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Food, energy and environment: Is bioenergy the missing link?

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ABSTRACT

We study price linkages between the food, energy and bioenergy markets. A vertically integrated multi-input, multi-output market model allows us to derive testable hypothesis, which we test by applying time-series analytical mechanisms to nine major traded food commodity prices along with one weighted average world crude oil price. The data consists of 939 weekly observations from January 1993 to December 2010. The empirical findings confirm the theoretical hypothesis that the prices for crude oil and food commodities are interdependent: a USD 1/barrel increase in oil prices and food commodity prices increase by between USD 0.09/tonne and USD 1.65/tonne.

Introduction

The potential role of bioenergy in the recent food price increase has sparked lively debate and controversy concerning the contribution of biofuels to food commodity price developments. On the one hand, international organisations, such as the World Bank, the FAO, and the OECD, argue that biofuels were an important factor leading to higher food prices (Mitchell, 2008; FAO, 2008; OECD, 2009). On the other hand, the EU and US policy executives play down the importance of biofuels in the recent food price developments. For example, the USDA agrees that the biomass demand for biofuels has an impact on food commodity prices, but argues that it is not a major factor (Reuters, 2008). Similarly, the European Commission acknowledges that energy prices affect food commodity prices through the indirect input channel by increasing the cost of inputs, such as nitrogen fertilisers and transport costs. However, the European Commission argues that the impact of biofuels is rather small (European Commission, 2008).

Price volatility has similarly increased in energy and agricultural commodity markets, which raises the question about the links between fossil energy and agricultural commodity prices. Three types of approaches have been followed in the literature. First, cointegration analyses are performed to estimate the long-run relationship between fuel and biomass prices (Campiche et al., 2007; Yu et al., 2006; Hameed and Arshad, 2008; Imai et al., 2008). 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. Secondly, theoretical models are developed to identify and understand the channels of adjustment between agricultural, bioenergy and energy markets (Gardner, 2007; de Gorter and Just, 2008, 2009; Saitone et al., 2008). This strand of literature is relatively new and only few theoretical models exist to date. Thirdly, partial and general equilibrium (CGE) models have been developed to simulate the interdependencies between agricultural, bioenergy and energy markets (Hayes et al., 2009; Birur et al., 2008; Kancs and Wohlgemuth, 2008). The main disadvantage of the CGE approach is that the simulated effects largely depend on calibrated or arbitrary assumed price transmission elasticities. No other study combines theoretical underpinnings with empirical evidence in a unified framework, which is the main purpose of this paper.

The objective of this paper is to theoretically and empirically examine the interdependencies between the energy, bioenergy and agricultural markets. Our theoretical model (Section "Theoretical framework") builds on the models developed by Gardner (2007) and de Gorter and Just (2008, 2009), which develop a vertical market integration model of ethanol, by-product and corn markets. Our study contributes to the literature by including the indirect input channel of price transmission between food and

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biofuel prices in the model. Our second contribution is to analyse price transmission not only for agricultural commodities directly used but also for those commodities not employed in biofuel production. The theoretical model's results are verified in a simulation analysis. Our empirical approach (Cointegration analysis) is based on cointegration analysis (Johansen, 1988; Johansen and Juselius, 1990; Kielyte, 2008). We examine the long-run relationship between crude oil and agricultural commodity prices by estimating an error correction model.

Theoretical framework

Bioenergy models in the literature

Several models have been developed for studying the effect of biofuels on agricultural markets. Gardner (2007) developed a vertical market integration model of ethanol, by-product and corn markets to analyse the effects that corn and ethanol subsidies have on welfare in the US. The main shortcoming of this model is that the ethanol market is modelled separately from the aggregate fuel market (fossil fuel and biofuels). The price transmission between fuel and corn depends crucially on the assumption about the cross-price elasticity between fuel and ethanol.

De Gorter and Just (2008, 2009) extended the *Gardner's* model by incorporating ethanol in the aggregate fuel market. The price transmission between fuel and corn is effectuated through the demand for corn in ethanol production and occurs when the fuel price is high enough and/or when the corn price is low enough, ensuring that corn-based ethanol production is more profitable than corn for food use.[1] Saitone et al. (2008) also focused on the US ethanol/corn sectors and income distribution effects of ethanol subsidies. *They* showed that market power upstream in the input market and downstream in the corn-processing sector may constrain price transmission between ethanol and corn.

Although innovative, these models contain important methodological shortcomings. In particular they fail to account for some key inter-linkages present in the fuel–biofuel–food markets. First, all three models described above show that the price transmission from fuel to agricultural markets is effectuated only through the demand for agricultural commodities in biofuel production. They do not consider the indirect input channel. In reality, fuel is an important input in agricultural production, such as diesel, fertilisers and pesticides; hence it affects agricultural prices through the agricultural production costs. Ignoring this effect may lead to upward bias in estimates of biofuel expansion on agricultural prices. Second, all three models only consider one agricultural commodity (i.e. that used for biofuel production). With multiple commodities, the derived effects may change and the fuel market may affect not only biomass crops, but also those commodities, which are not directly used in biofuel production.

The model

The present study builds on models developed by Gardner (2007) and of de Gorter and Just (2008, 2009) and introduces two important extensions. First, to account for cross-commodity price effects, we introduced two agricultural commodities: one suitable for biofuel production (referred to as 'biomass')[2] and one not suitable for biofuel production (referred to as 'food'). Second, we consider the price transmission also through the input channel by explicitly modelling the agricultural input markets. Furthermore, to take into account the international price linkages, we have not focussed on a particular region but the model is for the world market in general.

The world economy is assumed to consist of vertically integrated agricultural, biofuel, fossil fuel, by-product, and input markets. We assume that the representative farm can substitute between producing two agricultural commodities (biomass and food) using constant returns to scale production functions of two substitutable inputs: fuel and other inputs (referred to as 'land'). Biomass output can be supplied to both food and biofuel markets whereas food commodity can only be supplied to the food market. The biofuel sector uses biomass to produce biofuels and by-product. The aggregate fuel market is a sum of biofuel and fossil fuel.

We firstly considered the agricultural sector. The representative agricultural farm is assumed to maximise a standard profit function which is the difference between sales revenue from biomass and food commodity and cost expenditures on land and fuel: $\Pi = \sum p^i Q^i(N^i, K^i) - wN^i - rK^i$ (for $i = AB, AN$), implying the following equilibrium conditions:

$$p^i \partial Q^i / \partial N^i = w \quad \text{for } i = AB, AN \tag{1}$$

$$p^i \partial Q^i / \partial K^i = r \quad \text{for } i = AB, AN \tag{2}$$

where Q is production function, N is non-fuel input (land), K is fuel input, p is farm output price, w is land rental price, and r is fuel price. The indexes AB and AN stand for biomass and food commodity, respectively. Equations (1) and (2) describe the marginal conditions for land and fuel inputs, respectively. Solving Eqs. (1) and (2) yields farm input demand and output supply of agricultural commodities as a function of output and input prices.

We then considered biofuel production. We assumed a constant Leontief transformation technology in the biofuel sector with the constant extraction coefficient denoted by β. Each biomass unit results in β units of biofuel.[3] Additionally, biofuel production yields feed by-product, γ, measured in terms of feed quantity per unit of biomass. To simplify the analyses, we assumed constant value of unit processing costs (adjusted for the mark-up), c, incurred to biofuel production from one unit of biomass. Therefore, biofuel profitability is determined by both biomass and by-product prices net of processing costs. The possibility to use biomass for both food and biofuel productions implies that biofuel, $S^B(r)$, and by-product, $S^O(p^O)$, supplies represent the excess supply of biomass over biomass food demand adjusted by the extraction coefficients, $S^B = \beta(S^{AB} - D^{AB})$ and $S^O = \gamma(S^{AB} - D^{AB})$, respectively, where p^O is the price for by-product.

The world's fossil fuel supply together with the biofuel supply generate the aggregate fuel supply curve, $S^{TF}(r) = S^F + S^B$, where $S^F(r)$ is the world supply curve of fossil fuel. The aggregate fuel demand, $D^{TF}(r)$, is a sum of agricultural fuel demand, $K^{AB} + K^{NB}$, and non-agricultural fuel demand, $D^{NF}(r, t)$, where t is an exogenous parameter, which we used to derive the comparative static effects of fuel demand shocks.[4]

The market equilibrium conditions can be summarised as follows:

$$\text{if } p_o^{AB} \geqslant \beta r + \gamma p_o^O - c \;\Rightarrow\; S^B = S^O = 0 \;\Rightarrow\; D^{AB} = S^{AB} \tag{3a}$$

[1] Price transmission will not occur for low fuel and/or high corn prices. In this case, the corn-based ethanol production is not competitive, implying zero ethanol production in equilibrium.

[2] Note that we have considered the case where the agricultural commodity suitable for biofuel production may be used for both food and biofuel production. We have named it biomass to simplify the text.

[3] We assume that this coefficient also adjusts for quality differences between biofuel and fossil fuel. It therefore represents biofuel as an equivalent of fossil fuel.

[4] In order to simplify the analysis, we assumed perfect substitutability between biofuel and fossil fuel in consumption. In reality, fuel containing a low proportion of biofuels (e.g. 10% or less in the case of ethanol) can be used in virtually all standard vehicles. However, fuel with a high proportion of biofuels requires engine adaptation, which implies additional (fixed) costs to consumers. Therefore, depending on the relative importance of these adjustment costs, the theoretical model may slightly overstate the impact of biofuels on agricultural prices.