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Price Relationships of Crude Oil, Biofuels and Food Commodities

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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. Crude oil, volatility, price relationships, commodities

1. Introduction

Several measures and policies have been set out to address the challenges of hunger, environmental deterioration, and lack of energy [1]. One that has obvious relations to all these 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 [2,3]. However, almost parallel with the raise of biofuel production and use in roughly 2006, unfavorable conditions in global food commodity markets developed. The FAO estimates that the spikes in food prices in 2008 added 115 million persons to the pool of people afflicted by chronic hunger. Some authors pointed 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 [4,5].
The new developments on global food commodity markets are attributed to different sources. A mix of causal factors that triggered the first food price spike in 2008: low

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harvests due to unfavorable weather conditions, the exchange rate of the dollar, and high oil prices and increased biofuel use [6]. 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. 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 [7].

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, [7; 3]. Moreover, regarding biofuels, there is recent evidence that more and more food product prices are becoming linked with crude oil over time [8,9]. Given this state of the contemporary biofuel research, we set up our 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.

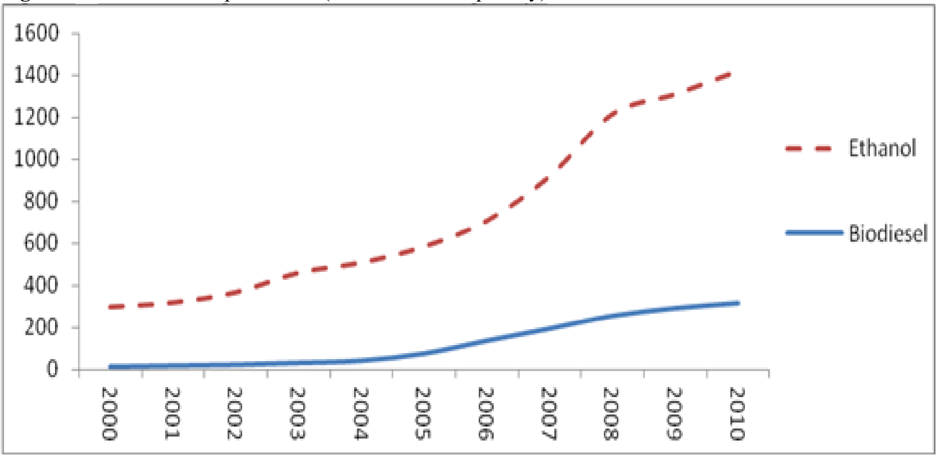
We analyze our extensive dataset of food commodities and oil prices in the same way that most previous research applied: Cointegration. We perform additional cointegration tests that can detect more complex, non-linear relationships. We also perform analysis of possible causalities of co-movements, which 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.

3. Previous research results

The price links between food and oil prices have been mostly investigated empirically by cointegration analysis. The standard cointegration based on Johansen tests and Breitung test suppose linear relationships between two series [10,11]. Some authors could find a linear cointegration relationship between crude oil prices and prices of various commodities [12,13,2,8,3]. However, others studies fail to find any co-movement between crude oil prices and any commodity prices. [14,15].

Only a minor group of studies uses newer cointegration tests (based on Hansen and Seo, test or Enders and Siklos test) that we also use in our analysis [16,17]. These methods are capable of detecting more complex co-movements of data series.

Peri and Baldi apply cointegration analysis based on Hansen and Seo test and find that the cointegration relation of rapeseed and diesel prices is a case of threshold cointegration [18]. Sunflower oil and soybean oil prices are found to have no cointegration relation with diesel, although they do not apply the Ender and Siklos test to check whether these two series do feature threshold cointegration. In another study where threshold analysis based on Hansen and Seo test is used to investigate the price relationship of future contracts of crude oil, gold and eight food commodities [19]. The authors find that only cocoa, wheat and gold move together with crude oil in the long run over the entire sample period. In the same vein, a linear and threshold cointegration analysis (based on Hansen and Seo test) was conducted on crude oil, ethanol and corn prices [20]. The authors of the study 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, results indicated 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 [21]. Furthermore, a threshold cointegration analysis was applied to US data on corn, ethanol, oil, and gasoline prices for the US. The study demonstrates the existence of a strong link between corn and energy prices, where energy price increases trigger price increases for corn through the ethanol market [22].

However, past researches 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

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". 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 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. Therefore, we also install two control groups to investigate possible interactions: Non-biofuel food products (wheat, rice, beef) and Non-edible agricultural products (rubber, coffee, wool).

The price data on the food commodities plus crude oil were taken from the International Monetary Fund database available under www.imf.org. 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).

4.2 Methodology

To detect price co-movements in this paper we used both linear and non-linear cointegration methods. Different types of cointegration tests exist. The linear cointegration tests based on Johansen tests [10] and Breitung test [11,23] suppose linear co-movements. However, 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 [16] and Ender and Siklos [17], who test if the cointegration relationship is better described if a threshold ECM is specified, accounting for two regimes separated by a threshold.

The asymmetric/threshold cointegration tests mentioned above are follow-ups of linear cointegration tests. They are applied after the linear cointegration test of Johansen [10] and Breitung [11,23]. 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).

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:[2]

$$Y_t = \alpha + \beta X_t + \varepsilon_t$$

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:

$$\varepsilon_t = Y_t - (\alpha + \beta X_t)$$

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.[3]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 [17] 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

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[2] For a detailed technical description of the cointegration methods applied here consult our article [24].

[3] Hence the value of εt 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.

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).[4] Two different analyses exist to shed more light on the direction of causalities, that is, which price is more likely to move exogenously and which is more likely to perform the adjustment movement afterwards or which price series "leads" the other. The first one, called "momentum equilibrium adjustment path" (MEAP) is a by-product of the ECM in the threshold cointegration analysis. 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 results of the MEAP and Granger causality tests are used to define which price series "leads" the other.
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. 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.[5]
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. In the following we will comment on all relevant test outcomes for each commodity pair.

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. Soybean oil, sugar, coffee, palm oil, and rice were identified as threshold cointegrated with crude oil by the Enders and Siklos test. Sunflower oil and wheat were found to have threshold cointegration with crude oil by use of the Hansen

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[4] 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 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.

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

and Seo method. Hence, seven out of the ten commodity price pairs analyzed are threshold cointegrated with the crude oil price.

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.[6]

The momentum equilibrium adjustment path (MEAP) and Granger causality provide some insightful results. 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. 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.

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. These three groups are:

- 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.[7] 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

[6] 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.

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

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 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 [19]. 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.

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 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.[8]

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.[9]

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.[10] In the other categories of non-food and agricultural commodities, either no causality is found or the oil price is the price-leader.

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

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[8] 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.

[9] 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.

[10] 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 [15], 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 [14], who found that sugar prices lead the prices of the four other food commodities that were included in their analysis.

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.

6. Conclusions

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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