would cause a rise in corn, soybean and rapeseed demand for biofuel production, with a respective effect on their prices of 9.3%, 4% and 3.65%. For wheat and sunflower, their prices increased by 3.98% and 8.85%, respectively. Note that these results are valid when biofuel production exceeds the threshold, leading to a maximum price effect through the biofuels channel, and the original oil-price effect is not considered. With the latter, the corn, soybean and rapeseed price increased by 8.17%, 4.24% and 8.17%, respectively. For wheat and sunflower, their rise was 4.9% and 8.85%.

Let us study initially the cases of corn, soybean and rapeseed. Corn is the main feedstock used in US ethanol production. Because the latter is found more frequently in this country than biodiesel production, it is normal for the oil-biofuel effect to be high in the corn price formation mechanism.[20] The very high value of the oil-biofuel effect for corn, compared with soybean and rapeseed, can be explained by two other reasons. First, the biofuel sector used approximately 46% of the corn consumed in the US in 2011-2012 against 27%[21] for soybean. The dependence is therefore stronger between corn and biofuels. Second, the share of

[20] Despite the rapid development of biodiesel production since 2001, ethanol production still accounts for approximately 90% of biofuel production in the United States.
[21] To be more specific, it is the soybean oil ratio. However, 94% of US soybean consumption took the form of oil in 2012.

corn consumption for animal feed fell from 74.24% in 1995-1996 to 41.68% in 2012-2013, whereas it decreased only from 7.5% to 5.87% in soybean. The income effect, highlighted previously, has declined for corn. The additional oil-price effect was comparable between soybean and rapeseed. In 2013, they accounted for approximately 53% of biodiesel production inputs in the European Union and the United States. Unfortunately, the detailed data do not seem to be available for European rapeseed.

The cases of wheat and sunflower are even more interesting. Indeed, these two commodities are rarely used in biofuel production; their main remaining use is food. However, these results can highlight two indirect effects of biofuel production through the substitution effect. On the one hand, rising corn prices after the increase of biofuel production caused a food consumption diversion of corn to wheat and caused wheat prices to rise due to the substitution effect of demand. This effect could be observed in the increase in the share of wheat used in food from an average of 66% between 1986 and 2000 to 79% over the 2001-2014 period. On the other hand, the rise in corn prices may have caused a diversion of wheat producers to corn crops that decreased the wheat supply and raised its price. This last channel was encouraged by the fact that crop rotation, in particular wheat to corn, is good for the soil balance. Note that this substitution effect is very important for sunflower, with an oil-price effect linked to biofuels near 0.9. This importance is due to a stronger substitutability between vegetable oils compared with cereals.

Our study shows that biofuel production has led to the increase, or the appearance, of a long-term oil-price positive effect on each commodity studied.

4.2.4 Biofuel production effect dynamic

Let us now study the evolution of the oil-price effect. As previously mentioned, an important advantage of the chosen methodology is the possibility to analyse the oil-price effect dynamic.

Insert Figure 3

As seen from Figure 3 above, as long as the daily biofuel production was less than approximately 200,000 barrels, i.e., before 2002, the oil-price effect did not increase for corn. This situation corresponds to a share of corn used in this sector compared with total domestic consumption of less than 10%. Once this threshold was exceeded, the oil-price effect with biofuels channel appeared. The oil-price effect reached its maximum at a daily production of nearly 1.4 million barrels, attained in 2011. On this date, corn consumption related to biofuels achieved 45%. Note also a relatively slow evolution of the oil-price effect for corn with the lowest transition speed parameter, 5.491, compared with other commodities. This result is due to the low growth of ethanol production in 2002-2011 compared with biodiesel, with an average monthly growth rate of 1.9% against 6.5% for biodiesel. An extremely interesting point visible on the previous figure is the proximity between the appearance of the oil-biofuel effect for wheat and the switch to a positive oil-price effect for corn and the relative parallelism between the two slopes. This confirms the substitution between these two cereals.

Insert Figure 4

Figure 4 presents the oil-price effect dynamic for the last three commodities. The transition speed between the two extreme regimes is higher for soybean than for corn and is related to the difference in development speed between ethanol and biodiesel in the United States. This situation is difficult to interpret in the case of rapeseed and sunflower. Indeed, their parameters are both very high, indicating a fast transition, and non-significant, suggesting a lack of nonlinearity. This problem is most likely due to the difference in time between US and EU biodiesel production development. Development was very strong in 2005 and 2006 in the US, with annual respective growth rates of 225% and 176%, whereas it was slower and spread out over time in the EU. It experienced a growth rate of 40% to 50% from 2004-2007. The oil-biofuel effect for soybean appeared in 2005 when the consumption of this sector in soybean oil reached almost 10% of domestic use. The price effect was maximal for a use rate of 20%. The proximity at the onset of this effect for rapeseed and sunflower suggests that there has been a substitution in oil food consumption in the European Union. However, this point should be checked with a study based on European consumption data.

4.3 Short-term oil-price effect

Having highlighted the long-term oil-price effect on agricultural commodity prices and having described the biofuel production effect on this oil-price effect, we now focus on the short-term oil-price effect with the estimation of equation (6). Table 6 presents the ECM estimation results with the associated break test.[22] The oil effect column represents the value of the short-term elasticity between the prices of oil and the agricultural commodity, noted as δ_{1i}, whereas the adjustment coefficient column is the estimator for the adjustment speed, π_i.

Insert Table 6

As shown, a weak positive oil-price effect exists in the short term, except for sunflower. Having used daily data, we can surmise that this effect comes from the speculation channel. Indeed, as we mentioned previously, Gohin and Chantret (2010) stated that the oil-cost effect should not be visible in the short term. In a period of rising oil prices, agents expect an increase in the agricultural commodity prices and make purchases on agricultural markets. As expected, the adjustment coefficient is negative, highlighting the return to an equilibrium process. When the commodity price is above its equilibrium level, the adjustment force tends to decrease that price. However, this process is relatively low given the value of the coefficient. The half-life of the deviation from equilibrium is approximately 46 weeks for corn, 35 for soybean and wheat and 23 weeks for rapeseed.[23]

The break test results allow us to check for a rupture occurrence in the relationship during the last recession. If the date mentioned was one of the limits of the period used, either 06/01/2007 or 12/31/2009, this would indicate that a larger rupture most likely occurred upstream or downstream of the crisis. The break dates for corn and rapeseed, 9/11/2007 and 8/22/2007, respectively, are interesting. Indeed, the relationship change for rapeseed occurred nine days after

[22] Regarding misspecification tests, note that despite the addition of dummies, the non-normality of residuals could not be corrected. Heteroscedasticty and autocorrelation issues are corrected using the White correction and lagged endogenous variables.

[23] The adjustment coefficient for sunflower being not significant, we did not calculate the half-life for this commodity.

an important liquidity injection by several central banks.[24] For corn, the break date was five days after a similar action.[25] It is possible that this liquidity led to a speculative rise in financial and agricultural markets. The break dates for soybean, wheat and sunflower did not correspond to any events, to our knowledge.

5 Conclusion

Given the rise in the prices of agricultural commodities in the last decade, this paper aims at investigating the effect of first-generation biofuel development on agricultural commodity prices via the oil-price effect. To this end, we rely on the estimation of a nonlinear, smooth transition regression model for five agricultural commodities.

Our key findings can be summarized as follows. First, the main conclusion is that there is a positive effect of biofuel production on agricultural prices. This effect confirms that biofuel production has been one of the key causes of agricultural price increases in recent years. Second, the biofuels effect is not confined to agricultural commodities used in its production; rather, it is transmitted to other agricultural markets through the substitution effect. Third, in the absence of biofuel production, there is a long-term positive oil-price effect, with a low magnitude, on some agricultural commodities prices. Fourth, corn prices are characterized by a long-term negative oil-price effect through the income channel. Finally, there is a weak positive short-term oil-price effect on agricultural prices, with a break during the last crisis.

Our results have important policy implications. They suggest that it is urgent to reduce first-generation biofuel production by accelerating the introduction of second-generation biofuels. Such acceleration would have no effect

[24] This liquidity injection was 35 billion dollars by the US Federal Reserve and 3.75 and 61 billion euros by the Japanese and European central banks, respectively. It occurred on 08/13/2007.

[25] The US Federal Reserve and the European Central Bank injected, respectively, 31.25 billion dollars and 42 billion euros on 9/06/2007.

on agricultural commodities prices because the production of second-generation biofuels only uses agricultural plant residuals and non-food plants.

As a possible extension and given the presence of a break in the short-term relationship during the last recession, it would be interesting to check the presence of nonlinearity in the short-term oil-price effect with respect to various financial variables.

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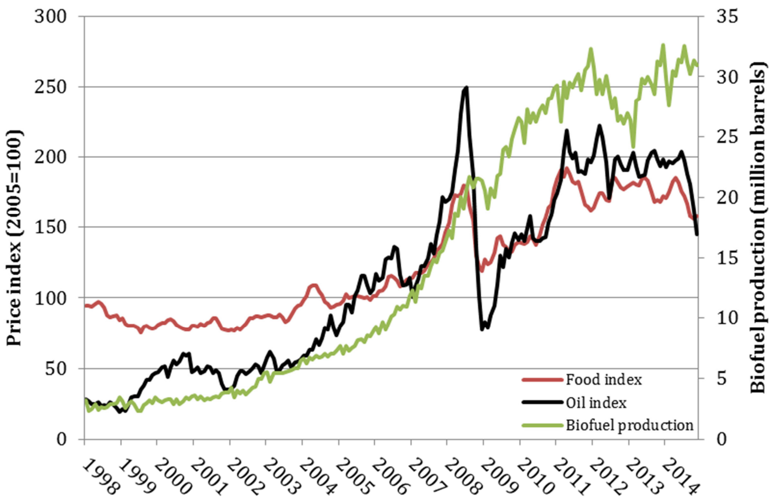
Figure 1 – Oil and food index evolution and biofuel production



Source: IMF and EIA

Table 1 – Summary of the literature on the oil-price effect

Paper	Period	Data	Methodology	Results
Yu et al (2006)	1999-2006	Palm, soybean, sunflower and rapeseed oils	Johansen (1991) cointegration	No short- or long-term oil-price effect
Campiche et al (2007)	2003-2007	Corn, sorghum, palm and soybean oils	Johansen (1991) cointegration	No long-term oil-price effect for the whole period but existence of a long-term oil-price effect on corn and soybean oil over 2006-2007 period
Zhang and Reed (2008)	2000-2007	Corn, pork and soybean meal	Johansen (1991) cointegration	No long- or short-term oil-price effect
Kaltalioglu and Soytas (2009)	1980-2008	Food and non-food commodities	Johansen (1991) cointegration	No long-term oil-price effect but weak short-term oil-price effect
Kwon and Koo (2009)	1998-2008	Agricultural commodities	Long-term Toda and Yamamoto (1995) and Dolado and Lutkepohl (1996) causality	Existence of a long-term causality relationship of oil price on agricultural commodity prices
Harri et al (2009)	2000-2008	Corn, cotton, soybean, soybean oil and wheat	Johansen (1991) cointegration with overlapping time periods	Appearance of a long-term oil-price effect on corn in April 2006
Zhang et al (2010)	1989-2008	Corn, soybean, sugar, rice and wheat	Johansen (1991) cointegration	No long- or short-term oil-price effect
Peri and Baldi (2010)	2005-2007	Soybean, sunflower and rapeseed	Johansen (1991) cointegration and Hansen and Seo (2002) threshold cointegration	Existence of a long-term diesel price effect on rapeseed with nonlinear adjustment
Nazlioglu and Soytas (2011)	1994-2010	Corn, cotton, soybean, sunflower and wheat	Long-term Toda and Yamamoto (1995) causality, LA-VAR model	No long-term oil-price effect and a short-term oil-price effect only on cotton
Natanelov et al (2011)	1989-2010	Cocoa, coffee, corn, rice, soybean, soybean oil, sugar and wheat	Johansen (1991) cointegration and Hansen and Seo (2002) threshold cointegration	For the whole and 2002-2010 periods, existence of a long-term oil-price effect on wheat; existence of this effect for corn, wheat and soybean oil for
Penaranda and Ruperez-Micola (2011)	1988-2009	Agricultural commodities	Price growth rate estimation, threshold regression and Bai and Perron (1998, 2003) break test	Existence of a break date in the relationship between 2003 and 2005, with a short-term oil-price effect appearance or increase for biofuel
Nazlioglu and Soytas (2012)	1980-2010	Agricultural commodities	Panel Pedroni (1999) cointegration	Existence of a long-term oil-price effect on all commodities
Bremond et al (2014)	2000-2011	Agricultural commodities	Pedroni (1999), Westerlund (2007) cointegration	No long-term oil-price effect but existence of a low short-term oil-price effect
Myers et al (2014)	1990-2010	Corn and soybean	Johansen (1991) cointegration and Gonzalo and Pitarakis (2002) criterion	No short- or long-term oil-price effect and no nonlinear effect

Figure 2 – Agricultural commodities, oil prices and biofuel production evolution in log

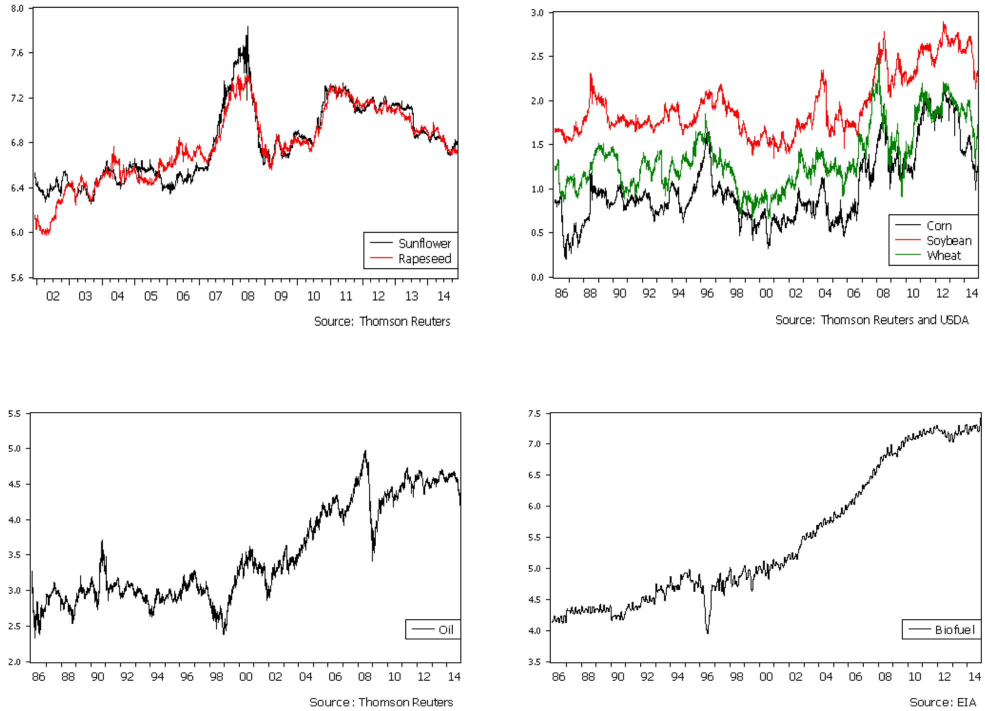


Table 2 – Daily growth rate statistics

		Corn	Soybean	Wheat	Oil	Biofuel	SP500	Sunflower	Rapeseed	
Average (percent)	1986-2014	0.01	0.01	0.01	0.01	0.04	0.03	0.01	0.02	2001-2014
	1986-2005	0.00	0.00	0.00	0.02	0.04	0.03	-0.01	0.04	2001-2005
	2006-2014	0.03	0.02	0.02	0.00	0.06	0.02	0.02	0.01	2006-2014
Standard error	1986-2014	1.91	1.61	1.61	2.47	1.03	1.15	2.55	1.90	2001-2014
	1986-2005	1.64	1.56	1.56	2.54	1.12	1.07	1.57	2.08	2001-2005
	2006-2014	2.42	1.73	1.73	2.29	0.80	1.32	2.88	1.81	2006-2014
Skewness	1986-2014	-0.34	-0.85	-0.85	-0.79	0.06	-1.31	-0.19	-0.45	2001-2014
	1986-2005	-0.42	-0.70	-0.70	-1.05	0.14	-2.09	0.50	-0.81	2001-2005
	2006-2014	-0.26	-1.09	-1.09	0.02	-0.35	-0.34	-0.24	-0.21	2006-2014
Kurtosis	1986-2014	19.39	27.73	27.73	18.87	59.48	31.91	133.64	19.70	2001-2014
	1986-2005	8.42	37.15	37.15	21.38	57.64	48.07	13.79	30.92	2001-2005
	2006-2014	20.53	13.05	13.05	9.56	38.59	13.72	117.92	10.10	2006-2014

Table 3 – Unit root tests

		ADF	PP	KPSS	ZA	P
Levels	**Biofuel**	2.596(3) -1.941	2.570(3) -1.941	2.233(1) 0.146	-4.541 -5.080 12/04/1995(B)	-4.562 -5.590 12/01/1995(B)
	Crude oil	-3.768*(1) -3.410	-3.607*(1) -3.410	1.557(1) 0.146	-4.615 -5.080 09/24/2003(B)	-4.616 -5.590 09/23/2003(B)
	SP500	2.352(3) -1.941	2.457(3) -1.941	1.876(1) 0.146	-3.183 -4.930 12/09/1994(I)	-3.153 -5.230 12/09/1994(I)
	Corn	-0.532(3) -1.941	-0.524(3) -1.941	1.208(1) 0.146	-4.293 -4.930 08/23/2006(I)	-4.334 -5.230 08/22/2006(I)
	Soybean	0.187(3) -1.941	0.155(3) -1.941	1.554(1) 0.146	-4.411 -4.930 10/02/2006(I)	-4.455 -5.230 09/29/2006(I)
	Wheat	-0.351(3) -1.941	-2.427(2) -2.862	1.180(1) 0.146	-4.601 -4.930 04/26/1996(I)	-4.505 -5.230 04/25/1996(I)
	Sunflower	0.287(3) -1.941	0.260(3) -1.941	0.507(1) 0.146	-3.607 -4.930 03/30/2007(I)	-3.475 -5.230 03/29/2007(I)
	Rapeseed	0.574(3) -1.941	0.506(3) -1.941	0.760(1) 0.146	-2.349 -4.930 09/17/2012(I)	-2.294 -5.230 09/04/2012(I)
First-differences	**Biofuel**	-17.323*(2) -2.862	-73.269*(2) -2.862	0.132*(2) 0.463	-	-
	Crude oil	-88.458*(3) -1.941	-88.734*(3) -1.941	0.066*(2) 0.463	-	-
	SP500	-65.552*(3) -1.941	-91.404*(3) -1.941	0.142*(2) 0.463	-	-
	Corn	-89.683*(3) -1.941	-89.637*(3) -1.941	0.047*(2) 0.463	-	-
	Soybean	-92.856*(3) -1.941	-92.719*(3) -1.941	0.041*(2) 0.463	-	-
	Wheat	-92.413*(3) -1.941	-92.584*(3) -1.941	0.035*(2) 0.463	-	-
	Sunflower	-19.029*(3) -1.941	-83.923*(3) -1.941	0.119*(2) 0.463	-	-
	Rapeseed	-48.628*(3) -1.941	-73.300*(3) -1.941	0.204*(2) 0.463	-	-

Note: For all the tests, the first and second lines present the test statistic and the critical value at the 5% significance level, respectively. The number in parenthesis mentions the variables of the selected model, (1) for trend and constant, (2) for constant and (3) for none. The star mentions the stationarity of the variable. Concerning the ZA and P tests, the third line shows the break date, whereas the letter mentions the break type, (I) for intercept, T for trend and (B) for both.

Table 4 – Terasvirta (1994) procedure

	Linearity test	Terasvirta procedure			
		H_{01}	H_{02}	H_{03}	Conclusion
Corn	1579.96	-5.11	51.56	38.83	Logistic
Soybean	2291.66	-7.55	58.46	48.01	Logistic
Wheat	794.80	-14.99	35.04	27.34	Logistic
Sunflower	428.87	-31.12	3.06	15.41	Logistic
Rapeseed	184.32	-9.62	-13.58	15.83	Logistic

Note: For the Linearity test and the three hypothesis of the Terasvirta procedure, we mention the test statistics. The linearity hypothesis was rejected when the test statistic was greater than the critical value at the 5% significance level (2.61), calculated with the F-distribution for 3 and 5 degrees of freedom. For the Terasvirta procedure, the null hypothesis was rejected when the t-statistic was greater than the critical value at the 5% significance level (1.96). The rejects of $H_{01}$and H_{03} led to the logistic function use, whereas the rejection of only H_{02} indicated exponential function utilization.

Table 5 – Long-term estimation with exclusion and cointegration tests

$$AP_{i,t} = (\alpha_{1i} + \alpha_{2i}.OP_t + \alpha_{3i}.SP_t) + (\beta_{1i} + \beta_{2i}.OP_t + \beta_{3i}.SP_t).g(\gamma_i, c_i, B_t) + u_{i,t}$$

	Corn	**Soybean**	**Wheat**	**Sunflower**	**Rapeseed**
$\hat{\alpha}_1$	1.218*** (0.046)	2.074*** (0.024)	1.700*** (0.038)	4.613*** (0.560)	6.061*** (0.277)
$\hat{\alpha}_2$	-0.113*** (0.018)	0.024*** (0.009)	0.092*** (0.011)	0.048 (0.031)	0.452*** (0.014)
$\hat{\alpha}_3$	-0.011 (0.008)	-0.060*** (0.005)	-0.126*** (0.006)	0.239*** (0.091)	-0.184*** (0.043)
$\hat{\beta}_1$	-1.387*** (0.166)	-2.327*** (0.145)	-3.616*** (0.137)	1.607*** (0.567)	0.325 (0.290)
$\hat{\beta}_2$	0.930*** (0.042)	0.400*** (0.033)	0.398*** (0.030)	0.885*** (0.034)	0.365*** (0.021)
$\hat{\beta}_3$	-0.248*** (0.031)	0.179*** (0.025)	0.338*** (0.024)	-0.705*** (0.093)	-0.237*** (0.047)
$\hat{\gamma}$	5.491*** (0.550)	10.032*** (1.166)	15.539*** (3.781)	63.469 (134.935)	51.538 (61.446)
$\hat{c}$	6.349*** (0.018)	6.245*** (0.015)	6.245*** (0.015)	6.363*** (0.030)	6.216*** (0.020)
Exclusion test	827.33 5.99	416.48 5.99	416.48 5.99	1887.20 5.99	2022.68 5.99
Shin test	0.267* 0.895	0.188* 0.895	0.223* 0.895	0.345* 0.895	0.204* 0.895
Choi and Saikkonen test	2.826 (3) 2.421	1.333* (4) 2.627	2.620 (3) 2.421	1.953* (3) 2.421	2.166* (3) 2.421

Note: For the coefficients rows, the first line is the estimated coefficient. The second line indicates the standard error. The number of stars indicates the significance level, one for 10%, two for 5%, three for 1% and none in case of non-significance. For the Exclusion test row, the first line indicates the test statistic, and the second line mentions the critical value at the 5% significance level from the chi-2 distribution. The oil exclusion hypothesis of the cointegration vector was rejected when the test statistic exceeded the critical value. For the cointegration rows, the first line indicates the test statistics and the second line mentions the critical value at the 5% significance level. The star mentions the non-reject of the null hypothesis of cointegration. For the Choi and Saikkonen test, the number in parenthesis is the number of subsample.

Figure 3 – Oil-price effect for corn and wheat based on biofuel production

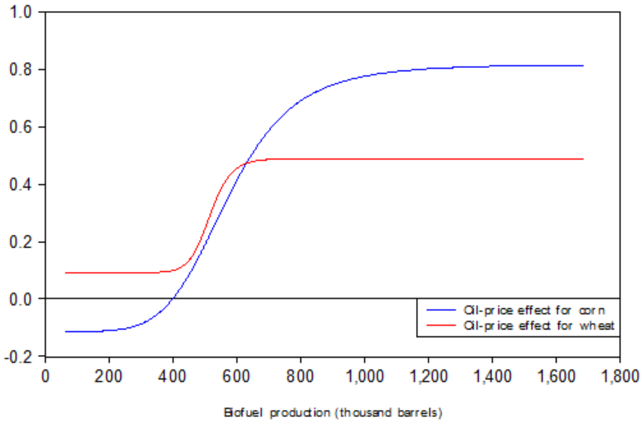


Figure 4 – Oil-price effect for soybean, sunflower and rapeseed oils based on biofuel production

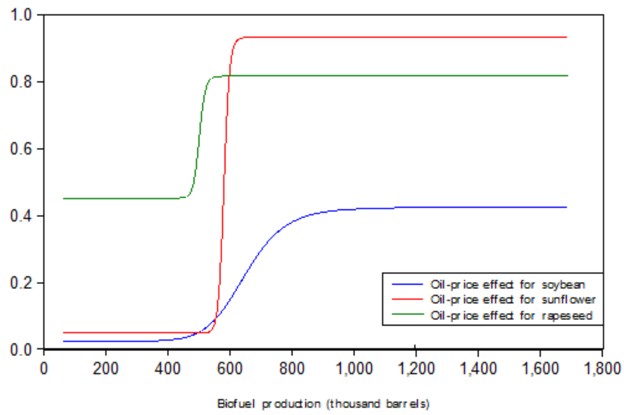


Table 6 – ECM estimation with and without corrections and break test

$$\Delta AP_{i,t} = \delta_{1i}.\Delta OP_t + \delta_{2i}.\Delta SP_t + \pi_i.\hat{u}_{i,t-1} + v_{i,t}$$

	Corn		Soybean		Wheat		Sunflower			Rapeseed	
	Without corr.	With corr.	Without corr.	With corr.	Without corr.	With corr.	Without corr.	With corr.	With corr.	Without corr.	With corr.
$\hat{\delta}_1$	0.087*** (0.009)	0.087*** (0.011)	0.071*** (0.007)	0.075*** (0.009)	0.101*** (0.010)	0.098*** (0.013)	0.021 (0.020)	0.007 (0.016)	- -	0.110*** (0.015)	0.118*** (0.018)
$\hat{\delta}_2$	0.124*** (0.019)	0.129*** (0.024)	0.086*** (0.016)	0.088*** (0.018)	0.133*** (0.022)	0.086*** (0.029)	0.077** (0.036)	0.089** (0.037)	0.092*** (0.035)	0.085*** (0.027)	0.086*** (0.029)
$\hat{\pi}$	-0.003*** (0.001)	-0.003** (0.001)	-0.004*** (0.001)	-0.004*** (0.001)	-0.005*** (0.001)	-0.004*** (0.002)	-0.012*** (0.003)	-0.004 (0.003)	-0.004 (0.003)	-0.010*** (0.003)	-0.004 (0.003)
R-square	0.020	0.112	0.018	0.139	0.021	0.104	0.007	0.495	0.495	0.028	0.187
Adj. R-Square	0.020	0.111	0.018	0.138	0.020	0.102	0.006	0.492	0.492	0.027	0.184
Jarque-Bera test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ljung-Box test	0.000	0.069	0.000	0.379	0.000	0.191	0.000	0.000	0.000	0.000	0.179
White test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	7541	7526	7541	7518	7541	7517	3388	3373	3373	3388	3373
Break test	-	09/11/2007 283.61 1.832	-	06/27/2007 16.755 1.753	-	03/04/2008 12.396 1.722	-	-	05/14/2008 2.466 1.574	-	08/22/2007 4.603 1.695

Note: The Without corr. columns mention the estimation results without correction. The With corr. columns mention the estimation results with White correction, lagged variable and dummy. For the coefficients estimated, the first line presents the estimated coefficient and the second line is the standard error. The number of stars indicates the significance level, one for 10%, two for 5%, three for 1% and any in case of non-significance. The test rows mention the p-value, the null hypothesizes of non-normality, non-autocorrelation and homoscedasticity were rejected when the p-value is lower than 0.05. The Ljung-Box test statistics were computed with 20 lags. The last row indicates, respectively, the break date of the relationship, the test statistic and the critical value at the 5% significance level.

Appendix 1: Production costs for corn, soybean and wheat

	Corn			Soybean			Wheat		
	Fertilizer	Energy	Oil cost	Fertilizer	Energy	Oil cost	Fertilizer	Energy	Oil cost
1986	36.23%	8.01%	44.23%	11.49%	15.88%	27.37%	33.69%	15.63%	49.32%
1987	34.23%	9.68%	43.90%	10.99%	18.63%	29.62%	31.34%	18.13%	49.46%
1988	39.56%	9.27%	48.83%	12.88%	17.77%	30.64%	35.09%	16.86%	51.94%
1989	37.73%	9.49%	47.22%	16.26%	12.61%	28.87%	34.75%	16.56%	51.31%
1990	33.90%	19.11%	53.01%	15.00%	14.20%	29.20%	30.57%	18.27%	48.85%
1991	34.17%	14.50%	48.66%	13.97%	14.20%	28.17%	32.56%	19.07%	51.63%
1992	32.75%	13.88%	46.63%	13.99%	12.61%	26.60%	30.28%	18.45%	48.73%
1993	32.92%	13.71%	46.64%	13.18%	12.42%	25.60%	29.59%	18.33%	47.92%
1994	33.02%	13.59%	46.60%	13.26%	11.37%	24.63%	29.74%	15.23%	44.97%
1995	37.21%	11.94%	49.15%	13.96%	10.93%	24.89%	34.06%	13.81%	47.87%
1996	32.60%	15.55%	48.15%	14.20%	12.84%	27.04%	32.32%	14.87%	47.18%
1997	31.82%	15.51%	47.33%	11.56%	9.21%	20.78%	30.31%	15.57%	45.88%
1998	29.53%	14.90%	44.43%	11.49%	7.71%	19.20%	33.19%	10.95%	44.14%
1999	27.92%	15.02%	42.94%	11.87%	7.91%	19.78%	31.65%	12.19%	43.84%
2000	26.90%	18.15%	45.05%	11.78%	11.45%	23.23%	30.45%	16.09%	46.55%
2001	34.51%	13.07%	47.59%	11.83%	10.80%	22.63%	37.43%	14.39%	51.82%
2002	29.46%	13.12%	42.58%	10.02%	9.58%	19.59%	31.30%	15.32%	46.62%
2003	31.58%	14.38%	45.96%	10.32%	11.30%	21.62%	34.33%	16.27%	50.59%
2004	31.28%	16.77%	48.05%	10.72%	11.64%	22.36%	32.50%	17.40%	49.91%
2005	44.24%	16.91%	61.15%	12.16%	15.35%	27.52%	33.49%	20.76%	54.25%
2006	46.48%	16.66%	63.13%	14.30%	14.81%	29.11%	34.26%	21.46%	55.72%
2007	48.39%	16.41%	64.79%	14.68%	14.60%	29.28%	35.93%	21.73%	57.65%
2008	55.48%	17.00%	72.47%	20.10%	16.16%	36.26%	42.13%	20.26%	62.38%
2009	49.39%	10.97%	60.37%	18.15%	10.35%	28.50%	38.45%	10.84%	49.29%
2010	39.15%	9.02%	48.17%	13.56%	12.76%	26.32%	31.71%	14.96%	46.67%
2011	44.36%	9.76%	54.12%	16.70%	15.34%	32.03%	36.38%	16.18%	52.56%
2012	44.80%	8.77%	53.57%	21.80%	12.34%	34.14%	36.39%	15.33%	51.72%
2013	43.14%	9.08%	52.22%	21.21%	11.98%	33.19%	36.03%	15.13%	51.16%
2014	41.82%	9.19%	51.02%	20.82%	11.99%	32.80%	34.53%	15.17%	49.70%

Note: The fertilizer costs include commercial fertilizer, soil conditioner and manure. The energy columns consist of fuel, lubrication and electricity costs. The oil cost is the sum of the two previous columns. All of these costs are expressed as a percentage of operating costs, including seed, fertilizer, chemicals, custom operations, energy, repairs, baling and irrigation.

Appendix 2: Feed, food and biofuel utilization for corn, soybean oil and wheat

	Corn		Soybean		Wheat	
	Feed	Biofuel	Feed	Biofuel	Feed	Food
1986-1987	79.07%	4.92%	8.28%	0.00%	33.50%	59.48%
1987-1988	79.28%	4.62%	7.46%	0.00%	26.48%	15.93%
1988-1989	75.19%	5.49%	7.70%	0.00%	15.36%	74.12%
1989-1990	76.18%	5.59%	8.10%	0.00%	14.02%	75.47%
1990-1991	76.38%	5.79%	7.45%	0.00%	35.34%	57.86%
1991-1992	75.78%	6.29%	7.56%	0.00%	21.60%	69.76%
1992-1993	77.15%	6.25%	9.13%	0.00%	17.17%	74.04%
1993-1994	74.37%	7.28%	6.95%	0.00%	21.92%	70.31%
1994-1995	76.09%	7.43%	9.63%	0.00%	26.78%	66.30%
1995-1996	74.24%	6.26%	7.50%	0.00%	13.48%	77.44%
1996-1997	75.48%	6.13%	7.64%	0.00%	23.65%	68.48%
1997-1998	74.80%	6.69%	8.84%	0.00%	19.93%	72.71%
1998-1999	74.55%	7.08%	11.22%	0.00%	28.29%	65.89%
1999-2000	74.46%	7.47%	9.48%	0.00%	21.49%	71.46%
2000-2001	74.65%	8.08%	9.31%	0.00%	22.60%	71.42%
2001-2002	73.93%	8.94%	9.06%	0.00%	15.27%	77.73%
2002-2003	70.21%	12.60%	7.52%	0.00%	10.35%	82.11%
2003-2004	69.40%	14.02%	6.66%	0.81%	16.96%	76.37%
2004-2005	69.39%	14.97%	10.21%	2.55%	15.47%	77.89%
2005-2006	66.95%	17.55%	10.29%	8.66%	13.61%	79.69%
2006-2007	61.01%	23.34%	7.99%	14.86%	10.30%	82.50%
2007-2008	56.87%	29.60%	4.93%	17.70%	1.52%	90.15%
2008-2009	50.53%	36.51%	5.99%	12.72%	21.08%	72.82%
2009-2010	46.11%	41.50%	6.01%	10.62%	12.59%	81.39%
2010-2011	42.64%	44.80%	7.24%	16.30%	7.85%	85.62%
2011-2012	41.31%	45.70%	5.06%	26.62%	13.40%	80.16%
2012-2013	41.68%	44.83%	5.87%	25.09%	26.21%	68.52%
2013-2014	43.65%	44.50%	5.33%	26.43%	17.75%	76.11%

Note: For corn, the periods began in September and ended in August. Corn's values were similar to the soybean feed column. For the biofuel column of soybean, the periods extended from October to September. For wheat, they ran from June to May. Each use is given as a percentage of domestic consumption of the commodity, excluding exports and storage, except for the soybean biofuel column, which is expressed as a percent of soybean oil domestic consumption.

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