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IES Working Paper: 32/2018



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**Bibliographic information:**

Janda K. and Kristoufek L. (2018): "The Relationship Between Fuel, Biofuel and Food Prices: Methods and Outcomes". IES Working Papers 32/2018, IES FSV, Charles University.

This paper can be downloaded at: <http://ies.fsv.cuni.cz>

# The Relationship Between Fuel, Biofuel and Food Prices: Methods and Outcomes

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October 2018

## **Abstract:**

We assess the fuel-food price linkage models of the structural and of the time series nature with the main attention devoted to the time series literature. We document shifting focus from a straightforward vector autoregressive and error-correction analysis of fuel-food commodity price level co-movement towards inclusion of biodiesel and ethanol prices directly into analysis, towards consideration of both price levels and price volatilities, and towards growing sophistication of econometric methodologies and integration of econometrics of price co-movement with theoretical considerations. The key insight of biofuels price transmission literature is that the price transmission is time and market specific, evolving with the development of biofuels policies and technologies. The most prominent relationships are coming from oil to agricultural commodities and then towards biofuels. While here are also studies not finding any strong connection between biofuels and their feedstock, the literature finding biofuels driving the prices of agricultural commodities up is negligible.

**JEL Classification:** Q16, Q42, Q56

**Keywords:** biofuels, fuels, food, ethanol, biodiesel, oil

## 1. Introduction

The interdependence between fuels and food commodity prices became a particularly important economic and policy issue in connection to the post-2005 biofuels boom. However, it is a part of the wider price co-movement research introduced by the agenda-setting contribution of Pindyck and Rotemberg (1990) who estimated the degree of co-movement among several commodity prices including crude oil and wheat. Carter et al. (2011) remind us that periodic commodity price booms and busts resonate with the populace and affect social welfare in a way that other asset price spikes do not. This is in particular true for food commodities, especially with respect to their impact on developing nations.

The price transmission between fuel and food commodities, in particular the role of biofuels policies in the food price increases, was one of the main policy arguments leading to the reformulation of biofuels policies in the EU and the US after 2010. We show that the results of econometric analyses of the fuel-food price co-movements cover a wide range of conclusions from price neutrality to strong price linkages. However, the main message of the literature is that indeed the introduction of significant biofuels policies around 2005 increased the price transmission between fossil fuels and food commodities with intuitively expected prevailing leading role of fuel prices over food prices. Particular price linkages are dynamically evolving in time and they depend on the particular market under consideration. The econometric results show that due to the policy induced trade barriers, there is no evidence of sufficiently integrated international biofuels market. Biodiesel and ethanol prices evolution and their linkages differ and on the ethanol side, the US and Brazilian markets and policies follow separate paths, mainly determined by different agricultural conditions in both major ethanol producing regions.

At the beginning of this article, we briefly introduce general price co-movement literature with emphasis on food and fuel prices. Then, in the rest of this article, we focus on the biodiesel and ethanol related price co-movements. Therefore, we first provide a brief

description of main biofuels markets and relevant government policies. This is followed by a discussion of three main approaches towards the analysis of price transmission between food and fuel. The main emphasis is put on the time series analysis approach from the point of view of both methods and results.

## **2. Commodity Prices Co-movement**

In their seminal paper, Pindyck and Rotemberg (1990) examined the degree of co-movement among seven commodity prices (cocoa, copper, cotton, crude oil, gold, lumber, and wheat) and concluded that these prices co-moved in excess of what the macroeconomic fundamentals could explain. This led them to formulate their excess co-movement hypothesis. Palaskas and Varangis (1991), Leybourne et al. (1994), and Deb et al. (1996) further studied the topic and showed that, although there in fact are excess co-movements, they are of small magnitude and include only few commodities.

Palaskas and Varangis (1991) scrutinized the results of Pindyck and Rotemberg in a working paper for the World Bank. Using the Engle-Granger cointegration techniques, they argued that there is no excess co-movement between various commodities. Nonetheless, they found 14 out of 42 pairs to exhibit excess co-movement. Deb et al. (1996) found weak evidence of excess co-movement using univariate and multivariate GARCH(1,1) models. Several reasons for this excessive co-movement 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 helped highlighting the effect of oil price on commodity prices and the transmission mechanism between energy and other commodity markets.

The emergence of co-movement of oil prices with the prices of other commodities can be traced back to the changes in oil industry in 1970s (Reynolds and Kolodziej, 2007).

This was the time of the nationalization of exploration and production in major oil producing countries. The nationalization led to the decoupling of upstream oil drilling from downstream operations of refining and distribution when the major private oil companies lost access to large volumes of equity crude oil and thus were forced to buy large quantities at arm's length from the newly nationalized oil companies. Consequently, the global oil market expanded swiftly. Companies started to sell and buy oil outside their network and by doing so stimulated the growth of the physical cash market. At the same time, the price volatility of crude oil prices prompted hedging needs for market participants leading to the growth of oil derivatives as the largest commodity derivative market (Natanelov et al., 2011).

Hanson et al. (1993) studied the cost effect of oil on various commodities using the computable general equilibrium (CGE) model developed by Economic Research Service of the US Department of Agriculture. They found that the heterogeneity of commodity price responses to an oil shock depends on 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 such co-movements.

Gohin and Chantret (2010) studied the effect of oil shocks on agricultural commodity prices using the GTAP CGE model with or without an income effect. They showed that the introduction of the income effect can reverse the sign of the relationship between oil and food products for the oil-importing countries. For beef and dairy products markets, the income effect was greater than the cost effect with a decreasing world price. However, this relationship was not observed in the wheat market with an increase of the world price or in the US and European markets. Authors argue that this absence was due to the lower income elasticity demand for wheat and other grains. In addition, they mentioned that the production-cost effect was unlikely to exist in the short term due to the quasi-fixation 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. (2006) used the quarterly inventory and harvest data for wheat, barley, corn, oats, and soybeans from January 1957 to September 2002 to fit the partial equilibrium model. The causes of co-movements were investigated 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 more efficient model to explain co-movements was the microeconomic model, showing that the supply factors would be the main causes of price co-movements.

As an energy-intensive sector, agriculture was traditionally linked to the energy industry through its input channels. While fuel and electricity are used directly in agricultural production, fertilizers and pesticides represent two most prominent indirect energy inputs. Through these energy input channels, higher energy prices increase the cost of producing and transporting food commodities.

The strong relationship between energy and non-energy prices had been established long before the post-2004 price boom. Gilbert (1989), using quarterly data between 1965 and 1986, estimated the transmission elasticity from energy to non-energy commodities of 0.12 and from energy to food commodities of 0.25. Hanson et al. (1993), utilizing the CGE model, found a significant effect of the oil price changes on the agricultural producer prices in the US. Borensztein and Reinhart (1994), using quarterly data from 1970 to 1992, estimated the transmission elasticity to non-energy commodities of 0.11. A strong relationship between energy and non-energy prices was found by Chaudhuri (2001) as well. Baffes (2007), using annual data from 1960 to 2005, estimated the elasticities of 0.16 and 0.18 for non-energy and food commodities, respectively. Moss et al. (2010) found that the US agriculture is highly responsive to energy prices. It is more sensitive to energy price changes than to price changes in any other input. The input-output values of the GTAP database show that the direct energy component of agriculture is four to five times higher

than of the manufacturing sectors (Baffes, 2013).

With the wide development of biofuels after 2005, the additional biofuels channel linking energy and agricultural prices appeared. The government policies, especially the compulsory biofuels blending mandates, created the new strong connection between agricultural and food markets (and thus prices). Emergence of the new biofuels refining capacities and demand for biofuels also opened the possibility for food and fuels price dynamics to interact through biofuels on the market profit-maximizing grounds, in addition to the mandatory blending requirements and other government programs supporting biofuels (Khanna and Zilberman, 2017).

### **3. Biofuel Quantities and Policies**

#### *3.1. Quantities*

After the post-2005 biofuels boom, the production and consumption of biofuels stabilized with a slow stable upward trend. Currently, according to IEA (2018), the global share of biofuels in the road transport energy consumption was 3.4% in 2017 with 3.8% expected in 2023. In 2017, according to EIA (2018), biofuels accounted for 5% of the US transportation sector energy consumption, with ethanol's share at 4% and biodiesel's share at about 1%.

With respect to the blending shares of biofuels in gasoline and diesel fuels, OECD-FAO (2018) provides the following figures for 2017. The ethanol blending was 45% in Brazil, 11% in Argentina, almost 10% in the US, 5% in the EU and Canada, and 2% in China. The biodiesel total blending share was 10% in Argentina, 8% in Brazil, 6% in the EU, and 4% in the US.

The US is the major ethanol producer, followed by Brazil, China and the EU. While the ethanol production expansion in 21st century was driven by the US corn ethanol, the current and expected evolution of ethanol production in developed and developing countries is driven by increases in the developing world and stagnation or decreases in

developed countries. The global ethanol production covers about 20% of the total biofuels production with the EU being the leading producer followed by the US and Brazil.

Given current policy developments and trends in diesel and gasoline demand, OECD-FAO (2018) predicts that the global ethanol production will have expanded from 120 bln L in 2017 to 131 bln L by 2027, while the global biodiesel production will have increased from 36 bln L in 2017 to 39 bln L by 2027. Advanced biofuels based on residues are not likely to take off during the period before 2027 due to insufficient investment into research and development. Trade in biofuels during the same period is likely to remain limited.

According to OECD-FAO (2018), the coarse grains and sugarcane will continue to be the dominant ethanol feedstock. The ethanol production is expected to use 15% and 18% of the global corn and sugarcane production, respectively, in 2027. The biomass-based ethanol is projected to account for only about 0.3% of the world ethanol production in 2027. Out of the predicted global 131 bln L of the ethanol production in 2027, the US should account for about 60 bln L, Brazil for about 33 bln L, the third largest ethanol producer China for about 11 bln L, and the EU for about 7 bln L.

For biodiesel, the EU is expected to remain by far the major producer with the 2027 expected production of about 13 bln L. In the US, the second major biodiesel producer, the biodiesel production is expected to be about 7 bln L in 2027. Brazil is likely to reinforce its position as the third major biodiesel producer with about 6 bln L production in 2027.

### *3.2. Policies*

The biofuel markets evolution has been strongly related to the policy environment (Khanna et al., 2016). Biofuel policies were initially motivated by a combination of factors, including the view that the biofuel use would improve energy security and reduce greenhouse gas emissions (GHG) (Khanna et al., 2018). Government support for the biofuel industry takes mainly the form of the blending mandates, exemptions from taxes applied to corresponding petroleum fuels, and investment support. Biofuel markets are also

affected by policies that apply sustainability criteria, fuel quality standards, and import tariffs on ethanol and biodiesel.

Developing countries (including Brazil) are likely to play a more important role on the biofuel markets in the upcoming years. There are several reasons for this. Transportation fuels demand is likely to continue its growth in those countries whereas it should either stagnate or decrease in the developed countries. As biofuels are mostly blended into transportation fuels, even a stable biofuel mandate would translate into higher biofuel demand. Trade uncertainty is also rising on biofuel markets. Major biofuel producers in developing countries (Brazil, Argentina, Indonesia) had developed their biofuel industries not only for the domestic use but also given prospects on key markets in developed countries (the US and the EU). The EU and the US have used trade duties to prevent imports of biofuels. This led the developing countries encourage domestic biofuel use, in particular through increasing the mandates.

### *3.2.1. USA*

In the US, the Energy Independence and Security Act (EISA) defined a more ambitious version of the Renewable Fuel Standard program (RFS2) in 2007. Under this program, EISA established four quantitative annual mandates up to 2022: the total and advanced mandates that require fuels to achieve at least a 20 % and a 50 % GHG reduction, respectively, as well as the biodiesel and the cellulosic mandates that are nested within the advanced mandate. The Environmental Protection Agency (EPA) establishes (on an annual basis) the minimum quantities for each of the four classes of biofuels required. The EPA rulemaking for 2019 and the biodiesel volume requirement for 2020 were issued in June 2018. Similar to the 2017 and 2018 final ruling, an important part of the initial levels proposed in EISA for the total, the advanced, and the cellulosic mandates was waived based on the fact that production capacity for cellulosic ethanol had not developed. The difference between the total ethanol mandate and the advanced ethanol mandate, which

is also known as an implied coarse grains mandate constant, was maintained at 56.8 bln L. The final standards that were announced in 2018 were kept at high level, which means that the availability of higher ethanol blends at the US pumps will need to be developed over the short- to medium-term. Presently, in 2018, even if the maximum blend of ethanol for the conventional petrol vehicles is set in the US at 15% for vehicles produced in 2001 or later, E10 is still the most commonly available gasohol in the US.

### *3.2.2. Brazil*

In Brazil, the flex-fuel vehicles can either run on gasohol or on E100 (hydrous ethanol). The current Brazilian anhydrous ethanol mandatory blending requirement for gasohol is 27% and the differentiated taxation system is favorable to the hydrous ethanol rather than the blended gasohol in the key Brazilian states. The Brazilian 10 % biodiesel mandate is likely to be met by 2020. The RenovaBio program, a follow-up of the Brazil's commitment under the 2015 Paris Climate Agreement to reduce the greenhouse gas emissions by 37% in 2025 and by 43% in 2030 compared to 2005, was officially signed in January 2018 with a not-yet defined implementation plan. The program defines a minimum blending target for the anhydrous fuel ethanol that should reach 30% by 2022 and 40% by 2030 as expressed in the volume terms. The fuel ethanol share in the fuels matrix should reach 55% by 2030 according to RenovaBio.

### *3.2.3. EU*

The 2030 Framework for Climate and Energy Policies for the EU, which targets a 40 % cut in the GHG emissions by 2030 compared to 1990 and a renewable energy share of 27% by 2030, does not propose concrete targets for the transport sector after 2020. At present, the policy framework concerning biofuels is determined by the 2009 Renewable Energy Directive, which states that the renewable fuels (including non-liquids) should increase to 10% of the total transport fuel use by 2020 on an energy-equivalent basis, and by the Fuel Quality Directive, which requires fuel producers to reduce the GHG intensity of the

transport fuels by 2020. Both directives were amended in September 2015 by the new Directive referred to as the Indirect Land Use Changes (ILUC) Directive. This ILUC Directive introduced a 7 % cap on the renewable energy in the transport sector coming from food and feed crops.

With the approach of 2020, the EU biofuels policies are very likely to further evolve. The European Parliament proposed on 17 January 2018 to reach 12% renewable energy in transport fuel by 2030. This proposal states that the consumption of biofuels based on food and feedstock cannot increase above the 2017 levels and defines a 7 % cap for food and feedstock biofuels at the Member States level. Palm oil based biodiesel would be prohibited after 2021 and the share of advanced biofuels, including waste-based biofuels, should reach 1.5% by 2021 and 10% by 2030.

#### *3.2.4. China and Other Major Producers*

Major uncertainty on the biofuel markets arises from China. In September 2017, the Chinese government proposed a new nationwide ethanol mandate that expands the mandatory use of the E10 fuel from 11 trial provinces to the entire country by 2020. The underlying rationale for that announcement has not been clearly stated but could be related to abundant grains stocks and to environmental concerns.

In Canada, the federal Renewable Fuels Regulations mandates 5 % renewable content in gasoline and 2 % in diesel fuel. Argentina has 10 % biodiesel and 12 % ethanol mandates. In Indonesia, the 10 % biodiesel mandate is quite realistic given currently (2018) already achieved blending rate of about 7%.

## **4. Structural Approaches to Fuel-Food Price Linkages**

### *4.1. Theoretical Models of Fuel-Food Price Transmission*

Three main approaches towards investigation of the fuel-food price linkages have been the following. Firstly, theoretical models were developed to identify and understand the

channels of adjustment between agricultural, bioenergy, and energy markets (Gardner, 2007; Saitone et al., 2008; de Gorter and Just, 2008, 2009a,b; Ciaian and Kanacs, 2011a,b; de Gorter et al., 2015; Drabik et al., 2016). Secondly, the partial and general equilibrium (CGE) models have been used to simulate the interdependencies between agricultural, bioenergy and energy markets (Elobeid and Tokgoz, 2006; von Lampe, 2006; Banse et al., 2008; Hertel and Beckman, 2011; Beckman et al., 2012; Lotze-Campen et al., 2014; Tabeau et al., 2015). The main disadvantage of the CGE approach is that the simulated effects largely depend on calibrated or arbitrarily assumed price transmission elasticities. And thirdly, the time series analyses are performed to estimate the long-run relationship between fuel and biomass prices (Zhang et al., 2010; Serra et al., 2011; Serra and Zilberman, 2013; Filip et al., 2016, 2018). The main shortcomings of these reduced-form empirical studies are that they do not provide a theoretical basis about the relationship, and they do not identify price transmission channels.

The first two approaches (theoretical and partial/general equilibrium models) are more inclined towards investigation of impact of introduction of biofuels on commodity food prices rather than towards a direct analysis of the relationship between fuel and food prices, which is the focus of the time series econometric approaches. In this section, we briefly review the first strand of literature – theoretical models of biofuels policies – while the other two strands are covered in the following sections.

The biofuels theoretical literature argues that the biofuels policies play an important role in the price transmission between fuel and food markets. This literature therefore usually uses specialized models that take a close look at which biofuel policy is binding and at the specific relations between the gasoline (diesel), biofuel, and feedstock or crop prices domestically and internationally. This literature focuses on the new and unique role of energy and environmental policies that created a direct link between biofuel and crop prices.

Biofuel policies considered in these theoretical models include biofuel consumption man-

dates, biofuel consumption subsidies (e.g. tax exemptions), production subsidies for both biofuels and feedstocks, environmental regulations, import tariffs and tariff rate quotas, and binary sustainability standards requiring biofuels to reduce greenhouse gases relative to fossil fuel. Each of these biofuel policy categories has its unique impact on biofuel feedstock prices.

The founding contribution to the theoretical modeling of biofuels-related price links was published by Gardner (2007) in a special issue of *Journal of Agricultural and Food Industrial Organization* devoted to biofuels. Gardner (2007) developed a vertical market integration model of ethanol, its by-products, and corn, which was further used to analyze the price effects of corn and ethanol subsidies in the US. A limitation of this model was that the ethanol market was modeled separately from the aggregate fuel market (fossil fuel and biofuels). Therefore, the price transmission between fuel and corn in that model depended crucially on the assumption about the cross-price elasticity between fuel and ethanol.

de Gorter and Just (2008, 2009a,b) extended Gardner (2007) by incorporating ethanol in the aggregate fuel market. In these models, the price transmission between fuel and corn is channeled through the demand for corn in the ethanol production and occurs when the fuel price is high enough and/or when the corn price is low enough, ensuring that the corn-based ethanol production is more profitable than corn for the food use.

The models of Gardner, and de Gorter and Just were theoretical, without inclusion of the econometric analysis price transmission. Ciaian and Kancs (2011a,b) then extended this theoretical modeling framework by considering more agricultural products than just corn and by adding the input price transmission channel into the model. Importantly, they also integrated their theoretical models with time series econometric cointegration analysis.

The theoretical concepts of de Gorter and Just (2008, 2009a,b) were used in a string of papers evaluating price-related issues related to both ethanol and biodiesel, and including welfare effects, interaction effects between mandates and subsidies, carbon leakage and indirect land use change (Rajcaniova et al., 2013; de Gorter et al., 2013; Rajcaniova et al.,

2014; Drabik et al., 2014, 2015, 2016; Boutesteijn et al., 2017). This approach departs from the standard literature of commodity price determination by modeling the explicit relationships between corn and ethanol prices, and between ethanol and gasoline prices, and the economics of blend mandates. This approach was also used by Cui et al. (2011) and Lapan and Moschini (2012). Considering the two main policies used to promote biofuels (mandates and tax exemptions), this stream of literature has shown that ethanol/biodiesel and gasoline/diesel prices are locked together when the tax credit is binding. If the mandate determines the biofuel market price (above what it would be under the tax credit), then biofuel prices become delinked from energy prices.

Another recurring theme in the early theoretical modeling of the fuel and food price linkages was the role of capacity constraints and blend walls (Abbott, 2014; Zilberman et al., 2013). However, with the development of both biofuels refining capacities and technological advancements of car engines, these technological constraints lost their key importance after 2012. Subsequently, instead of the technological constraints, the biofuels price transmission was rather influenced by government policies, which reflected changing public perception of biofuels (Timilsina, 2018). This public attitude towards biofuels is mainly formed by evolution in understanding of the environmental impacts of biofuels (Searchinger et al., 2008) with the food security question emphasized mainly during period of high food prices in 2007 and 2011. However, the major capacity constraint of naturally limited agricultural land area still remains to be fully integrated into the theoretical models of the fuel-food price transmission (Goetz et al., 2018).

#### *4.2. Partial and General Equilibrium Models of Biofuels*

The food price spikes in 2007 and 2008, which occurred as biofuel production was increasing rapidly, brought the food-fuel issue to the forefront of the partial and general equilibrium modeling at that time (Sajedinia and Tyner, 2017). Concerns about the food price effects of an increase in the biofuel production were raised by Elobeid and Tokgoz

(2006) and von Lampe (2006). Both studies were based on the partial equilibrium models (Aglink, Cosimo and OECD world sugar model) and utilized exogenous shifters for biofuel demand to investigate the interactions between agricultural and energy markets.

In the 2007 GTAP conference presentation of the draft of (Banse et al., 2008), a computable general equilibrium model was used for the first time to account for the direct and indirect effects of the first generation biofuels on the agricultural markets. Using the LEITAP model, they demonstrated that with the mandatory blending policies, biofuel could have a strong impact on the global agriculture markets and that declining trends of agricultural product prices would slow down or even reverse. Reversely, in the absence of mandatory blending, subsidies or other incentives, there would be little effect on the agricultural markets from the biofuel industry because production levels would be much lower given absenting incentives.

The biofuels production increase changes the type and strength of the bonds between energy and conventional agricultural markets by linking energy and food commodity markets in new ways. These additional relationships between different markets increase the importance of the CGE models in studying the cause and effects of different issues in the economy as a whole and more specifically in the affected energy and agriculture sectors. Hertel and Beckman (2011) and Beckman et al. (2012) are examples of the major GTAP CGE modeling efforts on investigation of price volatility linkages between energy and agricultural markets. Their results indicate that agricultural price variation is driven in large part by the energy price volatility in the presence of large-scale biofuel production. However, the nature of some of the biofuel market conditions under policy supports can lessen the price variability. In this way, the RFS places a required minimum on biofuel production regardless energy prices while the blend wall can limit the maximum amount of ethanol regardless energy prices. Thus, under these conditions, fossil energy prices cannot be transmitted to agricultural commodity markets as effectively.

Due to the links among different markets and direct and indirect interactions among

different parts of the economy, any change in a sector will affect other sectors in different ways. Tabeau et al. (2015) look into the interaction of biofuel and food markets from a different perspective. Their approach is to investigate changes in food security as a result of using agricultural residue for bioenergy production. Using the MAGNET model, they implement a conceptual framework for analyzing effects of transforming these residues into biofuel on profitability of agricultural and forestry sectors. Their results suggest a main commodity crop price decrease and an increase in production and consumption of the crops. This result predictably occurs because of the increase in profitability of agriculture owing to the new market for the residues. They conclude that using the agricultural residue will improve food security and alleviate some of the adverse effects of using crops for energy production on the food markets.

LotzeCampen et al. (2014) and Searchinger et al. (2015) both used results from different general and partial equilibrium models to offer better understanding of interactions between the biofuel and food markets. LotzeCampen et al. (2014) compared results of two general equilibrium models – AIM and MAGNET – in addition to three partial equilibrium models – GLOBIOM, MAgPIE and GCAM. A detailed inter-model comparison of results for impacts of high demand for the second-generation biofuels on food prices shows a modest price increase. AIM and MAGNET show higher average price responses compared to the partial equilibrium models used in the study, due to a more limited trade implementation. While allocation of the biomass production differs between models, most of them show the land supply elasticity beyond existing croplands or some tradeoffs with livestock and feed production. The land use change and new land expansion results show that MAGNET and AIM expand most of biomass production into currently unmanaged lands. They also compare a very ambitious emission reduction scenario with the worst case scenario for climate change and report a significantly larger price increase in the climate impacts scenario (25 % average increase across models) compared to the mitigating scenario (5 % average increase across models). Searchinger et al. (2015) pick another ap-

proach and by using results from the GTAP, FAPRI-CARD and MIRAGE models, they argue that all biofuel policies gains in the area of emission reduction are at the cost of decreasing food resources and reducing food consumption. Considering this, they emphasize the importance of having a broad view on the direct and indirect consequences of biofuel policies.

Moschini et al. (2012) survey six Global Trade Analysis Project (GTAP) model simulations of biofuel policies on food commodity prices and six studies by the Center for Agriculture and Rural Development, Iowa State University and the Food and Agricultural Policy Research Institute, University of Missouri (CARD-FAPRI). In all cases, the biofuel policies are found to have just a small impact on grain and oilseed prices. However, there is a number of structural models of biofuels providing widely different estimates of impact of biofuels on agricultural commodities or food prices. Zhang et al. (2013) review four studies using the partial equilibrium models and five using the general equilibrium models. The impacts of biofuels on corn prices range from a 4.7 % to a 52.6 % increase, with an average of approximately 20%.

In their meta-analysis of the biofuels policies impact on the U.S. corn prices, Condon et al. (2015) consider 150 estimates from 29 published partial or general equilibrium studies and find a range of corn price increase from nil to over 80 percent. Most recently, Hochman and Zilberman (2018) also report a meta-analysis of the US biofuels policies with quite a wide dispersion of the estimates of corn or soybean price changes.

## **5. Time Series Models**

Table 1: Summary of time series literature with no explicit biofuel prices included

Reference	Modeling Approach	Period	Frequency	Key Findings
<i>Neutrality hypothesis</i>				
Fowowe (2016)	ECM, Nonlinear causality	2001-2014	Weekly	No price transmission from crude oil to agricultural commodities. Agricultural prices are neutral to oil prices.
Reboredo (2012)	Copulas	1998-2011	Weekly	The price rise of corn, soybean and wheat was not attributed to extreme changes in crude oil prices.
Gilbert (2010)	Granger causality, 2SLS, 3SLS	OLS, 1971-2008	Quarterly	Economic activity, monetary expansion and exchange rate fluctuations lead to higher food prices.
Nazlioglu and (2011)	Soytas and Toda-Yamamoto causality, Generalized impulse-responses	1994-2010	Monthly	Prices of agricultural commodities respond weakly to crude oil price variations in the short-run.
Yu et al. (2006)	Cointegration	1999-2006	Weekly	The influence of crude oil price on edible oil prices is not significant over the studied period.
Zhang and Reed (2008)	VARMA	2000-2007	Monthly	Influence of crude oil price was not significant over the studied period. The pork demand and supply result in the skyrocketing pork price.
<i>Crude oil/energy prices affect prices of agricultural commodities</i>				
Baffes (2007)	OLS	1960-2005	Annual	Agricultural price index increases by 1.8 per cent in response to the 10 per cent increase in crude oil prices.
Cha and Bae (2011)	SVAR	1986-2008	Quarterly	Increased crude oil price increases ethanol demand which in turn raises the corn prices in the short run.

Chang and Su (2010)	EGARCH	2004-2008	Daily	Prices spill over from crude oil to corn and soybeans.
Chen et al. (2010)	ARDL	1983-2010	Weekly	Crude oil price changes significantly influence the prices of soybeans, corn, and wheat during 2005-2008.
de Nicola et al. (2016)	MV-GARCH	1970-2013	Monthly	Strong correlation between prices of crude oil and agricultural commodities (soybean, corn, rice, wheat, sugar).
Koirala et al. (2015)	Copulas	2011-2012	Daily	Corn and soybean prices are correlated with energy prices.
Obadi and Korcek (2014)	VECM, Granger causality	1975-2013	Monthly	Prices of corn, wheat, rice, barley and palm oil are affected by the crude oil price movements.
Ibrahim (2015)	NARDL	1971-2012	Annual	Asymmetry in food price changes to crude oil price shocks.
Pal and Mitra (2016)	QADL	2004-2014	Monthly	Soybean price fluctuations react strongly to diesel price in the upper quantiles in comparison to the lower quantiles.
Rafiq and Bloch (2016)	NARDL	1971-2012	Annual	Corn reacts asymmetrically to crude oil price shocks.
Zhang and Qu (2015)	ARMA-GARCH	2004-2014	Daily	Crude oil price shocks have asymmetric impact on corn, soybean, and wheat price changes.
Campiche et al. (2007)	VECM	2003-2007	Weekly	No cointegration during the 2003-2005 time frame; however, corn prices and soybean prices are cointegrated with crude oil prices during the 2006-2007 time period.
Ciaian and Kancs (2011a)	VECM	1993-2010	Weekly	Prices of crude oil and agricultural commodities are interdependent. Indirect input price transmission channel is small and statistically insignificant.
Ciaian and Kancs (2011b)	VECM	1994-2008	Weekly	Co-movement is dynamic. Biofuel policy buffers the co-movement of crude oil and corn until crude oil price sur-passes certain threshold.
Natanelov et al. (2011)	VECM, TVECM	1989-2010	Monthly	

Nazlioglu (2011)	TY and DP causality tests	1994-2010	Weekly	Nonlinear relationships between oil and agricultural prices. A persistent unidirectional nonlinear causality running from the oil prices to the corn and to the soybeans prices.
Nazlioglu and Soytas (2012)	Panel cointegration, VECM	1980-2010	Monthly	Strong evidence on the impact of world oil price on agricultural commodity prices, positive impact of weak dollar on agricultural prices.
Peri and Baldi (2010)	TVECM	2005-2007	Weekly	Rapeseed oil price adjusts rapidly to its long-run equilibrium determined by fossil diesel prices.
Peri and Baldi (2013)	VECM	2001-2010	Daily	Four structural breaks in the relationships between the price of diesel and rapeseed oil were identified.
Rosa and Vasciaveo (2012)	VECM	2002-2010	Weekly	Causality in US markets with exogeneity of the oil on the US agricultural commodities, cointegration between US and Italian commodities.
Ziegelback and Kastner (2011)	TVECM	2005-2010	Daily	Asymmetric movements and presence of a threshold defining three different regimes of the rapeseed price adjustment.
Lucotte (2016)	VAR	1990-2015	Monthly	Strong positive co-movements between crude oil and food prices in the aftermath of the commodity boom. No statistically significant co-movements over the pre-boom period.
Pal and Mitra (2017)	Wavelet, TY causality	1990-2016	Monthly	World food price index and crude oil co-move with crude oil prices leading.
Pal and Mitra (2018)	DCCA	1990-2016	Monthly	World food price index and crude oil co-move.
Zafeiriou et al. (2018)	ARDL	1987-2015	Monthly	Crude oil prices affect the prices of corn and soybean.

Ji et al. (2018)	Copula	2000-2017	Daily	Price dependence between crude and agricultural commodities is stronger in a positive correlation regime than in a negative correlation regime.
Hasanov et al. (2016)	MGARCH-M, VIRF	2008-2015	Daily	Soybean, sunflower and rapeseed oil prices significantly respond to the shocks in oil prices.
<i>Other research focus</i>				
Cooke and Robles (2009)	VAR	2002-2009	Monthly	Financial activity in futures markets and/or speculation in these markets help explain the behavior of agricultural prices in recent years.
Esmaeili and Shokoohi (2011)	VAR, PCA	1961-2005	Monthly	The crude oil price has indirect effect on the world GDP via its impacts on food production index.
Adams and Gluck (2015)	SDSVaR	1994-2013	Quarterly	Price links between crude oil and agricultural commodities are attributed to the global financial crisis due to the increasing use of agricultural commodities as financial assets.
Han et al. (2015)	Multivariate normal mixture models	2000-2014	Daily	Financialization produces a long-term effect on dependence between energy and agriculture commodity prices.

Abbreviations: 2SLS – Two-stage least squares, 3SLS – Three-stage least squares, ARMA-GARCH – autoregressive moving average with generalized autoregressive conditional heteroskedasticity, (N)ARDL – (nonlinear) autoregressive distributed lag model, DCCA – detrended cross-correlation analysis, (V)ECM – (vector) error-correction model, EGARCH – exponential GARCH, MGARCH-M – multivariate GARCH-in-mean, MV-GARCH – multivariate GARCH, OLS – ordinary least squares, PCA – principal component analysis, QADL – quantile autoregressive distributed lag model, SDSVaR – state-dependent sensitivity Value-at-Risk, (S)VAR – (structural) vector autoregression, (T)VECM – (threshold) VECM, TY – Toda and Yamamoto, VARMA – vector ARMA, VIRF – volatility impulse-response functions

Table 3: Summary of time series literature with biofuel prices included

<i>Ethanol</i>						
Al-Maadid et al. (2017)	VAR-GARCH	2003-2015	Daily	Significant linkages between food and both oil and ethanol prices. The 2006 food crisis and 2008 financial crisis lead to the significant shifts in the volatility spillovers between the price series.		
Bentivoglio et al. (2016)	VECM, Granger causality	2007-2013	Weekly	Ethanol prices are affected by both sugar and gasoline prices, ethanol prices do not have an impact on sugar prices.		
Capitani et al. (2018)	SVAR	2010-2016	Daily	Linkage between ethanol prices and the international market is weak.		
Dutta (2018)	ARDL	2003-2016	Weekly	Oil and sugar prices lead the Brazilian ethanol prices in the long run. Sugar prices are not affected by the fluctuations in ethanol price.		
Fernandez-Perez et al. (2016)	SVAR	2006-2016	Daily	Crude oil has a unidirectional contemporaneous impact on the agricultural commodities, and corn and soybean have a unidirectional contemporaneous impact on ethanol.		
Saghaian et al. (2018)	BEKK-MGARCH	2007-2015	Daily/ weekly/ monthly	Volatility transmission between corn and ethanol prices is asymmetric.		
Myers et al. (2014)	VECM	1990-2010	Monthly	No indication of long-run cointegration between crude oil, ethanol, corn and soybean prices.		
Zhang et al. (2010)	VECM	1989-2008	Monthly	No long-run price linkage between crude oil and agricultural commodities (corn, soybean, and wheat).		

Qiu et al. (2012)	SVAR, distributed graph	acyclic	1994-2010	Monthly	Biofuel production does not cause long run food price shifts. Oil, gasoline, and ethanol market shocks do not spill over to grain prices.
Bastianin et al. (2016)	Granger causality		1987-2012	Monthly	Ethanol returns do not Granger cause food price variations. Ethanol is Granger caused by returns on corn.
Bastianin et al. (2014)	Predictability in distribution		1987-2012	Monthly	Ethanol does not predict field crops or cattle, but field crops predict ethanol.
Kristoufek et al. (2016)	Wavelet		2002-2014	Weekly	Ethanol price co-moves with corn (US) and sugar (Brazil).
Mallory et al. (2012)	VECM		2006-2010	Daily	Without structural breaks: no long-run relationship between energy and agricultural prices. With structural breaks: such long-run relationships exist and even intensified over time.
Natanelov et al. (2013)	VECM		2005-2011	Daily	Crude oil price is strongly linked to corn and ethanol prices.
Saghaian (2010)	VECM, Granger causality		1988-2002	Monthly	Crude oil price changes Granger cause fluctuations in ethanol, corn, soybean, and wheat prices.
Balcombe and manikis (2008)	Rapso series expansion of VECM, AVECM, TVECM		2000-2006	Weekly	Crude oil price fluctuations carry asymmetric impact on ethanol and sugar price variations in the long-run.
Serra et al. (2011)	STVEC		1990-2008	Monthly	Corn prices adjust nonlinearly to crude oil price changes.
Serra et al. (2011)	BEKK-MGARCH		2000-2008	Weekly	Strong link between Brazil ethanol and sugar prices, both in terms of price levels and volatilities.
Rajcaniova and (2011)	Pokrivcak VECM		2005-2010	Weekly	Long-run cointegrating relationship among the selected time series in the later years while the interrelationship among the variables was weaker in earlier period.

Rapsomanikis and Hallam (2006)	TVECM	2000-2006	Weekly	Both sugar and ethanol prices are found to be determined by oil prices and no evidence for a causal relationship that runs from oil to ethanol to sugar is found.
Wixson and Katchova (2012)	TVECM	1995-2010	Monthly	Asymmetric price changes do occur in the commodity and energy markets.
McPhail (2011)	SVAR	1994-2010	Monthly	A policy-driven ethanol demand expansion causes a statistically significant decline in real crude oil prices. Ethanol supply expansion does not have a statistically significant impact on real oil prices.
Pokrivcak and Rajcamiova (2011)	VECM	2000-2009	Weekly	Cointegration relationship between oil and gasoline prices, but no cointegration between ethanol, gasoline and ethanol, oil prices.
<i>Biodiesel</i>				
Hassouneh et al. (2012)	VECM and MLPR	2006-2010	Weekly	Long-run equilibrium relationship between the prices of sunflower oil, biodiesel and crude oil.
Busse et al. (2012)	MS-VECM	2002-2008	Weekly	Before 2005 and after 2007, strong orientation of biodiesel towards diesel prices. Between 2005 and 2007, biodiesel and rapeseed oil prices are mutually interdependent.
Bentivoglio et al. (2014)	VECM	2008-2013	Weekly	Biodiesel prices are affected by rapeseed prices in long run and by diesel prices in short run.
Abdelradi and Serra (2015a)	BEKK-MGARCH	2006-2010	Weekly	Bidirectional and asymmetric volatility spillovers between the Spanish prices of biodiesel and sunflower oil.

Abdelradi and Serra (2015b)	Serra	MGARCH	2008-2012	Weekly	Significant asymmetries in volatility spillovers between biodiesel and rapeseed oil prices.
Cabrera and Schulz (2016)	VECM, GARCH	mM- MGARCH, GARCH	2003-2012	Weekly	Biodiesel production cannot adequately explain the price co-movement between crude oil and agricultural feedstocks.

*Both ethanol and biodiesel*

Vacha et al. (2013)	Wavelet		2003-2011	Weekly	Ethanol prices co-move with corn prices; however, the correlation varies over time and frequency.
Kristoufek et al. (2012)	Minimal hierarchical trees	Minimal spanning trees and hierarchical trees	2003-2011	Monthly/weekly	In the short-run, both ethanol and biodiesel are very weakly connected with other commodities. In the medium-run, the biofuels network becomes more structured. The system splits into two well separated branches – a fuels part and a food part. Biodiesel tends to the fuels branch and ethanol to the food branch.
Kristoufek et al. (2014)	VAR		2003-2011	Weekly	Ethanol and biodiesel prices are responsive to their production factors as well as to their substitute fossil fuels.
Filip et al. (2016)	Minimal wavelet	Minimal spanning trees, wavelet	2003-2016	Weekly	Feedstocks of Brazilian and US ethanol lead biofuels prices, and not vice versa. European biodiesel exhibits only moderate ties to its production factors.
Filip et al. (2018)	VECM		1989-2016	Monthly/weekly	Price co-movements are markedly different before and after 2008. There are also differences between US, Brazil and EU markets.

Abbreviations: ARDL – autoregressive distributed lag model, (A)VECM – (asymmetric) vector error-correction model, BEKK-MGARCH – Baba, Engle, Kraft and Kroner multivariate generalized autoregressive conditional heteroskedasticity model, (m)MGARCH – multivariate GARCH (in-mean), MLPR – multivariate local polynomial regression, MS-VECM – Markov-switching VECM, (S)VAR – (structural) vector autoregressive model, TVECM – threshold VECM

### *5.1. US Ethanol and Related Commodities*

Price transmission between the fossil fuels and the US agricultural commodities is the most developed part of the biofuels-related price transmission literature. This US-focused literature is naturally concerned primarily with the ethanol-related commodities, mainly corn, but a substantial number of papers also include soybean and other agricultural commodities which do not serve as ethanol feedstock into their analysis. Also some of the papers enlarge their coverage by including world prices and other explanatory variables besides the US fossil fuels, ethanol and ethanol feedstock. A comprehensive meta-analysis of the biofuels literature on the US corn ethanol and biofuels policies has been recently prepared by Hochman and Zilberman (2018).

A considerable group of researchers argue that food prices are majorly driven by crude oil prices which form an important input of production of the agricultural commodities. Others see that food prices are driven by the rising demand for food commodities potentially through increased production of biofuels. We first review the studies that identified a price relationship between fuels and agricultural commodities.

With a broad data coverage, Baffes (2007) examines the effect of crude oil prices on 35 internationally traded primary commodities for the 1960–2005 period. The author finds a positive pass-through effect of crude oil price to the overall non-energy commodity price level. In particular, the most evident influence is identified for fertilizer and agricultural prices. Focusing solely on the agricultural commodities, Campiche et al. (2007) find corn and soybean prices to be cointegrated with crude oil prices starting from the 2006-2007 time period. Later, Cha and Bae (2011) investigate the impact of oil price on the ethanol and corn markets in the US. They show that an increase in oil price supports ethanol demand for corn. Corn prices increase in the short run and then stabilize in the long run as corn exports and feedstock demand for corn decline. Similar results attributing higher food prices to the increased consumption of biofuels are obtained by Chang and Su (2010), who describe price spillover effects from crude oil to corn and soybean markets during the

periods of higher oil prices. A consistent evidence is delivered also by Chen et al. (2010) for corn, soybeans, and wheat. In the same vein, Ciaian and Kancs (2011a) and Ciaian and Kancs (2011b) confirm that the prices of fossil energy and food are interdependent with crude oil affecting the food prices primarily through the direct biofuel channel.

Another strong evidence of the impact of world oil price changes on agricultural commodity prices is delivered by Nazlioglu and Soytaş (2012). Their research study finds support for the role of world oil prices on a panel of 24 agricultural commodities. Moreover, positive effect of weak dollar on agricultural prices is also stressed. While linear causality analysis may rather support neutrality between agricultural and oil prices, Nazlioglu (2011) suggest studying the nonlinear causal relationships between the world oil and agricultural commodity prices. Nonlinear causality analysis shows that there is a persistent unidirectional causality from oil prices to corn and soybeans. In their study, Obadi and Korcek (2014) use pairwise Granger causality and VECM-based causality to identify a long run relationship between crude oil price and prices of several examined food commodities with the direction of causality running from crude oil price to food prices. Similar results are further obtained by Peri and Baldi (2010), Natanelov et al. (2011) and Ziegelback and Kastner (2011).

The most recent stream of the topical literature studies the relationship between energy and food prices based on newer data and a wider array of statistical techniques. Using high-frequency data, Koirala et al. (2015) investigate dependence between agricultural commodity futures prices and energy futures prices in a copula based model. Their results reveal strong positive correlation between agricultural commodity and energy future prices. Covering monthly data between 1970 and 2013, de Nicola et al. (2016) provide a comprehensive analysis of the extent of co-movement among energy, agricultural, and food commodities. They state that the price returns of energy and agricultural commodities are highly correlated with a recently increased overall level of co-movement between energy and agricultural commodities, in particular for maize and soybean oil, which are

important inputs in the production of biofuels. Lucotte (2016) divides the 1990-2015 period into sub-periods. While the author reveals strong positive co-movements between crude oil and food prices during the commodity boom after 2007, no statistically significant co-movements are observed over the pre-boom sub-period. Rafiq and Bloch (2016) do not only identify long-run price relationships using both the linear and nonlinear ARDL models and capture short-run causalities through the Granger causality tests, but they also argue that the price effect of crude oil on agricultural commodities is asymmetric. Similarly, Ibrahim (2015) sees a significant long-run relation between oil price increases and food prices. However, the long run relation between oil price reduction and the food price is absent. Furthermore, in the short run, only changes in the positive oil price exert significant influences on the food price inflation. Consistent evidence of the asymmetric impact of oil price shock is also delivered by Zhang and Qu (2015) for the case of the Chinese agricultural commodities.

The literature that we have touched so far did not explicitly employ biofuel price data in the examination of the food-fuel nexus. Also it was focused on the US ethanol market. In the next few paragraphs, we review the biofuels transmission literature which identifies significant price transmission in the models which explicitly include the US ethanol, sometime together with other biofuels or non-US commodities or financial assets.

Examining the time and frequency aspects of the relationships using wavelet analysis, Vacha et al. (2013) distinguish between stable periods, when ethanol is correlated with corn and biodiesel is correlated with German diesel, and crisis periods with ethanol being led by the price of corn and biodiesel by German diesel. This shows important differences between the US and European biofuels markets. Characteristics of the price dependencies among oil, biofuel and its feedstock have been further documented by Saghaian (2010), Serra et al. (2011), Wixson and Katchova (2012), Mallory et al. (2012), Natanelov et al. (2013), Serra (2013) and Bastianin et al. (2014). Recently, Kristoufek et al. (2016) and Filip et al. (2016) employed the wavelet coherence methodology to investigate the evolution

of the relations between prices of ethanol and its feedstocks. They show that the long-run price relationship between ethanol and corn (in the US) or sugar (in Brazil) is positive, strong and stable in time with feedstock leading the prices of ethanol and not the other way around. In contrast, European biodiesel is found to exhibit only moderate ties to its production factors.

Kristoufek et al. (2014) use VAR to study mutual price responsiveness of fuels, biofuels and related commodities in a large system involving all major biofuel markets. Their results reveal that both ethanol and biodiesel prices are responsive to their production factors as well as their substitute fossil fuels (ethanol linked to corn, sugarcane and the US gasoline; biodiesel linked to soybeans and German diesel). Moreover, mutual responsiveness of all significant pairs increased during the food crisis of 2007/2008. Bastianin et al. (2016) find no evidence that ethanol returns Granger cause food price variations. However, ethanol itself is Granger caused and can be predicted by returns on corn. Drabik et al. (2016) conclude that ethanol is a source of imperfect price transmission in the food supply chain. Ethanol reportedly weakens the response of corn and food prices to shocks in their respective markets.

Kristoufek et al. (2012, 2013) and Lautier and Raynaud (2012) enrich the energy price transmission literature by introducing new methodology of minimal spanning trees and hierarchical clustering. As these are primarily data mining techniques, they do not impose any structure on the relationship between analyzed assets and the identified major relationships are based purely on their dynamical properties and not a specific structural model. Lautier and Raynaud (2012) focus on analysis of energy derivatives with the graph theory minimal spanning tree approach. Kristoufek et al. (2012) and Kristoufek et al. (2013) consider both minimal spanning trees and hierarchical trees with explicit inclusion of biofuels prices. Kristoufek et al. (2012) provide a closer look at the structure of biofuels network which splits into two well-separated branches – a fuels part and a food part. Biodiesel tends to the fuels branch and ethanol to the food branch.

Some of the researchers attribute the dramatic agricultural price development of the last decade to a variety of other sources. Adams and Gluck (2015), Han et al. (2015) and Nagayev et al. (2016) agree that the price links between crude oil and agricultural commodities intensified due to the global financial crisis through an increased use of agricultural commodities as financial assets. In addition to a higher economic activity, Gilbert (2010) sees the reason for increased food prices in monetary expansions and exchange rate fluctuations. Cooke and Robles (2009) conclude that it is financial activity in futures markets that helps explain recent behavior of commodity prices. Corresponding reference is provided also by Pokrivcak and Rajcaniova (2011) and McPhail (2011) and most recently by Ordu et al. (2018).

However, there is also a considerable body of literature that speaks in the favor of neutrality between energy and agricultural prices. Zhang and Reed (2008) and Nazlioglu and Soytas (2011) find no significant influence of crude oil on food commodities or on edible oils (Yu et al., 2006). Both Reboredo (2012) and Fowowe (2016) claim that agricultural commodity prices are neutral to oil with no price transmission from oil to agricultural commodities. According to Qiu et al. (2012), biofuel production does not cause long-run food price shifts. Oil, gasoline, and ethanol market shocks are believed not to spill over into grain prices. Cabrera and Schulz (2016) see the existence of oil-feedstock commodity relationship, although it cannot be explained by biofuel production. Similar conclusions are reached also by Hassouneh et al. (2012) and Myers et al. (2014). Myers et al. (2014) investigate long-run and short-run co-movement between spot prices for crude oil, gasoline, and ethanol, and spot prices of corn and soybeans. Their results suggest that spot fuel prices transmit to spot agricultural feedstock prices in the short run, but that the relationship dissipates in the long run. In particular, long-run equilibrium spot fuel and spot agricultural prices were found to be driven by separate stochastic trends and therefore “meander away” from one another over long time horizons. Furthermore, shocks to long-run equilibrium spot fuel prices explain only a relatively small portion of the forecast

error variance in the long-run equilibrium spot agricultural prices. These results suggest that while spot fuel and spot agricultural prices co-move to some extent over intermediate time horizons, corn and soybean prices will be driven more by factors such as productivity growth, acreage response, and the non-ethanol demand for biofuel feedstocks in the long run, rather than by changes in energy prices.

In this context, Zhang et al. (2010) employ the cointegration analysis and the vector error-correction model (VECM) on prices of fuel (ethanol, gasoline, oil) and agricultural commodities (corn, rice, soybeans, sugar, and wheat) to study existence of possible mutual price relationships between the two commodity groups. Based on their results, Zhang et al. (2010) come to the conclusion that there are no direct long-run price relations between fuel and agricultural commodity prices and limited if any short-run relationships. These results are contested in the replication study by Filip et al. (2018).

## *5.2. Brazilian Ethanol*

Covering the Brazilian markets for the early 2000s, Rapsomanikis and Hallam (2006) and Balcombe and Rapsomanikis (2008) find that both sugar and ethanol prices are determined by oil price. Balcombe and Rapsomanikis (2008) use the Bayesian approach to test for the non-linear price adjustments. They find that oil prices are the main drivers of both sugar and ethanol prices. Specifically, they show that a causal hierarchy runs from oil to sugar and then to ethanol, and that nonlinearities characterize the price adjustment processes of sugar and ethanol prices to the oil price. Dutta (2018) uses ARDL bound tests to show that oil and sugar prices lead the Brazilian ethanol prices in the long run and that sugar prices are not affected by the fluctuations in ethanol price.

The analysis by Serra et al. (2011) studies how price volatility in the Brazilian ethanol industry changes over time and across markets. Seo's maximum likelihood approach, which allows for joint VECM and MGARCH estimation, is used here. Their results suggest a strong link between food and energy markets, both in terms of price levels and volatilities.

Bentivoglio et al. (2016) show that ethanol and gasoline, as well as ethanol and sugar price levels are linked in the long run by equilibrium parity. These links show that ethanol prices grow with an increase in both gasoline and sugar prices. The positive relationship between ethanol and sugar prices is not surprising, given the influence of feedstock costs within the total costs of producing ethanol (60%). Furthermore, gasoline prices may affect ethanol prices because ethanol serves as a substitute for gasoline. Their empirical results also show that sugar and gasoline prices drive ethanol prices in the short run. Conversely, they found that ethanol prices have limited influence on food and energy prices. In fact, nowadays the variability of sugar prices depends especially on the international sugar markets while the Brazilian government establishes domestic gasoline prices.

While there is a large number of studies focused on ethanol related domestic price transmission both in US and Brazil, the international price transmission was recently investigated only by Capitani et al. (2018). In particular, their study focused on price analysis and the use of time series models to assess long run relationship, causality and the linkage level over prices in both domestic and international markets, employing methodological frameworks of cointegration and causality testing, as well as the estimation of a structural autoregressive vector model with errors correction (SVECM). The Capitani et al. (2018) analysis of the domestic markets shows that ethanol prices are influenced by international oil prices, indicating that fuel markets are still very important to the ethanol price formation in both markets, especially considering the substitution effects of ethanol by fossil fuel, as gasoline or diesel. In Brazil, sugar prices also have significant causality effect on ethanol prices. In the US, ethanol prices cause corn prices, but corn prices seems to have no causality effect on ethanol prices. When Capitani et al. (2018) analyzed the price causality between countries, they found a causality effect of Brazilian ethanol on US ethanol prices, indicating that the traditional Brazilian production still has a relevance to influence the main producer in the world. Brazilian ethanol prices, however, are more independent, with only 20% of its forecasted errors explained by other prices, as sugar, US ethanol and oil

prices.

There are at least five possible reasons for a weak linkage along the ethanol prices in the international market, especially in the direction from Brazil to the US, as well as the small hedge effectiveness in the use of foreign futures contracts. (i) the outstanding raise of the US ethanol production in the past years created a new important player in this market, however its production is still driven by the US domestic government regulations and mandatory levels of production; (ii) the dramatic drought in the US Mid-West during 2013 had affected the domestic corn production and stocks, changing the price dynamics of both corn and ethanol; (iii) the intensification of intervention policies of the Brazilian government in the gasoline prices, especially from 2011-2015, reduced the profit margins of the ethanol mills; (iv) the decreasing of sugarcane yield in Center-South Brazil from 2011-2014, due to severe climate changes, as well as from the changing of the manual to the mechanical harvesting process; (v) the volatility of the Brazilian exchange rate (BRL/USD), especially in 2015-2016, that could underestimate the hedge effectiveness coefficients in a simultaneous hedge position.

### *5.3. European Biodiesel*

As opposed to the US and Brazilian national markets, there is not really a unified EU biodiesel market. Different EU countries have their separate leading biofuel feedstock and separate biofuels markets and policies. Germany, Spain and to a lesser degree Italy may be considered as the leading EU biodiesel regions.

Spanish biodiesel market is investigated by Hassouneh et al. (2012) where the authors apply a parametric VECM as well as a nonparametric multivariate local polynomial regression (MLPR) to sunflower oil, biodiesel and crude oil price data. The results of the VECM suggest that only biodiesel reacts to deviations from the long run equilibrium. However, sunflower oil reacts to short-run price changes of biodiesel. Furthermore, the results of the MLPR reveal that biodiesel adjusts faster to the long-run equilibrium when its price is

below the equilibrium price than when it is above the equilibrium price.

Peri and Baldi (2010) used the threshold cointegration approach to investigate the presence of asymmetric dynamic adjusting processes between the prices of rapeseed oil, sunflower oil, soybean oil, and diesel. Their results suggest a two-regime threshold cointegration model only for the rapeseed oil-diesel price pair. Thus, the rapeseed oil price adjusts rapidly to its long-run equilibrium, determined by the fossil diesel prices, but this adjustment is asymmetric: it differs if the divergence between the two prices is above or below a critical threshold. Combining a multiple structural change approach with rolling cointegration, Peri and Baldi (2013) identify four structural breaks in the relationships between the price of diesel and rapeseed oil. Their results show that policy instruments are responsible for these structural changes in the long-run relationships between prices. The analysis also shows that from the implementation of the directive 2003/30/EC, the price dynamic of rapeseed oil has shifted from its own market to the diesel market.

Hasanov et al. (2016) focus on examining the impact of crude oil price volatility on the price changes of rapeseed, soybean, and sunflower oils, which are the main feedstock for the biodiesel industry in the European Union. For this purpose, a four-variate version of non-diagonal GARCH-in-mean model that allows for asymmetry in the covariance matrix is used. They show that the crude oil price uncertainty appears to be responsible for a significant decline in price returns of major feedstock edible oils. The volatility impulse response analyses support the conclusion that the conditional variances of both edible and crude oil and covariances between them are generally highly responsive to historical shocks. However, the size of the impacts is mainly commodity specific. The Granger causality test and generalized impulse response function analysis show that there is strong evidence of causality from crude oil price volatility to all edible oil prices under study and that the European edible oil prices significantly respond to the shocks in oil prices.

Rajcaniova and Pokrivcak (2011) focus on the EU fuel prices (oil, gasoline, ethanol) and selected food prices (maize, wheat, and sugar). Conducting a series of statistical tests, they

find a long-run cointegrating relationship between the price series in the later years while merely weak relations prevailed in earlier periods. Due to the significant market changes, Busse et al. (2012) claim a strong orientation of German biodiesel towards diesel prices before 2005 and after 2007. Between 2005 and 2007, biodiesel and rapeseed oil prices were mutually interdependent. In order to allow for changes in the price adjustment behavior of crude oil, rapeseed oil, soy oil and biodiesel due to changing economic and political influences in Germany, Busse et al. (2012) apply a regime-dependent Markov-switching VECM, which allows the parameters of the model to differ between regimes. They find that in the long run, crude oil is the driving force of biodiesel prices and that in turn biodiesel prices drive vegetable oil prices.

Paying attention to the EU biodiesel market, Abdelradi and Serra (2015b) report significant asymmetries in volatility spillovers between biodiesel and rapeseed oil prices. Abdelradi and Serra (2015b) utilized the MGARCH model with exogenous variables in the covariance matrix to estimate price volatility spillovers. Their empirical study uses biodiesel, rapeseed oil, and crude oil prices. Their findings suggest that these three prices have a long-term equilibrium association that is maintained by the pure biodiesel price. Pure biodiesel price volatility is impacted by its own past volatility and past biodiesel and rapeseed market shocks.

## **6. Conclusions**

The development of food prices and global food security is one of the most important questions in the economics of agricultural development. Therefore the price linkages between food and fuels became a leading topic of agricultural economics discussion of global food crises in 2007-2011. The contribution of biofuels to the rise of food prices was one of the primary policy reasons for the changes in government biofuel policies towards implementing limits to public support of first-generation biofuels (Timilsina, 2018). The other major factor against support of biofuels being indirect land use change debate (Zilberman,

2017) which significantly reduced initial high assessment of the positive role of biofuels in mitigation climate change through lower green house gas emissions of biofuels as compared to fossil fuels (Goetz et al., 2018; Searchinger et al., 2008, 2015, 2017; Goldemberg et al., 2018).

After the period of changes during the introductory phase of biofuel policies and during the revision of these policies after the food price crises in 2007- 2011, the price transmission between fuel and food again stabilized. This new stabilized regime of fuel-food price linkages is conducted both through traditional cost transmission channel and through new biofuels policy and profitability channel. As opposed to expectations before the 2007 food crisis, both academic literature and industry do not predict huge expansion of biofuels. The prevailing expectation is of a slow stable growth of biofuels, essentially convergence of global utilization of biofuels close to the current US practice for majority of economies accompanied by further biofuels expansion in the most developed and favorable biofuels market of Brazil.

In our discussion of price transmission between fuel and food markets literature we did not invoke the notion of commodity storage in the determination of agricultural commodity prices (Wright, 2014; Hochman et al., 2014). Carter et al. (2017) estimate in their commodity storage based SVAR model that US corn prices were about 30% higher from 2006 to 2014 than they would have been without the increase of corn demand due to US biofuel policies. Also, in our review we focused mainly on agricultural commodities prices without consistently continuing along the price transmission path towards the consumer food prices. However we included some articles dealing with price impact of crude oil price on consumer food price indexes (Esmaeili and Shokoohi, 2011; Pal and Mitra, 2017, 2018). Similarly on the other side of food production chain, we did not consider the details of the price determination of crude oil (Hochman et al., 2010, 2011).

The time series modeling of fuel-food price transmission follows the trend towards higher sophistication of utilized approaches and towards integration of new methodologies

(graph theory, copulas, wavelets, principal component analysis) with standard time series econometrics methods (variants of GARCH, VAR, cointegration, causality testing). Also time series econometrics is increasingly enriched by integrating structural changes and by improved understanding of biofuels markets. This provides guidance with respect to identifying different market regimes. While the results of the time series models of biofuels are quite varying, it is not a specific feature of this methodological approach since the meta-analyses of structural (partial or general equilibrium) models reveals similarly wide differences or contradictions in their conclusions (Hochman and Zilberman, 2018; Condon et al., 2015) about the impacts of ethanol policies on corn prices.

## **Acknowledgements**

This paper is part of a project that has received funding from the European Union Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 681228. The authors further acknowledge financial support from the Czech Science Foundation (grants number 16-00027S and 18-26714S) and from Charles University internal support scheme PRIMUS/17/HUM/16. Karel Janda acknowledges research support provided during his long-term visit at Australian National University.

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