economics for energy

This working paper has been developed within the Alcoa Advancing Sustainability Initiative to Research and Leverage Actionable Solutions on Energy and Environmental Economics

ALCOA FOUNDATION

WP FA06/2013

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www.eforenergy.org
ISSN nº 2172 / 8437

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Abstract

World agricultural markets have featured unusual price peaks and volatility in the last years. It has been argued that the previously unseen price movements in food prices are related to price peaks of crude oil, where biofuel production is suspected to have created a new link between crude oil and food prices. In this paper we present new evidence on the relationship of food and oil prices. Past investigations on this relationship have mainly applied linear cointegration analysis. However, recent methodological innovations in cointegration analysis allow for a more thorough analysis of the co-movement of commodity prices, detecting asymmetric and thresholds co-movements. These techniques give additional information about the dynamics of price relationships and can identify co-movements that earlier linear cointegration analysis could not detect. Our results indicate that increased biofuel use did indeed create new links between prices foods and crude oil, especially so for those food products that have been used to produce biofuel. This finding is surely relevant for policy-making regarding biofuels and should be taken into account when designing programs to incentivize biofuel production and consumption.

Keywords: Linear, Threshold, Cointegration, food, biofuels, crude oil

JEL classification: Q11, Q18, Q42, Q48

The authors gratefully acknowledge funding from Alcoa Foundation Advancing Sustainability Research Initiative. They are also thankful to Xavier Labandeira, José M. Labeaga, Pedro Linares and María Loureiro for their comments and advice. The usual disclaimer applies.

1. Introduction

Humankind today faces several challenges related to hunger, environmental deterioration, and lack of energy. Escobar et al. 2009, referring to Greek mythology, call these challenges the "three furia of mankind" (Escobar et al. 2009, p 1276). Several measures and policies have been set out to address these problems. One that has obvious relations to all three furia is the promotion and extended use of biofuels. Biofuels have recently been used heavily in the U.S, Brazil, and the European Union; In Europe the EU set out clear targets for biofuel use in the transportation sector - the transport sector is responsible for 57,7% of global fossil fuel use. Clearly, these biofuel initiatives are due to environmental and energy security or energy independence concerns.[1] However, almost parallel with the raise of biofuel production and use in roughly 2006, unfavorable conditions in global food commodity markets developed. Global food prices experienced new record highs and were also subject to previously unseen volatility. The FAO estimates that the spikes in food prices in 2008 added 115 million persons to the pool of people afflicted by chronic hunger. Hence, the third fury brought forward by (Escobar et al., 2009) – world hunger – aggravated. Senauer (2008) and Sari et al. (2011) point out that the consequences of high food prices are vast, leading not only to starvation itself, but also to migratory and geopolitical instability, which in turn induces new social and economic distortions.

The new developments on global food commodity markets are attributed to different sources. Abbott et al. (2009) name a mix of causal factors that triggered the first food price spike in 2008: low harvests due to unfavorable weather conditions, the exchange rate of the dollar, and high oil prices and increased biofuel use. The view that biofuels have created a new link between oil and food products and that oil price peaks are transferred into food commodity markets is supported by various other authors.[2] The question whether and how the prices of food commodities and oil are linked and what part biofuels play in such a possible link has been one of the most debated topics in energy and agricultural economics during the last years (Zilberman et al., 2013).

In this paper we summarize basic facts about biofuels and the new link of oil and food prices. We summarize the results of previous literature on the price links between food commodities and oil. Most previous research applied cointegration analysis, and the results have been incoherent. Some investigations found price links, others did not. This inconsistency of earlier evidence is believed to be due to differences in location, the frequency of the data, modeling specifications, and the particular food and fuels considered, (Zilberman et al., 2013; Hassouneh, 2012). Moreover, regarding biofuels, there is recent evidence that more and more food product prices are becoming linked with crude oil over time (Ciaian and Kancs, 2011; Kristoufek et al., 2012). Given this state of the contemporary biofuel research, we set up our

[1] Hao et al. (2013) p1; Hassouneh et al. (2012).
[2] See section 3 on previous research for sources.

analysis to provide new insight: We apply one coherent methodological approach with new superior analytical features to the prices of various food commodities and crude oil and use data after 2000 when biofuel production reached significant levels.

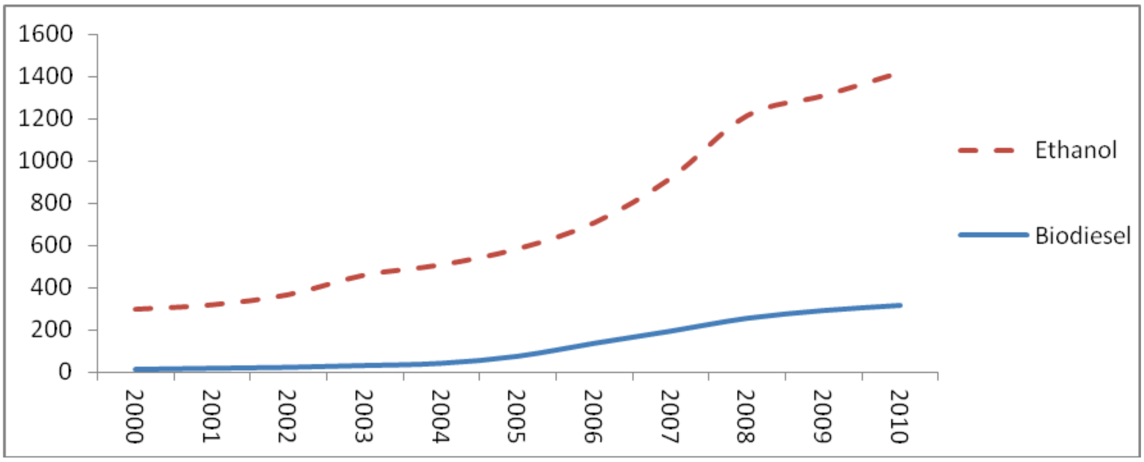
We analyze our extensive dataset of food commodities and oil prices in the same way that most previous research applied: Cointegration. However, our cointegration technique goes beyond the usually applied linear cointegration analysis. This is because linear cointegration imposes linear co-movement patterns on two series. Hence, possible nonlinear relationships remain undetected. We perform additional cointegration tests (Hansen and Seo; Enders and Siklos) that can detect more complex, non-linear relationships. We also perform analysis of possible causalities of co-movements, which give information on which of the two commodities is the leading part and which responds to changes in the other price series. This system of various cointegration and causality tests provides new information on price relationships of crude oil and food commodities, revealing relationships that earlier linear cointegration analysis were unable to detect. Moreover, including various different food commodities in the analysis allows us to draw conclusions on price transmission channels between oil and foods. This enables us to determine how much potential movements are due to biofuels and how much to other forces. The distinction is highly relevant in the light of controversially discussed biofuel policies.

The outline of the paper is as follows: In section 2 we provide an overview of recent developments in biofuels, related policies and market developments. In section 3 we summarize results of previous literature on the biofuel link between food and oil. In section 4 we present the analytical system used to investigate the relationship of food and oil prices based on a new innovative framework of cointegration tests. Results are presented and discussed in section 5. Section 6 concludes.

2. Recent developments and facts regarding biofuels

Biofuel production started approximately in 1990, but total volume and growth was modest. Biofuel production reached significant levels in 2000 approximately, starting out with ethanol and biodiesel following in somewhat later. Figure 1 illustrates world biofuel production since 2000. Ethanol can be produced from sugarcane, sugar beetroot, wheat, barley, and corn and has represented the larger part of biofuel production since 2000. Palm, rapeseed, sunflower, soy and other vegetable oils or animal fats can be transformed into biodiesel. The U.S and Brazil are the main producers of ethanol, while biodiesel is predominantly produced in the European Union.

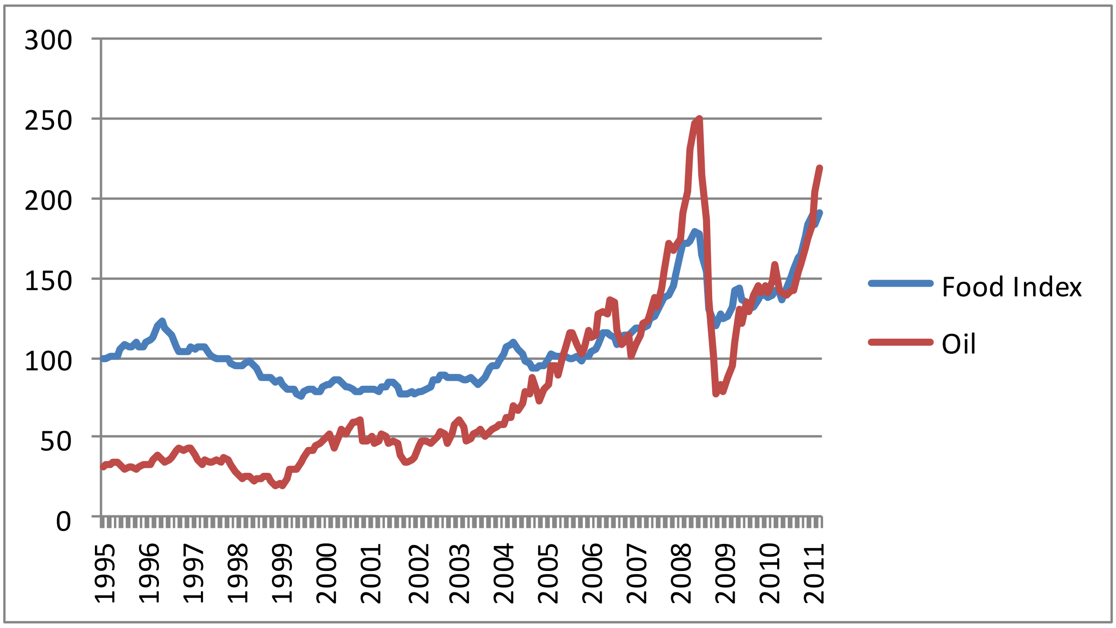
Figure 1. World biofuel production (thousand barrels per day)



Source: United States Energy Information Administration.

Interestingly, the rise in biofuel use coincides with new, undesirable events on food commodity markets. Figure 2 depicts the evolution of food commodity prices as represented by an index of various food commodities composed by the IMF together with the oil price.

Figure 2. Food and oil price evolution



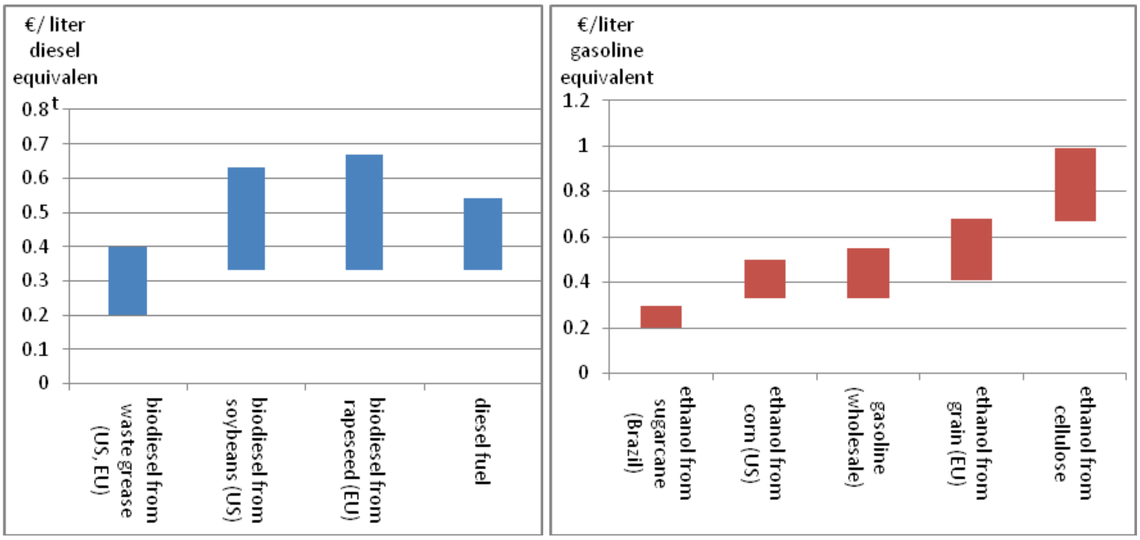
Notes: Indices based on world prices in US Dollar. Oil Price Index is the average of WTI, Brent, Fateh. The Food Price Index consists of Cereal, Vegetable Oils, Meat, Seafood, Sugar, Bananas, and Oranges.

Source: IMF.

Figure 2 illustrates various relevant developments. First, food prices were subject to price increases in the last years; there is a clear upward trend starting in 2003 or 2004. Second, since roughly 2006 food prices have moved up and down more sharply than previously; price volatility increased. Third, food prices apparently have developed a tendency to co-move more with oil prices than before. Again, this new trend is observable from roughly 2000 on.

Various theoretical considerations can be brought forward to explain a link between food and oil prices. As for almost all products, crude oil is an input factor in the value added chain of most agricultural products (machinery fuel, fertilizers, transport). Price changes in energetic inputs (like oil) are translating into price increases in the final product (the food commodity). Moreover, due to considerations of energy independence and environmental preoccupations, food products are increasingly used to produce energy in the form of biofuels (see figure 1 where this development gains momentum in 2005, approximately). Particularly in transport fossil fuels and biofuels can be used interchangeably. This added a new substitution relation between oil and food commodities which had not existed before. As fuel prices rise, converting food products into a fossil fuel substitute (thus into biofuel) becomes more attractive. WorldWatch (2006) performed calculations based on earlier work of Fulton et al. (2004) on relative costs of producing fuel from different sources (from food or from fossil sources). This is depicted in figure 3.

Figure 3. Biofuel production cost



Notes: Cost estimations for the year 2006. Diesel and biodiesel left; ethanol and gasoline right;

Source: Worldwatch (2006); Fulton et al. (2004).

The differences in the price ranges for biofuels is explained by differences in the energetic yield and growth speed of the crop, which in turn is related to climate conditions in different areas of the world (like temperature and water availability). In diesel products, the traditional fossil product is still cheaper to produce than biodiesel form soybeans (as done in the US) or biodiesel from rapeseed (as done in the EU). For ethanol, sugarcane and corn already provide highly competitive fuel alternatives. This also explains the higher ethanol production worldwide relative to biodiesel (see figure 1). Already today, there are financial incentives for farmers and food processors to convert their agricultural products into fuels instead of aliments. Further price increases of crude oil enhance these incentives, creating a potential new and stronger link between food and energy commodities than before.

3. Previous research results

The price links between food and oil prices have been mostly investigated empirically by cointegration analysis. The standard cointegration tests based on Johansen (1988) and Breitung (2001) suppose linear relationships between two series.[3]

3.1. Previous linear cointegration research on price relationships of crude oil with food commodities

Abdel and Arshad (2009) find a cointegrating relationship between crude oil and four vegetable oils with crude oil prices leading the vegetable oil prices. Zhang et al. (2010) investigate the price relationship of three different fuels with five standard food commodities. They do not find a cointegrating relationship between energy and food commodities. Yu et al. (2006) report similar results for four major traded edible oils prices. Esmaeili and Shokoohi (2010) construct a principal component of prices of different food commodities and investigate Granger causality between the food component and the oil price, among others. They do not find a direct relationship between the oil price and the food price component. In another study Chaudhuri (2001) finds that an index composed of prices of different commodities (including foods, metals, and other consumption goods) is cointegrated with the oil price. He finds also Granger causality in the direction from oil to the index. Hao et al. (2013) perform cointegration tests between biodiesel, petroleum diesel, crude oil, corn, and soybean. They find a long-run relationship between biodiesel and soybean prices. They also find corn prices to be drivers of the other commodity prices in their framework and consequently hypothesize that corn prices are a generally valid economic indicator. Ciaian and Kancs (2011) perform cointegration tests between crude oil prices and prices of various food commodities (including potential biofuel commodities and those that cannot be converted into fuel). They find cointegration relationships with oil prices for typical biofuel crops as corn and soybean from 1999 on. Hassouneh et al. (2012) find long-run equilibrium relationships between the prices of sunflower, biodiesel and crude oil based on Spanish data. Moreover, they find that energy prices influence sunflower oil prices through short-run price dynamics. Busse et al. (2012) investigate the price relationship of diesel, biodiesel, rapeseed and soy based on German data. They find that the relationships of the different commodity prices were affected heavily by regime switches of support policies.

[3] We explain these methods in more detail in section 4.

3.2. Previous non-linear (threshold, asymmetric) cointegration research on price relationships of crude oil with other commodities

Only a minor group of studies uses newer cointegration tests (based on Hansen and Seo, 2002 or Enders and Siklos, 2001) that we also use in our analysis. These methods are capable of detecting more complex co-movements of data series.[4]

Peri and Baldi (2010) apply cointegration analsysis based on Hansen and Seo (2002) and find that the cointegration relation of rapeseed and diesel prices is a case of threshold cointegration. Sunflower oil and soybean oil prices are found to have no cointegration relation with diesel, although Peri and Baldi (2010) do not apply the Ender and Siklos test to check whether these two series do feature threshold cointegration. Natanelov et al. (2011) use threshold analysis based on Hansen and Seo (2002) to investigate the price relationship of future contracts of crude oil, gold and eight food commodities. They find that only cocoa, wheat and gold move together with crude oil in the long run over the entire sample period. Elmarzougui and Larue (2011) apply linear and threshold cointegration analysis (based on Hansen and Seo, 2002) on crude oil, ethanol and corn prices. They find a cointegration relationship from 1999 on where corn and ethanol prices adjust to restore the equilibrium between corn and crude oil prices. In a comparable analysis Balcombe and Rapsomanikis (2008) find that oil prices are long-run drivers for sugar prices in Brazil, and the adjustment paths of sugar and ethanol prices after oil price impacts are nonlinear. Serra et al. (2011) apply threshold cointegration analysis to US data on corn, ethanol, oil, and gasoline prices for the US. They find a strong link between corn and energy prices, where energy price increases trigger price increases for corn through the ethanol market. Table 2 summarizes some details and results of these previous investigations.

3.3. Previous research on price relationships of crude oil with food commodities based on other related methodologies

Cointegration clearly has been the mostly used analytical method in the past. Nevertheless, recent approaches also used other tools to analyze the price links of crude oil, biofuels, and food commodities. Bastiani et al. (2013) use "bounded testing" instead of cointegration analysis, which also test for long-run relationships. In parallel they also perform short-run analysis based on Granger causality and find no evidence for interaction between prices of ethanol, crops and cattle. Kristoufek et al. (2012) construct minimal spanning trees and hierarchical trees to investigate the correlation of prices of biodiesel, ethanol and related fuels and agricultural commodities. In their approach they separate their dataset from 2003 to 2011 and find that correlations between food, biofuel, and fossil fuel prices have increased substantially.

[4] Again, consult section 4 for a description of these particular cointegration tests.

Table 2. Overview of previous studies and results

Study	Method	Data type	Data Time	Result
Abdel and Arshad (2009)	Linear cointegration, Granger causality	monthly prices: petroleum, palm oil, soybean oil, sunflower oil, rapeseed oil	January 1983 - March 2008	Crude oil prices lead vegetable oil prices
Balcombe and Rapsomanikis (2012)	Hansen and Seo threshold cointegration	weekly prices: sugar, ethanol, oil	July 2000 - May 2006	Oil prices are long-run drivers of Brazilian sugar price. Nonlinearities in adjustment of sugar and ethanol prices to oil.
Bastiani et al. (2013)	Bounded Testing, Granger Causality	monthly prices: ethanol, corn, soybeans, wheat, cattle	January 1987 - March 2012	No evidence for interaction between prices of ethanol, crops and cattle
Busse et al. (2012)	Linear cointegration, Granger causality	weekly prices: diesel, biodiesel, rapeseed oil, soy oil	July 2002 - July 2008	Different results for regimes. Biofuel policies affected price links.
Chaudhuri (2001)	Linear cointegration, Granger causality	monthly prices: 29 commodities (food, metals, other consumption goods)	January 1973 - May 1996	Important linkages between real commodity prices and oil prices. Different magnitude for each commodity
Ciaian and Kancs (2011)	Linear cointegration	weekly prices: corn,wheat, rice, sugar, soybeans, cotton, banana, sorghum and tea	1994–2008	cointegration relationships with oil prices for typical biofuel crops as corn and soybean from 1999 on
Elmarzougui and Larue	Hansen and Seo threshold cointegration	monthly prices: corn, ethanol, crude oil	January 1957 - April 2009	Corn and ethanol prices respond to crude oil prices
Esmeili and Shokooi (2011)	Linear cointegration, Granger causality	monthly prices: eggs, meat, milk, oilseeds, rice, sugar, wheat, CPI, GDP, crude oil price, food production index	1961 - 2005	No direct link of crude oil and food prices. Crude oil prices influence food prices indirectly, through food production index.
Hao et al. (2013)	Linear cointegration, Granger causality	biodiesel, petroleum diesel, crude oil, corn, soybean	2006 - 2011	Long-run relationship between biodiesel and soybean prices
Hassouneh et al. (2012)	Linear cointegration, Granger causality	weekly prices: biodiesel, sunflower, crude oil	November 2006 - October 2010	Positive long-run correlation between biodiesel and sunflower and crude oil prices.
Kristoufek et al. (2012)	minimal spanning trees and hierarchical trees	weekly and monthly prices: crude oil, ethanol, corn, wheat, sugar cane, soybeans, sugar beets, biodiesel, diesel, gasoline	November 2003 - February 2011	Growing correlations of food, biofuel, and fossil fuel prices from 2003 to 2011
Natanelov et al. (2011)	Hansen and Seo threshold cointegration	monthly future prices: crude oil, cocoa, coffee, corn, soybeans, soybean oil, wheat, rice, sugar, gold	July 1989 - Februery 2010	Cointegration between future prices of crude and future prices of: cocoa, wheat, gold. Not for the other commodities
Peri and Baldi (2010)	Hansen and Seo threshold cointegration	weekly prices: rapesead oil, soybean oil, sunflower seed oil, fossil diesel	January 2005 - November 2007	Diesel prices influence rapeseed oil prices, but not sunflower and soybean oil prices
Serra et al. (2011)	threshold cointegration	ethanol, corn, oil, gasoline	1990 - 2008	Energy price and corn prices are linked through the ethanol market. Price increases of energy trigger price increases of corn
Yu et al. (2006)	Linear cointegration	weekly prices: crude oil, soybean oil, rapeseed oil, palm oil, sunflower oil	January 1999 - March 2006	Crude oil prices have no significant influence on edible oil prices
Zhang et al. (2010)	Linear cointegration, Granger causality	monthly prices: corn, rice, soybeans, sugar, wheat, ethanol, gasoline, oil	March 1989 - July 2008	No direct link between oil and agricultural/food commodity prices. Sugar influences all other commodities

Notes: Grey rows mark those studies that also consider the possibility of non-linear cointegration.
Source: The authors

3.4. Implications of previous research for this investigation

Table 2 illustrates the variability of past results. Some of the studies summarized indicate cointegration and certain causalities, other do not.[5] Past research do not allow for a definite conclusion on whether biofuel production and consumption created a new link between food and oil prices. Additional research is necessary. A new feature of this study is the use of an extensive set of cointegration test that we explain in the following section. The combination of different cointegration analyses helps us to verify to what extent methodological techniques used in the previous literature are a source for the different results. In this way our study sheds light on how price relations really are, providing more precise information than the earlier studies summarized previously.

4. Data and methodological setup

The analytical framework was set up in order to represent market mechanism and price transmission channels between food and energy (oil) commodities in the most realistic way. Price transmission between food and crude oil can happen on the basis of different logical and theoretical grounds. First, energy is an important input in the production process of foods. Crude oil is central for the propulsion of agricultural machinery and transport of food products. This provides a clear theoretical link between prices of crude oil and food – henceforth referred to as the "input-channel". In addition the input-channel there is also the arguably new link between food and oil prices due to the increased use of food products as biofuels – henceforth referred to as the "biofuel-channel". Investigations on biofuel effects should thus intent to distinguish between these two channels, since it is only the second one that relates to the heated and morally-laden biofuel discussion on whether biofuel use in the rich countries leads to starvation in the third world. It is thus important to distinguish between the price transmission channels and design an analytical framework capable of differentiation between them to isolate real biofuel effect.

4.1 Data

We intent to distinguish possible price effects through the input-channel from those that work through the biofuel-channel by the choice of commodities whose price link with crude oil are investigated. To achieve this we create three groups of commodities. The first group consists of food products which can be (and have been) converted into biofuel: maize (corn), soybean oil, sunflower oil, palm oil, sugar. For this group both price transmission channels (input-channel and biofuel-channel) should be at work. The other groups are designed to serve as a control group where the biofuel channel should not be at work theoretically. By observing possible differences between the price links with crude oil of typical biofuel food commodities

[5] For example, Abdel and Arshad (2009); Esmeili and Shokooi, (2011); Yu et al. (2006); Zhang et al. (2010).

and other food and agricultural commodities (that are not used to produce biofuels), we can evaluate how powerful the biofuel link really is.

Logically, such food commodities that have not been used to produce biofuel are potential candidates for the control group. We therefore also investigate the price links with crude oil of wheat, rice and beef. However, even though there is no direct theoretical link with biofuels for these food products, we might argue that the biofuel transmission channel also links prices of these food commodities with crude oil indirectly, because food products (whether convertible into biofuel or not) are substitutes among each other (Lam et al. 2009). Price rises for corn - due to increased use of corn as a biofuel for example - can affect choices of producers and consumers of corn and other food commodities, thus affecting the prices of other food commodities indirectly as well. Consumers may switch to other food products, increasing demand for these other foods. Producers might slowly switch to biofuel crop production (like corn) to bank in higher prices. Moreover, Chen et al. (2010), Ciaian and Kancs (2011), and Sarris and Morrison (2009) mention the limited availability of space for agriculture. If the total production of one food or agricultural commodity rises, the farming space available to grow the other products is automatically crowded out, reducing quantity supplied and increasing prices of these other goods. These effects may reduce the usefulness of non-biofuel food products like wheat, rice and beef as a control group in our exercise. Therefore, we also install a second control group of agricultural commodities that are not edible. For these commodities only the input-channel is expected to be relevant for possible links with crude oil prices. The commodities to represent this group are rubber, coffee, and wool. By use of these three different groups of food and agricultural commodities we intent to retrieve additional information on the importance of a possible price link of food and oil price due to the increased use of biofuels.[6]

The price data on the food commodities plus crude oil were taken from the International Monetary Fund database available under www.imf.org. Previous research has shown that the pattern of commodity prices has changed approximately with the new millennium[7] and biofuel production was insignificant before. Therefore, it may affect the quality of the estimation results negatively if the investigated time span covers the period prior and after the year 2000. Consequently, our series consists of monthly data from January 2000 to April 2011 to avoid possible distortions due to these different data patterns (This gives 114 observations).

[6] Note that this set of possible price transmission channels used here to create different groups of commodities is in line with previous analysis (for example von Braun and Pachauri, 2006).

[7] See for example Chen et al. (2010), Natanelov et al. (2011), Elmarzougui and Larue (2011).

4.2 Methodology

4.2.1 The concepts of cointegration

The method to detect price co-movements in this paper is the same one that was used by most earlier research: cointegration. Cointegration means that two series, commodity price series in the case of this study, move together in the long-run; they have a common equilibrium that is observable in the long-run. Hence, part of cointegration analysis simply defines whether the two data series have such a common long-run tendency. In the short-run the equilibrium can be broken, but it will be reestablished in time. Therefore, another part of cointegration analysis is concerned with the short-run dynamics, defining how the two data series return to the common long-run equilibrium after short-run shocks. This involves calculus based on an error correction model (ECM) which then provides detailed information about the short-run dynamics of the readjustment to long-run equilibrium.

Different types of cointegration tests exist. The linear cointegration tests based on Johansen (1988) and Breitung (2001, 2002) suppose linear co-movements. This also means that the adjustment to equilibrium is always proportional to the initial shock. Moreover, no difference is made between positive and negative shocks. These rather strict assumptions can lead to wrong conclusions about cointegrating relationships. There may exist co-movements that do not fulfill the assumptions of linear cointegration, and the linear cointegration test can fail to detect relevant co-movements for that reason.[8]

A readjustment reaction to the long-run equilibrium can be conditional on the magnitude of the shock; an adjustment only takes place if a certain threshold is surpassed, for example. Such asymmetry often arises with a threshold close to zero, meaning that the asymmetric reaction regions refer to positive or negative shocks. Since linear cointegration analysis does not account for such asymmetric reactions, other cointegration methods must be employed. These methods were provided by Hansen and Seo (2002) and Ender and Siklos (2001), who test if the cointegration relationship is better described if a threshold ECM is specified, accounting for two regimes separated by a threshold.

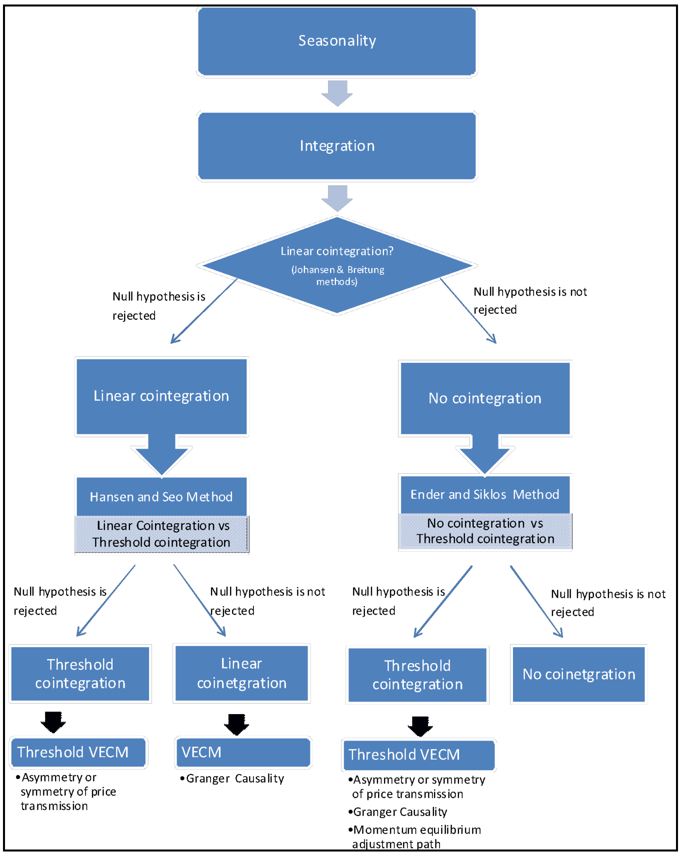
[8] Note that the large part of earlier research used linear cointegration analysis to investigate price links of energy and food commodities – see section 3. The potential to misinterpret price co-movements by sole use of linear cointegration is also illustrated by our results which are described in section 5.

4.2.2. The analytical system of tests applied in our study

A technical prerequisite to perform cointegration analysis is stationarity in the data series once first differences are taken. This *I(1)*-condition is tested for by use of the Augmented Dickey-Fuller, Phillips-Perron and Breitung test, which are all applied before starting with cointegration analysis.

The asymmetric/threshold cointegration tests mentioned above are follow-ups of linear cointegration tests. They are applied after the linear cointegration test of Johansen (1998) and Breitung (2001, 2002). This is what we do in our system of cointegration tests. If the initial linear cointegration test yields “linear cointegration” between two price series, the Hansen and Seo test can be applied to test, whether this relationship is indeed linear or whether an asymmetric/threshold relationship better describes the found cointegration. In case the initial linear cointegration test finds “no cointegration”, the Ender and Siklos cointegration test can be applied to verify whether there is indeed no relationship or whether there is cointegration of an asymmetric/threshold type (which the initial linear test could not detect due to the strict linearity assumptions). Hence, in our analysis there are always two cointegration tests applied to each pair of price series. The linear cointegration test is always performed to start with, followed by an asymmetric cointegration test either based on Hansen and Seo (2002) or Enders and Siklos (2001), depending on the finding of the initial linear test. This analytical system is visualized in figure 3.

Figure 3. Analytical system of cointegration tests



Source: The Authors

The asymmetric threshold tests also provide information about the adjustment speeds back to long-run equilibrium in case of short-run deviations. This is an important part of the analysis.

The (re)adjustments and (re)adjustment speeds require some more technical detail to explain: In general the long-run cointegration relationship can roughly be described by the following simplified condition:[9]

$$Y_t = \alpha + \beta X_t + \varepsilon_t \tag{1}$$

where Y_t represents the price of one of the non-crude oil commodities whose relationship with the crude oil price is investigated (for example the soybean oil price), X_t is the crude oil price and ε_t is the error term (the deviation). Rearranging yields:

$$\varepsilon_t = Y_t - (\alpha + \beta X_t). \tag{2}$$

The long-run equilibrium would expect ε_t to be zero, but in the short run this will frequently not be the case. The value of ε_t can be affected by the two prices. It becomes bigger, representing a positive deviation, if either Y_t is unusually high or X_t is unusually low (or both), and vice versa.[10] For Y_t and X_t to be cointegrated ε_t has to be stationary, that is –loosely speaking- the statistical properties of ε_t do not change over time. When this condition is tested and is proven to be valid, long-term equilibrium exists and even though the variables Y_t and X_t may deviate from the equilibrium in the short-term they will eventually adjust their direction and preserve the long-term equilibrium. Therefore, the second step of the analysis is concerned with the short-term white noise disturbance μ_t. Introducing this disturbance yields $\Delta\varepsilon_t = \rho\, \varepsilon_{t-1} + \mu_t$. If $-2 < \rho < 0$ is satisfied the long-run equilibrium with symmetric adjustment is accepted. Nevertheless, recent evidence indicates that this condition is often not satisfied in cases of asymmetric adjustment patterns. For these cases alternative approaches are provided, for instance by Enders and Siklos (2001) who propose two modifications to this simple model in order to test for asymmetries: a threshold autoregressive (TAR) model, and a momentum-threshold autoregressive (M-TAR) model. These specifications assume that the speed of adjustment of prices will depend on the size of the price deviation in the previous period with respect to a certain threshold τ. Deviations from the long-run equilibrium occur in two different regimes (above and below τ), and their corresponding adjustments can either have the same speed (symmetry) or different ones (asymmetry).[11]

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[9] Technically these equations are slightly different from the ones in textbooks. They have been simplified here to explain the intuition of cointegration and error correction, not the precise mechanics of the calculus. For a detailed technical description of the cointegration methods applied here consult Bakhat and Würzburg (2013).

[10] Hence the value of ε_t does not provide information about which of the prices was responsible for the short run deviation, it might be either one of them or both.

[11] If the price deviation of the previous period is below the threshold, so $\varepsilon_{t-1} \prec \tau$, the non-crude oil commodity price is below its long-run equilibrium value augmented by the value of the threshold ($Y_{t-1} \prec \hat{Y} + \tau$); and If $\varepsilon_{t-1} \geq \tau$ the

As commented before, a certain deviation value (or deviation direction) ε_{t-1} does not provide information about which of the price series caused the deviation and / or which one adjusts to reestablish equilibrium. This is of great interest, however. Two different analyses exist to shed more light on these causalities about which price is more likely to move exogenously and which is more likely to perform the adjustment movement afterwards. The first one, called "momentum equilibrium adjustment path" (MEAP) is a by-product of the ECM of the initial cointegration relationship. It is only available for threshold cointegration analysis, which is another reason why this type of cointegration analysis yields more precise results. Alternatively, the Granger causality test can also provide additional evidence as to whether, and in which direction, price transmission is occurring between oil and the other commodities. Technically, the methods provide information about which data series moves before the other. But often the results of the MEAP and Granger causality tests are used to define which price series "leads" the other.[12] Whenever the procedures applied allow MEAP and Granger causality analysis, we did calculate it and report the results.
The combination of different cointegration tests applied in this study and described above yields the maximum detail about the co-moving dynamics of data series that contemporary cointegration analysis can provide. Most earlier analysis applied much simpler analytical systems to commodity price pairs.

5. Results and discussion

Before cointegration analysis the stationarity of the first differences of each price series must be affirmed. The tests yield that the data are valid for cointegration analysis.[13]

As described in the methodology section the framework of cointegration tests can yield three different results for each pair of commodity prices (where a pair always consists of the crude oil price and the price of one of the other commodities): No cointegration, linear cointegration, and threshold integration.[14] In the following we will comment on all relevant test outcomes for each commodity pair. Table 3 also summarizes all test results for the price link with crude oil of all the food and agriculture commodities.

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non-crude oil commodity price is above its long-run equilibrium value augmented by the value of the threshold ($Y_{t-1} \succ \hat{Y} + \tau$). Therefore, if the deviation from the long-run equilibrium in the previous period is larger than the threshold τ, the speed of adjustment is then different from when the deviation is smaller than the threshold. Threshold cointegration is particularly interesting if the threshold value is found to be close to zero, meaning that the two regimes correspond (roughly) to positive and negative deviations.

[12] For example, Abdel et al. (2009) and Zhang et al. (2010) use this interpretation of causality results.

[13] This I(1) condition is tested by use of three unit root tests: Augmented Dickey-Fuller (ADF), Philips-Perron (PP) and Breitung (2002), the latter being consistent to structural breaks.

[14] Where the result "threshold cointegration" can be yielded by either the Enders and Siklos or Hansen and Seo test, depending on the result of the initial linear cointegration test.

Commodity	Category	Cointegration type	Method	Price transmission	Speed of equilibrium adjustment	Threshold	Momentum equilibrium adjustment asymmetry	Granger Causality
Soybean oil	Biofuel	Threshold	E & S	Asymmetric	-Deviations ABOVE threshold are eliminated at a rate of 0.7% per month -Deviations BELOW threshold are eliminated at a rate of 25.5% per month	-0,014	In the short term, the price of crude responds to deviations BELOW the threshold (no result for other deviations).	Soybean oil $\xrightarrow{SR}$ Crude oil
Sugar	Biofuel	Threshold	E & S	Asymmetric	-Deviations ABOVE the threshold are eliminated at a rate of 7% per month -Deviations BELOW the threshold are eliminated at a rate of 17.4% per month	-0,030	In the short term, the price of sugar responds to deviations ABOVE AND BELOW the threshold	No causality
Palm oil	Biofuel	Threshold	E & S	Symmetric	-Deviations from the lon-run equilibrium are eliminated at a rate of 15% per month ABOVE AND BELOW the threshold	-0,020	n.a. (Impossible to compute)	Palm oil $\xrightarrow{SR}$ Crude oil
Sunflower oil	Biofuel	Threshold	H & S	Asymmetric	-Adjustment for deviations ABOVE threshold is faster than BELOW threshold	1,437	n.a. (Impossible to compute)	Impossible to compute
Maize	Biofuel	No cointegration	E & S					
Wheat	Food	Threshold	H & S	Symmetric	-Deviations are eliminated at an equal speed ABOVE AND BELOW threshold.	0,768	n.a. (Impossible to compute)	Impossible to compute
Rice	Food	Threshold	E & S	Symmetric	-Deviations from the lon-run equilibrium are eliminated at a rate of almost 10% per month ABOVE AND BELOW the threshold	-0,050	n.a. (Impossible to compute)	No causality
Beef	Food	No cointegration	E & S					
Wool	Agriculture	No cointegration	E & S					
Rubber	Agriculture	No cointegration	E & S					
Coffee	Agriculture	Threshold	E & S	Asymmetric	-Deviations ABOVE the threshold are eliminated at a rate of 8.2% per month -Deviations BELOW the threshold are eliminated at a rate of 1.2% per month	-0,014	In the short term, the price of coffee and crude oil respond to deviations ABOVE the threshold (no result for other deviations).	No causality

Source: The authors

5.1. Test results of price pairs

There is no evidence indicating the presence of cointegration between the crude oil price and the price of the following commodities: maize, beef, wool and rubber.

The majority of the commodities feature threshold cointegration of their prices with the crude oil price (as indicated in column three of table 3). Soybean oil, sugar, coffee, palm oil, and rice were identified as threshold cointegrated with crude oil by the Enders and Siklos test (marked as "E & S" in column four). Sunflower oil and wheat were found to have threshold cointegration with crude oil by use of the Hansen and Seo method (marked by "H & S" in column four). Hence, seven out of the ten commodity price pairs analyzed are threshold cointegrated with the crude oil price; i.e.: in 2/3 of the cases a threshold cointegration relationship describes the found price relationship more precisely than a linear model can. In 5 of these seven threshold cointegration findings the initial linear test would have yielded "no cointegration". The other 2 relationships would have been declared "linearly cointegrated". These numbers show to what extent our system of cointegration tests (which can detect thresholds and asymmetries) delivers much more precise results than research based on only the linear cointegration test.

Column five to seven in table 3 provide information on the (a)symmetry of each price pair, adjustment speeds and value of the threshold. The following commodity prices feature asymmetric adjustment speeds with crude oil prices: Soybean oil, sugar, sunflower oil, coffee. No such differences in the adjustment speeds for the two threshold regimes are found for palm oil, rice, and wheat; the adjustment speeds are symmetric.[15]

Table 3 also reports the results for the momentum equilibrium adjustment path (MEAP) and Granger causality (columns eight and nine). For soybean oil, both the momentum equilibrium adjustment path and Granger causality test report a clear result. They both indicate that the soybean oil price tends to move before the crude oil price; in other words: the crude oil price is more likely to perform the adjustment movement to restore long-run equilibrium; soybean oil prices lead crude oil prices, especially so for deviations smaller than the threshold. Soybean oil is the only commodity where both causality tests indicate a coherent result. For other causalities found, only one of the tests indicates a price leadership.[16] The results suggest that soybean oil and palm oil prices lead crude oil prices. The crude oil price is found to lead only the price of sugar.[17]

5.2. Test results concerning groups of different food and agricultural product categories

The results found by the system of cointegration and causality tests applied in our study are particularly interesting in light of the different groups of food and agricultural commodities that were defined previously.[18] These three groups are:

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[15] Asymmetric threshold cointegration means that the adjustments speeds back to long-run equilibrium are different in the two regimes divided by the threshold. This is the case for soybean oil for example, where deviations above the threshold of -0,014 are eliminated at a rate of 0,7% per month (relatively slow), and deviations below the threshold are eliminated at a rate of 25,5% per month (relatively fast). Symmetric threshold cointegration means that there is no difference in the adjustment speeds to long-run equilibrium for the two regimes (for palm oil, for example). Note also that the Enders and Siklos method can provide concrete numbers of adjustment speeds while the Hansen and Seo method can only indicate which one is faster, but not by how much.

[16] It is important to note though that a MEAP result could only be calculated for three out of seven threshold relationships. Granger causality, on the other hand, could only be calculated for the pairs that entered the Enders and Siklos threshold procedure.

[17] Note however, that in Bakhat and Würzburg (2013) we also find that crude oil prices lead the prices of commodities outside the food or agricultural category like aluminum, nickel, and natural gas.

[18] This is defined in section 4: A price relationship between crude oil and food or agricultural products is theoretically possible also without a biofuel impact through the input channel; crude oil is used in the production process of most agricultural and food products. A possible link provided by this price transmission channel can be expected to be equally relevant for all types of agricultural or food products, whether they are used for biofuel production or not. The difference for biofuel foods is that, on top of this input channel, there would be a possible stronger price link with crude oil originating from the growing importance of some food products as a source of energy (biofuels). Therefore, it is important to observe food and agricultural products from different categories and evaluate possible differences in the price links in these categories.

- Biofuel foods (corn, sugar, sunflower, soybean, palm oil)
- Non-biofuel food products (wheat, rice, beef)
- Non-edible agricultural products (rubber, coffee, wool)

In four out of five cases of biofuel foods, a clear price relationship with crude oil could be identified (sugar, soybean, sunflower, palm oil), and three of these cases are also more complex and asymmetric in adjustment speeds (sugar, soybean, sunflower oil). The first control group consisting of food products with indirect theoretical transmission with crude oil yields less complex price relationships.[19] The two cases of cointegration with crude oil (rice and wheat) are symmetric, beef prices appear to have no correlating relationship with crude oil prices. For the third group, the alternative control group of agricultural products for which only the input-channel can be expected to take effect, we find the weakest evidence of price relationships with crude oil among the three groups. Hence, there are some indications that the price links in the first group of biofuel foods are strongest and most complex. The price links with crude oil become somewhat weaker and simpler in the second group of non-biofuel foods, and are weakest in the third group of agricultural products that are not edible. As a consequence, the results indicate some additional complexities in price transmission and price links with crude oil due to the use of food products for biofuel production.

This evidence is not entirely coherent, however. This is because corn, which is heavily used in biofuel production in the US, does not show any price links with crude oil. A possible explanation of this finding is provided by Natanelov et al. (2011) who highlight that corn is processed into biofuel mostly in the US and consequently they hypothesize that the high US subsidies made the production of ethanol with corn profitable in the US, no matter what the energy prices in the fossil markets were. This could have unlinked crude oil and corn prices, and would explain why no cointegration relationship between corn and crude oil prices was found for our dataset.[20]

Our system of different cointegration tests and analytical tools can provide more information on the cointegrating relationships of the price pairs which are relevant when analyzing the results for the three different commodity groups. Three out of the four cases of asymmetric adjustment speeds of price links are from the biofuel category, indicating that most complexity of price links with crude oil are in the biofuel food category: For soybean oil and sugar, the price equilibrium with crude appears to reinstall quicker for positive then for negative deviations. This means, if we suppose that the short-run deviations originate

[19] Recall that these food commodities feature a substitution relationship (wheat, rice) or production factor relationship (beef) with biofuel foods.

[20] However, no quantification can be made about how much subsidy would eliminate the link with crude oil prices. This is of course problematic since other biofuel foods also receive subsidies but still are found to be cointegrated with crude oil in our study (sugar, soybean oil).

from crude oil prices, soybean and sugar prices return much faster to their equilibrium with crude oil prices in case of crude oil price increases than for crude oil price decreases.[21]

Apart from the asymmetry of adjustment speeds, the overall values of the adjustment speed results do not allow for concrete conclusions on differences between categories of food or agricultural commodities. The range of values for the adjustment speeds towards the price equilibrium with crude oil is not different for those foods that are used for biofuel production and those that are not.[22]

The calculations on the causalities in price transmission do provide some additional insight. The only cases where crude oil does not assume the leading part in the price relationship are in the biofuel food category. The results show that some biofuel foods (soybean, palm oil) do move before the oil price. In the case of sugar, the oil price seems to assume the price-leading part.[23] In the other categories of non-food and agricultural commodities, either no causality is found or the oil price is the price-leader. In Bakhat and Würzburg (2013) we perform the same analysis of cointegration with crude oil price for more commodities outside the food and agricultural categories like metals and natural gas. Interestingly, we did not find any case where another commodity would be found to lead the crude oil price, not even when expanding the analysis to metals and natural gas.[24] This is only the case in the biofuel category, which is then another indicator that the price relationship with crude is different and more complex for biofuel foods than for other commodities.

Summing up, our results show that price links with crude oil are possible also without any biofuel impact. At the same time the results provide some soft, albeit not entirely coherent evidence that the increased production and use of biofuels has affected the price links of food commodities with crude oil. Growing biofuel use has led to closer links of food and oil prices and possibly more complex interconnections between oil and food prices since 2000, more so for those foods that are used in biofuel production than for those that are not.

[21] For sunflower oil we found that the adjustment is asymmetric as well; adjustments are faster when the deviations are above the threshold. However, this threshold is different from zero in this case.

[22] Adjustment speeds for biofuel foods are: sugar 7-14.4% per month; soybean oil 0,7-25.5% per month; palm oil 15%. The only price pair outside the biofuel food category that allowed for a calculation of adjustment speeds is coffee (1.2-8.2 %). Also note that the econometric tools could not provide information on adjustment speeds in all cases.

[23] Relating these results to earlier research provides some interesting additional information: The importance of soil bean oil in the determination of prices of other commodities in the biofuel group is in line with earlier results of Yu et al. (2006), who found that soy bean oil prices lead the prices of other edible oil seeds. They did not find cointegration between prices of oil seeds and crude oil, however. The sugar result is particularly interesting when considering earlier results of Zhang et al. (2010) who found that sugar prices lead the prices of the four other food commodities that were included in their analysis.

[24] We only find linear bi-directional causality between crude oil and natural gas in Bakhat and Würzburg (2013), but no other case of uni-directional causality from another commodity price towards the crude oil price.

6. Conclusions

Peak oil and oil price increases have resulted in worries about wealth and sustainability of economic systems, especially in developed countries with high energy consumption and little own fossil resources. The use of crop to produce energy has been increasing constantly since roughly the new millennium as countries sought to protect themselves from these global oil price spikes and reduce their foreign energy dependence. Parallel to these developments the world markets of food commodities also experiences price hikes and risen price volatility similar to those in energy markets. This rose suspicions that the increased use of food products for biofuel production had caused the food price increases, which in turn provoke hunger and starvation in the third world where the populace has problems to satisfy their basic nutritious needs at rising world food prices. The food vs. fuel debate arose which spurred a large number of research projects on the relationship and causal effects between crude oil and food prices.

Given the bulk of research that has been carried out on the price links of food commodities and crude oil in the last years, the added value of our analysis on the matter is twofold. First we apply a system of different contemporary cointegration tests which enables us to unveil co-movements that could not be detected by analytical tools of earlier efforts. The combined tests provide new details about the co-movement dynamics regarding asymmetries, adjustments speeds and causalities, rendering important new information for actors and policy makers in these markets. Secondly, we present result for different categories of food and agricultural products and their price relationships with crude oil. This is important since a possible correlating price relationship of food commodities and crude oil is theoretically possible even without any biofuel production, because crude oil is an important production factor for food and agricultural products. Hence, finding a cointegration relationship for crude oil and food commodities does not necessarily mean that biofuel use plays any role in this relationship. Therefore, it is necessary to investigate the price relationship of different food and agricultural products, distinguishing between those food products that are used for biofuel production and those that are not. In this way differences in the strengths and characteristics of price relationships between the typical biofuel foods (like corn, sugar, soybean etc) and other food and agricultural products can be observed. This provides information on how much stronger the price link with crude is for biofuel foods than for non-biofuel foods. The extensive system of cointegration tests of our analysis is helpful in this endeavor, because it provides additional information on the price relationships which is then used to detect differences between the types of food and agricultural commodities.

The results of our cointegration analysis provide some moderate evidence that biofuel production has increased the link between food prices and oil prices. Generally, the most complex price links with crude oil are found for those foods that are used for biofuel production, but not exclusively so. Some more complex price relationships (asymmetries and complex causalities) are also found for a price relationship between crude oil and an agricultural product that is neither edible nor used for biofuel production (coffee), but most of these complex price relationships are found for the typical biofuel foods (sugar, soybean, sunflower, palm oil). Given that no cointegration relationship with crude oil prices could be identified for one of the most prominent biofuel foods (corn), the results are not entirely coherent and unanimous. This leads us to conclude that our analysis provides some indications of biofuel production providing an additional link between food and oil prices, but the evidence is not entirely coherent and clear. More research, particularly following our approach to analyze price links with crude oil for different food products (with different theoretical price transmission channels and biofuel impacts), may be necessary to draw clear-cut conclusions.

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