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The Effect of Biodiesel Policies on World Oilseed Markets and Developing Countries

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Abstract

Using an empirical model, this study provides some insights into the functioning of the oilseed-biodiesel-diesel market complex in a large country that determines the biodiesel price, reflecting market equilibrium changes resulting from volatility in the crude oil price. Oilseed crushing produces joint products—oil and meal—and this weakens the link between the biodiesel and oilseed feedstock prices. Higher crude oil prices increase biodiesel prices if biofuel benefits from a fuel tax exemption, but lower them with a blending mandate (minimum biofuel content requirement in marketed fuel). When both canola and soybeans are used to produce biodiesel, an increase in the crude oil price leads to higher canola prices, but the effect on soybean prices is ambiguous and depends on relative elasticities of meal demand and canola supply because canola produces more oil than soybeans. An oil price shock with a blending mandate results in a smaller change in oilseed prices compared with a fuel tax exemption. Jumps in world crude oil prices have differential impacts on commodity prices and welfare in developing countries, depending on which policy determines the biodiesel price in OECD countries.

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The Effect of Biodiesel Policies on World Oilseed Markets and Developing Countries*

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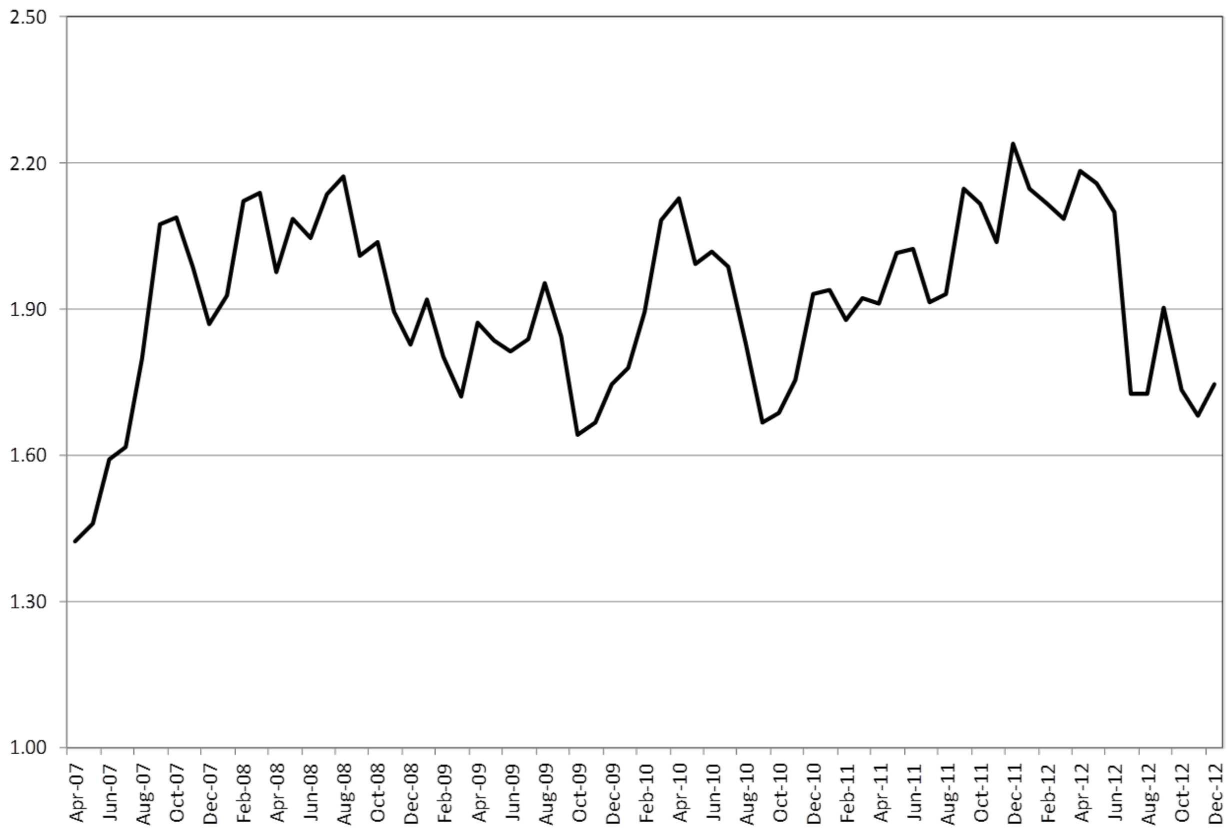
1. Introduction

Biodiesel averaged 17.9 percent of total world biofuel production in the period of 2010-2012;[1] however, its share in vehicle miles traveled (VMT) equivalent is higher as a gallon of biodiesel produces 91 percent of the VMT compared to the same volume of diesel, while ethanol produces only 70 percent of the VMT compared to gasoline. In the United States, biodiesel prices were on average 1.91 times higher (or 1.49 times higher on energy equivalent basis) than ethanol prices in the period from April 2007 to December 2012, reaching a peak in December 2011 with a multiple of 2.24 or 1.74 on an energy equivalent basis (Figure 1). A similar pattern is found in the European Union and Brazil.[2]

Figure 1. Ratio of Biodiesel to Ethanol Prices



There are several reasons for this significant price differential. For example, the United States and Brazil[3] have a specific biodiesel mandate where soybean oil is the primary feedstock,

[1] http://stats.oecd.org/Index.aspx?DataSetCode=HIGH_AGLINK_2011
[2] The European Union, the United States and Brazil are world's most important biodiesel producers and consumers.
[3] Brazil's market is isolated from world markets through a government price setting program.

and the European Union employs significantly higher import barriers on biodiesel than on ethanol (with canola oil being the principal feedstock).[4]

The implications of OECD biodiesel policies for developing countries are not only higher oilseed prices, but also a substantial increase in the relative value of oil *versus* oil meal for oilseeds which affect food prices and consumer welfare because vegetable oil consumption rises significantly as a country develops. Moreover, world prices of corn and other feedstocks for ethanol also increase as a result of biodiesel policies in large developed countries – because of competition for land – thus, altering income distribution in developing countries: net producers of staple commodities are better-off, while net consumers lose. Needless to say, changes in world commodity prices can change the trade position of a developing country.

The objective of this paper is to provide some insights into the functioning of the oilseed-biodiesel-diesel market complex in a large country that determines the biodiesel price and to determine how the market equilibrium changes in response to volatility in the crude oil price. Since (small) developing countries act as price takers in the commodity markets analyzed in this paper (i.e., soybean, canola and oils/meat thereof, as well as biodiesel), the predictions of our model can be used, for example, for shaping biofuel policies in developing countries. We assume that biodiesel producers in the large country face stable and sufficient supply of feedstock, an assumption that might not be appropriate for a small developing country (Msangi and Evans, forthcoming).

The analytical model captures the most important features of the oilseed-biodiesel-diesel market complex by incorporating the value of joint products, processing costs, fuel taxes and biodiesel policies. We also study how volatile crude oil prices affect the biodiesel feedstock prices. Our model assumes a large country in world biodiesel and oilseed (soybean, canola) markets that implements either a biodiesel consumption subsidy (e.g., the U.S. tax credit or tax exemption at the pump level as in the European Union; see de Gorter et al. 2011 for details) or imposes a blending mandate on the share of biodiesel in the final diesel fuel blend (as in most countries with a biofuels policy). In addition to the major biodiesel feedstocks – soybean and canola – the model is applicable to a variety of other oilseeds that are crushed into oil and meal; the model can also be used, after small adjustments, for analyses of biodiesel from jatropha or oil palm.

We emphasize how the different production process of ethanol and biodiesel affects the link between a biofuel and its feedstock. While corn-ethanol is directly produced from yellow corn, hence the direct relationship between ethanol and corn prices (de Gorter and Just, 2009; Cui et al., 2011; Drabik, 2011; Lapan and Moschini, 2012), soybean (canola) has to be crushed first into soybean oil and meal, and biodiesel is then produced from the extracted soybean (canola) oil. It is the *jointness* in oilseed crushing (producing oil and meal) that breaks the direct link, observed for ethanol, between the biofuel and its feedstock prices.

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[4] In the United States, biodiesel is regarded as the second generation biofuel and its consumption is thus important for meeting the overall Renewable Fuel Standard. Some EU countries also set biodiesel specific blending targets.

We find that higher crude oil prices that translate into higher diesel prices increase the biodiesel price under a (binding) tax exemption (or tax credit), but reduce it under a binding blending mandate. This occurs because under the tax exemption consumers are free to choose which fuel they buy, depending on fuel's price per mile traveled; hence diesel and biodiesel are substitutes under a binding tax exemption (tax credit).[5] However, a binding blend mandate dictates a fixed proportion of biodiesel to diesel, thus implying complementarity between the two fuels. However, the impact of a crude oil price surge on the feedstocks prices is generally ambiguous and depends on the number of biodiesel feedstocks modeled – the results are equivocal when both soybean and canola are used to produce biodiesel (because canola yields more oil per hectare than soybean). We also find that for the same biodiesel production, a shock in the diesel price under a binding blend mandate results in a change in canola (soybean) price of a lower magnitude than under a binding tax exemption.

The remainder of the paper is structured as follows. The next Section outlines the basic model with only one biodiesel feedstock, soybean. In Section 3, we extend the basic model to include a second feedstock (canola) that yields more oil per hectare and is thus preferred by farmers. We show how the inclusion of the second feedstock alters the model's responses to a higher crude oil price. In Section 4, we empirically illustrate our theoretical results using the United States as an example of a large country in soybean and biodiesel markets. The final section concludes and draws some implications of the model for small developing countries.

2. A Model with One Oilseed Feedstock (Soybeans)

This section develops a simple analytical model that captures the key features of the soybean–biodiesel market complex.[6] We build a model for a country whose biofuel policies affect world prices of biodiesel and biodiesel feedstocks, such as soybean or canola, but the country is a price taker in the crude oil market. The price taking assumption makes it easier to model the effects of crude oil price volatility on the soybean-biodiesel market equilibrium and thus present the key results more transparently. In this section, we present the model for a binding tax exemption.[7] The mathematical representation of a model for a binding blend mandate is presented in Appendix 1.

Consider a volumetric tax exemption, t_e, for biodiesel that determines the biodiesel price, meaning that the tax exemption is the binding biofuel policy. This assumption reflects, for example, the market situation in the European Union prior to 2008 (de Gorter et al., 2011). Competitive fuel blenders equate their marginal revenue per gallon of biodiesel (inclusive of the net fuel tax, i.e., gross fuel tax, t, less the tax exemption), $P_B^v + t - t_e$, to the consumers'

[5] Although, vehicle engines could, in theory, run on pure biodiesel (B100), in practice the upper limit for blending approved by vehicle manufacturers is 5 (B5) or 20 (B20) percent, meaning that the fuel blend contains 5 (20) percent of biodiesel and 95 (80) percent of conventional diesel. The EPA recommends that biodiesel blends containing more than 20 percent of biodiesel should be evaluated on a case-by-case basis (EPA, 2007).
[6] For analytical tractability, we abstract from trade in soybeans, soybean oil, soybean meal, and biodiesel.
[7] The model equally holds for a blender's tax credit.

willingness to pay that reflects fewer vehicle miles traveled per gallon of biodiesel, $\lambda(P_D + t)$; where P_B^v and P_D are biodiesel and diesel market prices in \$/gallon, and the parameter λ denotes vehicle miles traveled per gallon of biodiesel relative to diesel ($\lambda \approx 0.91$). The volumetric market price of biodiesel under the binding tax exemption then equals

$$P_B^v = \lambda P_D - (1-\lambda)t + t_e \tag{1}$$

For proper comparisons,[8] we express all prices and quantities in diesel energy-equivalent gallons (DEEG),[9] which entails dividing equation (1) by the parameter λ to obtain

$$P_B = P_D - \left(\frac{1}{\lambda} - 1\right)t + \frac{t_e}{\lambda} \tag{2}$$

When the tax exemption binds, the fuel price, P_F, equals the sum of diesel market price and the fuel tax because consumers are willing to pay for the fuel (mixture of biodiesel and diesel) based on the mileage the fuel produces

$$P_F = P_D + t \tag{3}$$

The distinguishing feature of the soybean oil-biodiesel market is the *jointness in production*: soybean's crushing yields soybean oil and soybean meal.[10] We assume that processors of soybean oil and soybean meal operate under constant returns-to-scale and make zero marginal profits; moreover, the processing cost c_{0s} per metric tonne of soybean oil (crushing margin) is assumed to be fixed. The zero marginal profit condition

$$\beta_1 P_{SO} + \beta_2 P_M - P_{SB} - \beta_1 c_{0s} = 0 \tag{4}$$

then defines the price of soybeans, P_{SB}, in terms of the price of soybean oil, P_{SO}, and soybean meal, P_M

$$P_{SB} = \beta_1 P_{SO} + \beta_2 P_M - \beta_1 c_{0s} \tag{5}$$

where $\beta_1 = 0.19$ and $\beta_2 = 0.81$ denote metric tonnes of soybean oil and soybean meal, respectively, produced from one metric tonne of soybeans (FAPRI, 2012).

The market prices of soybean oil and biodiesel, P_B, are linked through a zero profit condition in biodiesel production as follows[11,12]

[8] We follow Lapan and Moschini (2012) who model welfare effects of the U.S. corn-ethanol policies; they too express all prices and quantities related to the fuel market in gasoline energy-equivalent gallons.
[9] One DEEG is the amount of fuel containing as much energy (translated into miles traveled) as there is in a gallon of diesel.
[10] In the corn-ethanol case, we have a *co-product* in the form of DDGS (Dried Distillers Grains with Solubles) while in the sugarcane-ethanol market, we have *competing products* (ethanol versus sugar) and *by-products:* molasses from sugar production used in ethanol production; and bagasse used for electricity. Note: a by-product is not the same as a co-product; the latter refers to a product that is returned to the market in an equivalent form as the product comes from (e.g., DDGS come from corn).
[11] Lapan and Moschini (2012) present an analogous equation for ethanol and corn prices.
[12] Our model does not consider palm oil which is priced differently in practice than soybean oil because of the changing demand for animal feed. Hence the model does not allow for substitution between soybean oil and palm oil. For simplicity, we assume vegetable oil to be a homogeneous product used for biodiesel production regardless of its origin.

$$P_{SO} = \beta_3 \left(P_B - c_{0b} \right) \qquad (6)$$

where β_3 = 990.1 denotes DEEGs of biodiesel extracted from one metric tonne of soybean oil, and c_{0b} denotes the processing cost per DEEG of biodiesel.[13]

Market clearing requires that the demand for soybean meal, D_{SM}, equals the supply; the latter is derived from the supply of soybeans, S_{SB}, by a fixed coefficient production process

$$D_{SM} \left(P_M \right) = \beta_2 S_{SB} \left(P_{SB} \right) \qquad (7)$$

Soybean oil is used for biodiesel production, as well as for human consumption. The equilibrium in the soybean oil market is obtained by equalizing the demand for human consumption, D_{SOH}, with the residual supply of soybean oil. The residual supply comes from the difference between the total quantity of soybean oil available and the quantity of the soybean oil used for biodiesel, B^{SB}

$$D_{SOH} \left(P_{SO} \right) = \beta_1 S_{SB} \left(P_{SB} \right) - \frac{B^{SB}}{\beta_3} \qquad (8)$$

Rearranging equation (8), the production of biodiesel is expressed as

$$B^{SB} \equiv \beta_1 \beta_3 S_{SB} \left(P_{SB} \right) - \beta_3 D_{SOH} \left(P_{SO} \right) \qquad (9)$$

The market equilibrium consists of equations (2), (5), (6), and (7). Note that the production of biodiesel is determined by soybean and soybean oil prices, and the quantity of diesel consumed is equal to $D_F \left(P_F \right) - B^{SB}$, where D_F denotes the fuel demand curve.

The presented model enables us to analyze the effects of a shock in the diesel price (caused by a shock in the crude oil price) on the market prices of the analyzed commodities. Totally differentiating equations (2), (3), (5), (6), and (7) and solving for the effect of a higher diesel price, we obtain

$$\frac{dP_B}{dP_D} = \frac{dP_F}{dP_D} = 1$$

$$\frac{dP_{SO}}{dP_D} = \beta_3$$

$$\frac{dP_{SB}}{dP_D} = \frac{\beta_1 \beta_3 \eta_{SM}^D}{\eta_{SM}^D - \beta_2 \eta_{SB}^S \frac{P_{SM}}{P_{SB}}} > 0 \qquad (10)$$

$$\frac{dP_{SM}}{dP_D} = \frac{\beta_1 \beta_3 \eta_{SB}^S}{\eta_{SM}^D \frac{P_{SB}}{P_{SM}} - \beta_2 \eta_{SB}^S} < 0$$

where η_{SM}^D and η_{SB}^S denote elasticities of demand for soybean meal and of supply of soybeans, respectively.

[13] There are by-products from biodiesel production (e.g., glycerin) but their value is small and declining (even negative in Europe); hence, we incorporate them into the value of c_{ob}.

The first pair of derivatives in (10) shows that under a binding tax credit, an exogenous shock to the diesel price transmits one-to-one to the biodiesel market price and the consumer fuel price. The rise in the biodiesel price translates into a higher soybean oil price by the soybean oil-to-biodiesel conversion factor of β_3. The need for more soybean oil processed stimulates soybean production through higher soybean prices. As a result, the soybean meal price decreases to accommodate the greater quantity of soymeal due to increased soybean production. Notice that the parameters of the demand for soybean oil for human consumption are absent from the derivatives in (10). This is due to the assumption of a perfectly elastic diesel supply curve. In that situation, the prices of biodiesel, soybean oil, and fuel are directly linked to the diesel price. Only prices of soybean and soybean meal are endogenous. This means that higher crude oil prices negatively and directly affect the welfare of consumers of edible soybean oil, especially those in developing countries.

The shocks in the oil market that affect the oil price under the binding biodiesel blend mandate have almost exclusively reverse effects on the market prices compared to the situation with the binding tax exemption (Appendix 1). This point is, perhaps, best illustrated by the effect of a higher diesel price on the biodiesel price. Since the numerator of the first derivative in Appendix 1 is unambiguously negative, the denominator

$$\left(\beta_1^2 S_{SB}' - D_{SOH}'\right)\beta_3^2 + \frac{\left(\beta_1\beta_2\beta_3 S_{SB}'\right)^2}{D_{SM}' - \beta_2^2 S_{SB}'} - \alpha^2 D_F' \tag{11}$$

determines the overall sign of the derivative. Realizing that the term $\alpha^2 D_F'$ is always negative, the term D_F' denotes the derivative of the fuel demand curve and hence its slope, expression (11) will be positive if

$$\left(\beta_1^2 S_{SB}' - D_{SOH}'\right)\beta_3^2 + \frac{\left(\beta_1\beta_2\beta_3 S_{SB}'\right)^2}{D_{SM}' - \beta_2^2 S_{SB}'} \geq 0 \tag{12}$$

The inequality (12) reduces to $\left(\beta_1^2 S_{SB}' - D_{SOH}'\right) D_{SM}' + \beta_2^2 S_{SB}' D_{SOH}' \leq 0$, which must always hold because the soybean supply curve is positively sloped ($S_{SB}' \geq 0$), and the demand curves for soybean meal and edible soybean oil are negatively sloped ($D_{SM}', D_{SOH}' \leq 0$).

Thus, a higher diesel price reduces the biodiesel market price when the blend mandate binds. The reason is that a higher diesel price (due to a higher crude oil price) increases the marginal cost to fuel blenders who therefore increase the consumer fuel price. As a result, fuel consumption decreases, as does the blenders' demand for biodiesel because it is proportional to the total fuel use. Thus, the market price of biodiesel decreases and affects the movement of all other market prices in opposite directions relative to the results on the binding tax exemption.

The only exception is the effect of a higher diesel price on the fuel price: the fuel price rises; this result is qualitatively equivalent to the case of a binding tax exemption. However, the price pass-through is not generally perfect, as the last derivative in Appendix 1 shows. A dollar for dollar price transmission only occurs when the fuel demand is perfectly inelastic, in which case the biodiesel price does not respond to the fluctuations in the diesel price and so the relationship between diesel and fuel prices is one-for-one.

The simple model developed above does not only provide useful information about responses in commodity markets for a large country due to higher crude oil prices but has also important implications for developing countries. For example, it implies that an increase in the world crude oil price will have differential impacts, depending on which policy determines the biodiesel price in the large country. More specifically, because a small developing country is a price taker in, for example, soybean markets, the prices of this commodity are likely to increase when the tax exemption is binding, but decrease when the mandate is binding. This implies that the same increase in the world crude oil price under various biofuel policies in the large country can have different distributional effects on market participants in the small country.

However, as we show in the next section, caution is warranted not to take the predictions of the effects of higher diesel prices on the feedstock prices too far when the model considers only one oilseed.

3. A Model with Two Oilseed Feedstocks (Soybean and Canola)

Because of growing biodiesel demand, the increasing relative value of oilseed oil over meal incentivizes the switch to more oil intensive crops. To illustrate, as biodiesel prices in the United States have doubled since mid-2010, we observe farmers switching to canola over soybeans. Because oil represents 45 percent of the weight of canola and only 19 percent of soybean,[14] more oil can be obtained from one hectare of canola. This has implications for developing countries as they decide between (or may switch to) soybeans, palm oil or jatropha.[15] Canadian and U.S. farmers are converting to canola as the oil content of canola is much higher, even though the yield per acre is lower than that for soybeans. Because of food demand for oils, one may not expect a high divergence in soybean oil and canola oil prices but feedstock prices could diverge where canola prices increase relative to soybeans.

We now extend the model of one oilseed feedstock to include the canola market. In order to avoid repetition of the equations pertaining to the soybean market in the combined model, we only report the equations related to the canola part of the model. We assume soybean meal and canola meal are perfect substitutes in feed consumption, that is, demand for oilseed meal is equal to the sum of supplies of individual meals; the common price of the meal is denoted as P_M. However, because of consumers' preferences and different yields of biodiesel per pound of oilseed oil, we assume soybean and canola oils are imperfect substitutes, and we model the imperfect substitutability by establishing separate equilibria in soybean oil and canola oil markets.

[14] http://www.hort.purdue.edu/newcrop/afcm/canola.html

[15] Msangi and Evans (forthcoming) and Shinoj et al. (2011) point out possible problems with using jatropha, especially the absence of an economically usable joint product, that is, meal which adversely affects the profitability of biodiesel production from jatropha.

The zero profit condition for diesel production from canola oil establishes a link between the price of canola, P_{CN}, canola oil, P_{CO}, and canola meal

$$P_{CN} = \gamma_1 P_{CO} + \gamma_2 P_M - \gamma_1 c_{0c} \tag{13}$$

where γ_1 = 0.383 and γ_2 = 0.617 denote metric tonnes of canola oil and canola meal, respectively, produced from one metric tonne of canola (FAPRI, 2012). The parameter c_{0c} denotes the (fixed) crushing margin per metric tonne of canola oil.

The link between the price of canola oil and the biodiesel market price is similar to that for soybeans (and is also derived from the zero profit condition for biodiesel production)

$$P_{CO} = \gamma_3 \left(P_B - c_{0bC} \right) \tag{14}$$

where γ_3 = 990.1 denotes DEELs of biodiesel per metric tonne of canola oil, and c_{0bC} denotes the (fixed) processing cost per one DEEL of biodiesel from canola.

Market clearing for the meal market and the assumption of perfect substitutability between the soybean and canola meal in feed consumption require that the total demand for meal, D_M, equals the sum of the meal produced from soybean and canola

$$D_M \left(P_M \right) = \beta_2 S_{SB} \left(P_{SB} \right) + \gamma_2 S_{CN} \left(P_{CN} \right) \tag{15}$$

The equilibrium in the canola oil market is given by

$$D_{COH} \left(P_{CO} \right) = \gamma_1 S_{CN} \left(P_{CN} \right) - \frac{B^{CN}}{\gamma_3} \tag{16}$$

which translates into

$$B^{CN} \equiv \gamma_1 \gamma_3 S_{CN} \left(P_{CN} \right) - \gamma_3 D_{COH} \left(P_{CO} \right) \tag{17}$$

and B^{CN} denotes the amount of biodiesel produced from canola oil.

The question we want to answer in this section is: What are the market effects of an exogenous increase in the diesel price if biodiesel is produced from two oilseed feedstocks? Akin to the previous section, we start by assuming the biodiesel price is determined by the tax exemption. (The derivation of the results under a binding blend mandate can be found in Appendix 2.) In this case, the market equilibrium consists of equations (2), (5), (6), (13), (14), and (15). Totally differentiating this system of equations, we solve for the effect of an increase in the diesel price on individual market prices

$$\frac{dP_B}{dP_D} = \frac{dP_F}{dP_D} = 1$$

$$\frac{dP_{SO}}{dP_D} = \beta_3; \frac{dP_{CO}}{dP_D} = \gamma_3$$

$$\frac{dP_M}{dP_D} = \frac{\beta_1\beta_2\beta_3\eta_{SB}^S \frac{S_{SB}}{P_{SB}} + \gamma_1\gamma_2\gamma_3\eta_{CN}^S \frac{S_{CN}}{P_{CN}}}{\eta_M^D \frac{D_M}{P_M} - \beta_2{}^2\eta_{SB}^S \frac{S_{SB}}{P_{SB}} - \gamma_2{}^2\eta_{CN}^S \frac{S_{CN}}{P_{CN}}} < 0$$

$$\frac{dP_{CN}}{dP_D} = \frac{\gamma_1\gamma_3\eta_M^D \frac{D_M}{P_M} + \left(\beta_1\beta_3\gamma_2 - \gamma_1\gamma_3\beta_2\right)\beta_2\eta_{SB}^S \frac{S_{SB}}{P_{SB}}}{\eta_M^D \frac{D_M}{P_M} - \beta_2{}^2\eta_{SB}^S \frac{S_{SB}}{P_{SB}} - \gamma_2{}^2\eta_{CN}^S \frac{S_{CN}}{P_{CN}}}$$

$$\frac{dP_{SB}}{dP_D} = \frac{\beta_1\beta_3\eta_M^D \frac{D_M}{P_M} + \left(\gamma_1\gamma_3\beta_2 - \beta_1\beta_3\gamma_2\right)\gamma_2\eta_{CN}^S \frac{S_{CN}}{P_{CN}}}{\eta_M^D \frac{D_M}{P_M} - \beta_2{}^2\eta_{SB}^S \frac{S_{SB}}{P_{SB}} - \gamma_2{}^2\eta_{CN}^S \frac{S_{CN}}{P_{CN}}} \qquad (18)$$

The intuition for the first five derivatives in (18) is the same as for the model with only one oilseed feedstock. However, the effect of an exogenous increase in the diesel price on the canola and soybean prices critically depends on the sign of the term $\beta_1\beta_3\gamma_2 - \gamma_1\gamma_3\beta_2$. If $\beta_1\beta_3\gamma_2 - \gamma_1\gamma_3\beta_2 < 0$, then an increase in diesel (biodiesel) price unambiguously results in an increase in the price of canola. Indeed, for parameters' values given above, $\beta_1\beta_3\gamma_2 - \gamma_1\gamma_3\beta_2 = -$191. But since $\beta_1\beta_3\gamma_2 - \gamma_1\gamma_3\beta_2 < 0$ implies $\gamma_1\gamma_3\beta_2 - \beta_1\beta_3\gamma_2 > 0$, the effect on the price of soybeans is ambiguous, depending on the elasticities of meal demand and canola supply. The more elastic the canola supply curve, the more canola will be produced due to higher biodiesel price (caused by an increase in the price of diesel) and so soybean prices decline more for a given elasticity of the meal demand curve. Alternatively, for a given canola supply elasticity, the more inelastic the meal demand curve, the more meal prices decline due to higher canola production and so the more likely soybean prices decline.

In Appendix 2, we develop a parallel set of results for a situation where biodiesel is produced from two feedstocks but the binding policy is a biodiesel blend mandate. A careful comparison of the derivatives in (18) with those in Appendix 2 shows that an increase in the diesel price under a binding blend mandate has generally opposite effects on the market equilibrium relative to a binding tax exemption. However, the results are qualitatively the same for the effect of a higher diesel price on canola and soybean prices – the effect is ambiguous.[16] More importantly, however, because of the imperfect diesel-to-biodiesel price transmission (unlike under the tax exemption), we have *Result 1:* For the same biodiesel production, a shock

[16] That is, the sign of the derivatives depends on the sign of the term $\beta_1\beta_3\gamma_2 - \gamma_1\gamma_3\beta_2$.

in the diesel price under a binding blend mandate results in an (ambiguous) change in canola (soybean) price of a lower magnitude than under a binding tax exemption.

4. Empirical Illustration

In Table 1, we empirically investigate how biodiesel and soybean oil prices respond to an increasing crude oil price, depending on which biofuel policy is binding. We use the United States as an example of a large country producer of biodiesel. The underlying data for the calibrated model pertain to the year 2010.[17] The first column of Table 1 presents theoretical crude oil prices ranging between 40 and 120 $/barrel. The second column presents predicted diesel prices for each level of crude oil price.[18] The predicted prices of biodiesel under the tax credit and corresponding crude oil prices are in the third column and are calculated using equation (1). The fourth column presents predicted soybean prices, using equation (6), associated with the biodiesel price under the binding tax credit. Consistent with the theoretical model, the predicted biodiesel and soybean oil prices rise as the crude oil (diesel) price increases.

However, under a binding blend mandate, associated with a higher crude oil price is a lower biodiesel price, and hence soybean oil price. This inverse relationship exists because higher crude oil prices translate into higher market prices for diesel which increases the marginal cost for fuel blenders who transfer the increase in their marginal costs onto fuel consumers. As a result, the diesel fuel consumption decreases, as does the need for biodiesel that is blended proportionally to the fuel. Therefore, biodiesel prices decrease, and so do soybean oil prices.

In Table 1, we assume that only one biofuel policy is in place at a time. However, because higher crude oil prices result in increasing biodiesel prices under the tax credit and decreasing prices under the mandate, we can determine the minimum crude oil price that makes the tax credit binding; in Table 1, this price is approximately $84/barrel. This break-even crude oil price is important for small developing countries because, as we have shown earlier, the crude oil price has differential impacts on commodity prices, depending on which biofuel policy binds. For example, one implication of Table 1 is that if the large country pursues a biodiesel mandate and oil prices are below $84/barrel, then an increase in the crude oil price will, *ceteris paribus*, result in lower soybean oil prices, and hence the prices of soybeans.

[17] In 2010, the U.S. blender's tax credit for biodiesel was $1/gallon and the diesel tax $0.55/gallon. We set the blend mandate equal to 0.7 percent, which is equal to the observed energy share of biodiesel in the total biodiesel and diesel blend.

[18] The predicted diesel price is calculated as: diesel price = 0.055 + 0.029 times the crude oil price; the coefficients were estimated using OLS on historical data for diesel and crude oil.

Table 1. Predicted Biodiesel and Soybean Oil Prices for Alternative Crude Oil Prices

		Tax credit binding		Mandate binding	
Theoretical price of crude oil ($/barrel)	Predicted price of diesel ($/gallon)	Predicted price of biodiesel ($/gallon)	Predicted price of soybean oil ($/metric tonne)	Predicted price of biodiesel ($/gallon)	Predicted price of soybean oil ($/metric tonne)
40	1.22	2.07	585.8	3.32	943.0
45	1.37	2.20	623.9	3.30	939.3
50	1.51	2.33	662.1	3.29	935.9
55	1.66	2.47	700.2	3.28	932.9
60	1.80	2.60	738.3	3.27	930.1
65	1.95	2.73	776.5	3.26	927.5
70	2.10	2.87	814.6	3.25	925.1
75	2.24	3.00	852.8	3.25	922.9
80	2.39	3.13	890.9	3.24	920.8
85	2.53	3.27	929.0	3.23	918.8
90	2.68	3.40	967.2	3.22	917.0
95	2.83	3.53	1005.3	3.22	915.2
100	2.97	3.67	1043.5	3.21	913.6
105	3.12	3.80	1081.6	3.21	912.0
110	3.26	3.93	1119.7	3.20	910.6
115	3.41	4.07	1157.9	3.20	909.2
120	3.55	4.20	1196.0	3.19	907.8

Source: calculated

The very close co-movement of actual and predicted soybean oil prices depicted in Figure 2 empirically supports the theoretical link between biodiesel and soybean oil prices established by equation (6).[19] This link appears to be very strong because prices of biodiesel and soybean oil exhibit almost identical development as do actual and predicted soybean oil prices (not shown).[20] The three visible periods when our model over predicts (April – September 2007, February 2008 – April 2009, and February 2011 – April 2012) correspond to the periods of positive profits earned in biodiesel production, likely due to capacity constraints.

5. Conclusions

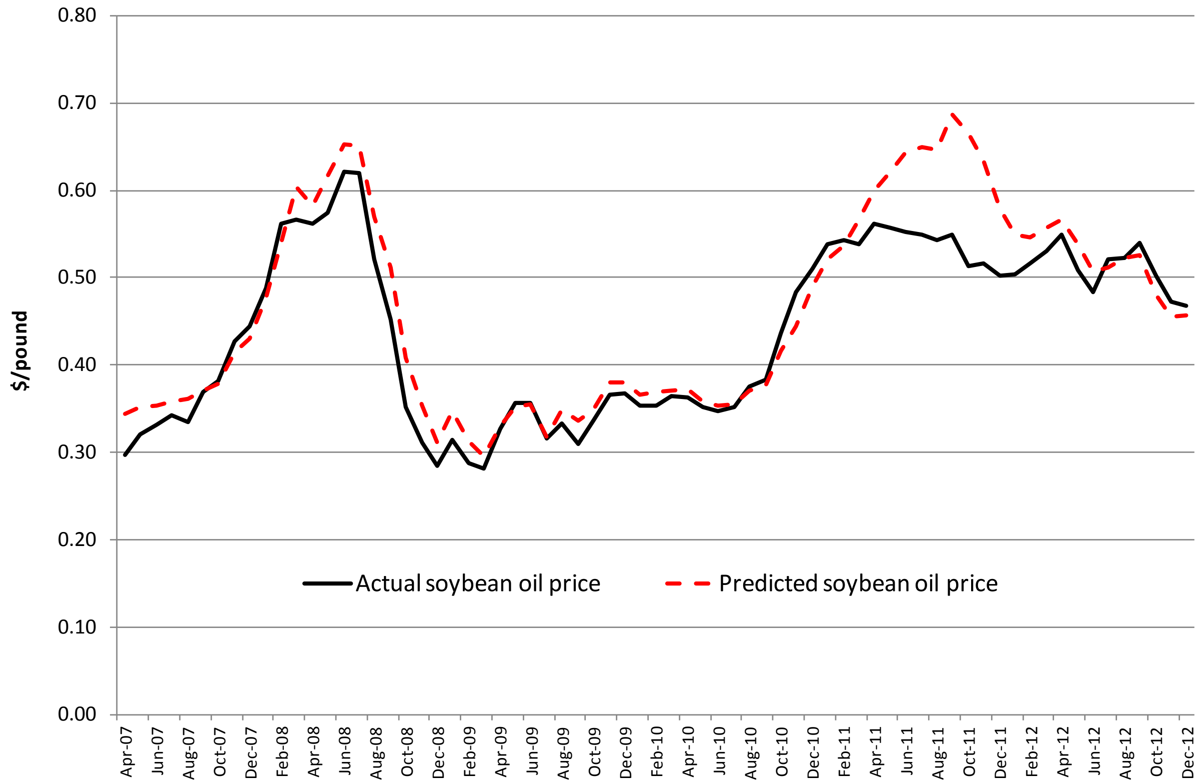
This paper has advanced an analytical framework to analyze the economics of biodiesel policies (tax exemptions/tax credits and mandates) and the effects of crude oil price shocks under either of these policies. We show how the jointness in soybean (rapeseed) crushing – i.e., the production of both soybean oil and meal – changes the otherwise direct link between a biofuel and its feedstock (as is, for example, the case for ethanol and corn). We also find that while

[19] The underlying data come from the "Historical Biodiesel Operating Margins" spreadsheet of the Centre for Agricultural and Rural Development of the Iowa State University. http://www.card.iastate.edu/research/bio/tools/hist_bio_gm.aspx

[20] Biodiesel prices ran up in 2007-08 because of 'splash and dash' (see de Gorter et al. 2011) and then crashed as the European Union invoked anti-dumping and countervailing duties. But the U.S. biodiesel mandate started to be enforced in mid-2010, causing prices to rise sharply again.

higher biodiesel prices make canola a more preferred choice over soybeans (because of more oil extracted per hectare of oilseed planted), the net effect of a higher diesel price on soybean is ambiguous, depending on the relative elasticity of the meal demand and canola supply.

Figure 2. Predicted vs Actual Soybean Oil Price



The theoretical results derived from our large country model produce several interesting implications for (small) developing countries, such as Zambia or Senegal, that are price takers in all relevant commodity markets and are considering the promotion of biodiesel production (Msangi and Evans, forthcoming). First, our finding that a higher diesel price increases the biodiesel market price under a binding tax exemption but reduces it under a binding mandate indicates that small developing countries should closely analyze which policy determines the biodiesel price in large countries (represented, for example, by OECD countries); the more so in periods of high volatility of crude oil prices.

Second, because in the new biofuel era crude oil prices do not only affect biodiesel prices but also feedstock prices, farmers in small developing countries should carefully plan the pattern of production of biodiesel feedstocks (e.g., soybean versus canola), keeping in mind that their world prices, and hence profitability, will not only depend on the binding biodiesel policy in the biodiesel price determining country, but also on the relative elasticities of meal demand and canola supply. This uncertainty about the feedstock prices might adversely affect the stability of feedstock supply in developing countries, thus affecting the profitability of the biofuel sector in those countries (Msangi and Evans, forthcoming).

While the focus of this paper has been on tax exemption/tax credit and mandates in large countries, the interactions between biofuel policies in small and large countries in biodiesel production are certainly very important as well. Equally important is the question about the relative welfare efficiency of prospective biofuel policies in small developing countries, as well as the question of what impact biofuel production will have in developing countries on their food security. These and similar questions present opportunities for future research.

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Appendix 1. Market Effects of an Exogenous Diesel Price under a Binding Blend Mandate and One Oilseed Feedstock

The equilibrium in the soybean–biodiesel market with a binding blend mandate, α, and an exogenous diesel price is given by

$$\begin{gathered} P_F = \alpha\left(P_B + t/\lambda\right) + \left(1-\alpha\right)\left(P_D + t\right) \\ B^{SB} = \alpha D_F\left(P_F\right) \\ P_{SB} = \beta_1 P_{SO} + \beta_2 P_M - \beta_1 c_{0s} \\ P_{SO} = \beta_3\left(P_B - c_{0b}\right) \\ D_{SM}\left(P_M\right) = \beta_2 S_{SB}\left(P_{SB}\right) \\ B^{SB} \equiv \beta_1\beta_3 S_{SB}\left(P_{SB}\right) - \beta_3 D_{SOH}\left(P_{SO}\right) \end{gathered} \tag{A1.1}$$

The first equation gives the fuel price as the weighted average of biodiesel and diesel prices, taking into account the volumetric fuel tax (the term t/λ represents the tax on biodiesel in \$/DEEG). The second equation represents the requirement that α [x100 percent] of the final fuel blend has to come from biodiesel. The interpretation of the remaining equations is the same as presented for the binding tax credit.

Substituting the last identity in (A1.1) into the second equation, totally differentiating the ensuing system of equations, and solving, we obtain

$$\begin{gathered} \frac{dP_B}{dP_D} = \frac{\alpha\left(1-\alpha\right)D_F{}'}{\left(\beta_1{}^2 S_{SB}{}' - D_{SOH}{}'\right)\beta_3{}^2 + \dfrac{\left(\beta_1\beta_2\beta_3 S_{SB}{}'\right)^2}{D_{SM}{}' - \beta_2{}^2 S_{SB}{}'} - \alpha^2 D_F{}'} \le 0, \ge -1 \\ \frac{dP_M}{dP_D} = \frac{\beta_1\beta_2\beta_3 S_{SB}{}'}{\left(D_{SM}{}' - \beta_2{}^2 S_{SB}{}'\right)}\frac{dP_B}{dP_D} \ge 0 \\ \frac{dP_{SO}}{dP_D} = \beta_3\frac{dP_B}{dP_D} \le 0 \\ \frac{dP_{SB}}{dP_D} = \frac{\beta_1\beta_3 D_{SM}{}'}{\left(D_{SM}{}' - \beta_2{}^2 S_{SB}{}'\right)}\frac{dP_B}{dP_D} \le 0 \\ \frac{dP_F}{dP_D} = \alpha\frac{dP_B}{dP_D} + 1 - \alpha > 0, \le 1 \end{gathered} \tag{A1.2}$$

Appendix 2. Market Effects of an Exogenous Diesel Price under a Binding Blend Mandate and Two Oilseed Feedstocks

The market equilibrium in this case consists of

$$\begin{gathered} P_{SB}=\beta_1 P_{SO}+\beta_2 P_M-\beta_1 c_{0s} \\ P_{CN}=\gamma_1 P_{CO}+\gamma_2 P_M-\gamma_1 c_{0c} \\ P_{SO}=\beta_3\left(P_B-c_{0b}\right) \\ P_{CO}=\gamma_3\left(P_B-c_{0bC}\right) \\ D_M\left(P_M\right)=\beta_2 S_{SB}\left(P_{SB}\right)+\gamma_2 S_{CN}\left(P_{CN}\right) \\ B^{SB}=\beta_1\beta_3 S_{SB}\left(P_{SB}\right)-\beta_3 D_{SOH}\left(P_{SO}\right) \\ B^{CN}=\gamma_1\gamma_3 S_{CN}\left(P_{CN}\right)-\gamma_3 D_{COH}\left(P_{CO}\right) \\ B=B^{SB}+B^{CN} \\ P_F=\alpha\left(P_B+t/\lambda\right)+\left(1-\alpha\right)\left(P_D+t\right) \\ B=\alpha D_F\left(P_F\right) \end{gathered} \tag{A2.1}$$

where *B* denotes the total amount of biodiesel. Simplifying and totally differentiating the system of equations (A2.1), we obtain

$$\frac{dP_B}{dP_D}=\frac{\alpha\left(1-\alpha\right)D_F'}{\beta_1^2\beta_3^2 S_{SB}'+\gamma_1^2\gamma_3^2 S_{CN}'-\beta_3^2 D_{SOH}'-\gamma_3^2 D_{COH}'+\dfrac{\left(\beta_1\beta_2\beta_3 S_{SB}'+\gamma_1\gamma_2\gamma_3 S_{CN}'\right)^2}{D_M'-\beta_2^2 S_{SB}'-\gamma_2^2 S_{CN}'}-\alpha^2 D_F'}\le 0,\ge -1$$

$$\frac{dP_M}{dP_D}=\frac{\beta_1\beta_2\beta_3 S_{SB}'+\gamma_1\gamma_3\gamma_2 S_{CN}'}{D_M'-\beta_2^2 S_{SB}'-\gamma_2^2 S_{CN}'}\frac{dP_B}{dP_D}\ge 0$$

$$\frac{dP_{CO}}{dP_B}=\gamma_3\frac{dP_B}{dP_D}\le 0$$

$$\frac{dP_{SO}}{dP_B}=\beta_3\frac{dP_B}{dP_D}\le 0$$

$$\frac{dP_{CN}}{dP_D}=\frac{\gamma_1\gamma_3 D_M'+\beta_2\left(\beta_1\beta_3\gamma_2-\beta_2\gamma_1\gamma_3\right)S_{SB}'}{D_M'-\beta_2^2 S_{SB}'-\gamma_2^2 S_{CN}'}\frac{dP_B}{dP_D}$$

$$\frac{dP_{SB}}{dP_D}=\frac{\beta_1\beta_3 D_M'+\gamma_2\left(\beta_2\gamma_1\gamma_3-\beta_1\beta_3\gamma_2\right)S_{CN}'}{D_M'-\beta_2^2 S_{SB}'-\gamma_2^2 S_{CN}'}\frac{dP_B}{dP_D}$$

$$\frac{dP_F}{dP_D}=\alpha\frac{dP_B}{dP_D}+1-\alpha>0,\le 1 \tag{A2.2}$$