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Producing biodiesel from soybeans in Zambia: An economic analysis

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ABSTRACT

Facing a huge fiscal burden due to imports of its entire petroleum demand in the face of ample supply of agricultural land to produce biofuels, Zambia has recently introduced a biofuel mandate. However, a number of questions, particularly those related to the economics of biofuels, have not been fully investigated yet. Using an empirical model, this study analyzes the economics of meeting the biodiesel mandate using soybean oil. The study finds that meeting the biodiesel mandate would reduce social welfare, mainly because of the welfare loss to fuel consumers and net reduction in foreign exchange earnings due to soybean oil imports. However, if Zambia increases its domestic soybean supply, as well as oil yield, soybean-based biodiesel is likely to be welfare-beneficial. The country's welfare is found to be the highest under expanded soybean production and its domestic processing but with no biodiesel mandate.

Introduction

Zambia is a Sub-Saharan country that depends entirely on imports to meet its petroleum demand. Currently, fuel wood accounts for more than 70% of the nation's energy needs while hydropower contributes about 14% but has the potential to contribute more.[1] Dependence on fuel wood and charcoal to meet most of the energy demand does not only cause rapid deforestation and biodiversity degradation but also significantly contributes to mortality and morbidity due to indoor air pollution. On the other hand, Zambia has plenty of arable land suitable for agricultural production. The fiscal burden due to imports of petroleum products on the one hand and huge availability of agricultural land on the other (42% of the total land area of the country according to ZDA (2011)), has caused increasing interest in biofuels in Zambia. The National Energy Policy of 2008 envisages development of biofuels in Zambia as it indicates: (i) expansion of biofuels in the national fuel blend; (ii) promotion of biofuels for transportation, thereby ensuring security of supply and stabilizing domestic prices of fuels; (iii) ensuring availability of data and information on market demand, resource assessment, and applicability of biofuels; (iv) providing a legal and institutional framework for the biofuels sub-sector; and (v) supporting investment in the biofuels industry through appropriate incentives, standards, and research (MEWD, 2008). In 2011, the government issued 5% biodiesel (B5) and 10% ethanol (E10) blending mandates to be achieved by 2015 (MEWD, 2011).

While promoting biofuels, policy makers in Sub-Saharan African countries, like Zambia, are asking if the production of biofuels would be an economically attractive option compared to continued imports of petroleum products. Moreover, considering the availability of a surplus of agricultural land, these countries are also wondering whether they can produce biofuels for export. Or would it be better to export the feedstock directly (e.g., soybean instead of biodiesel produced from soybean) or other products produced from the same feedstock (e.g., soybean oil)?

This paper seeks to provide a framework of analysis to assess such options by deriving a unique long-run economic model of biodiesel production in Zambia, a small developing country facing exogenous prices of traded commodities.[2] We also develop an empirical model of Zambia's soybean oil/biodiesel sector as an example. Our analysis answers two most important policy relevant questions: (i) will Zambia produce and export biodiesel in the absence of a mandate?; (ii) what is the opportunity cost of biodiesel production in terms of importing oil and of producing the soybean

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[1] Hydropower in Zambia is estimated to have potential of 6000 MW, of which less than one third (1715.5 MW) has been exploited so far.

[2] In trade literature, a "small" country refers to a country without the capacity to influence the world price of a commodity, for example, biodiesel in this study.

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oil for internal consumption and direct export? The opportunity cost depends on two key factors: the supply/demand conditions for soybean, soybean meal, and soybean oil (the supply curve for soybeans incorporates the agro-climatic conditions and underlying productivities, while the relative supply/demand curves determine the trade position); and the biodiesel price in the absence of any biofuel policy in the country, which depends on world oil prices and Zambia's fuel (diesel or biodiesel) tax/subsidy.

Market equilibrium for a small country in the absence of biofuel policies

Consider a small country, such as Zambia, that takes world commodity prices as given.[3] In this paper, we focus on the markets for soybean, soybean oil, and soybean meal, and also allow for biodiesel production (with soybean oil as a feedstock). We aim to determine the production, consumption, and trade pattern for a small country under various combinations of hypothetical domestic versus observed world prices for each of soybean, soybean oil, and biodiesel. To simplify the theoretical analysis, we assume that transportation costs are zero and that there are no trade barriers. We relax these assumptions in the empirical part of the paper.

Soybean (SB), soybean oil (SO), soybean meal (SM), and biodiesel (B) are internationally traded commodities. We denote world prices of the first three commodities as $\overline{P}_{SB}$, $\overline{P}_{SO}$, and $\overline{P}_{SM}$, where the bar indicates that the prices are exogenous to the small country. We use $T_i > 0$ to denote export and $T_i < 0$ import of a commodity $i = \{SB, SO, SM, B\}$. One metric ton of soybean in a small country yields $\hat{\beta}_1$[4] and $\hat{\beta}_2$ ($\hat{\beta}_2 = 1 - \hat{\beta}_1$) metric tons (mt) of soybean oil and soybean meal, respectively. We let $\hat{\beta}_3$ denote diesel energy-equivalent liters (DEEL) of biodiesel produced from one ton of soybean oil. The variable C_{SB} represents the amount of soybean crushed domestically; D_{SOH} and D_{SM} denote domestic demand for non-biodiesel soybean oil and soybean meal, respectively; and B and C_B denote biodiesel production and consumption, respectively. The trade position, T_i, in each commodity is then given by

$$\begin{aligned} T_{SB} &= S_{SB}(\overline{P}_{SB}) - C_{SB} \\ T_{SO} &= \hat{\beta}_1 C_{SB} - D_{SOH}(\overline{P}_{SO}) - \frac{B}{\hat{\beta}_3} \\ T_{SM} &= \hat{\beta}_2 C_{SB} - D_{SM}(\overline{P}_{SM}) \\ T_B &= B - C_B. \end{aligned} \tag{1}$$

System of Eq. (1) consists of four equations in seven unknowns: T_{SB}, T_{SO}, T_{SM}, T_B, C_{SB}, B, and C_B, and thus cannot predict the production, consumption, and trade pattern a priori. The missing pieces of information are how much soybean is crushed domestically and how much biodiesel is produced and consumed given world commodity prices and diesel taxes.

Let β_1 = 0.19 and β_2 = 0.81 denote metric tons of soybean oil and soybean meal produced from one ton of soybean in a representative large country (FAPRI, 2012),[5] and let c_{0s} denote the (fixed) processing cost per ton of soybean oil (the crushing margin). Assuming zero marginal profits in the long-run in crushing soybean into oil and meal, Drabik et al. (2014) show that the world market prices of soybean, soybean oil, and soybean meal are linked through[6]

$$P_{SB} = \beta_1 P_{SO} + \beta_2 P_{SM} - \beta_1 c_{0s}. \tag{2}$$

An analogous price link for a small country can be written as

$$\widehat{P}_{SB} = \hat{\beta}_1 \overline{P}_{SO} + \hat{\beta}_2 \overline{P}_{SM} - \hat{\beta}_1 \hat{c}_{0s}. \tag{3}$$

Because the world soybean price is exogenous to a small country, the price defined by of Eq. (3) does not represent the market price but rather a small country crushers' willingness to pay for soybean (i.e., a maximum price at which the crusher breaks even). Thus, if $\widehat{P}_{SB} \geqslant \overline{P}_{SB}$,[7] at least some domestic soybean production is crushed because the crushers are willing to pay as much as $\widehat{P}_{SB}$ dollars per metric ton of the feedstock but the market price they have to pay is only $\overline{P}_{SB}$; on the other hand, if $\widehat{P}_{SB} < \overline{P}_{SB}$, no soybean is processed domestically.

Whether or not small country producers will produce biodiesel (derived from either domestic and/or imported soybean oil) depends on the producers' willingness to pay for soybean oil compared to its world price. Denoting β_3 = 990.1 as DEELs of biodiesel extracted from one metric ton of soybean oil, and c_{0b} as the processing cost per DEEL of biodiesel,[8] the world soybean oil and biodiesel (P_B) prices are linked through a zero marginal profit condition for biodiesel production, which after a rearrangement yields (Drabik et al., 2014)

$$P_{SO} = \beta_3 (P_B - c_{0b}). \tag{4}$$

Letting $\widehat{P}_{SO}$ denote the willingness to pay for soybean oil by biodiesel producers in a small country, a corresponding (hypothetical) price link for a small country is given by

$$\widehat{P}_{SO} = \hat{\beta}_3 (\overline{P}_B - \hat{c}_{0b}). \tag{5}$$

Biodiesel will be produced as long as $\widehat{P}_{SO} \geqslant \overline{P}_{SO}$; in this case, domestic producers are willing to pay more for soybean oil than its market price.

The amount of biodiesel consumed in a small country in the absence of biofuel policies depends on the consumers' willingness to pay for biodiesel (taking into account fewer kilometers traveled per liter of biodiesel compared to a liter of diesel) relative to the world biodiesel price. Because consumers only buy biodiesel as part of the biodiesel–diesel blend, fuel blenders are an important element in affecting the market outcome.

In the absence of biofuel policies, the fuel price that consumers are willing to pay per liter is equal to $\overline{P}_D + t$, that is, the world diesel price plus the fuel tax regardless of the biodiesel content (consumers value kilometers traveled per liter of fuel, not its volume). If biodiesel is to be consumed in Zambia without a policy intervention, then its price (including the tax) per liter has to be no more than the price of diesel (accounting for fewer kilometers traveled), that is, $\widehat{P}_B + t = \lambda(\overline{P}_D + t)$. After dividing this equation by λ = 0.91 (that denotes miles traveled per liter of biodiesel relative to a liter of diesel) and rearranging, we obtain a hypothetical market price of biodiesel (in dollars per DEEL) corresponding to the consumers' willingness to pay for biodiesel in the absence of a biofuel policy (Drabik et al., 2014)

$$\widehat{P}_B = \overline{P}_D - \left(\frac{1}{\lambda} - 1\right) t. \tag{6}$$

[3] World prices are determined endogenously, but we do not model the price formation in our paper.

[4] The hat sign is used to distinguish the production and cost parameters pertaining to a small country from those in other countries as these parameters typically differ.

[5] These extraction coefficients reflect the US market conditions in 2012 and vary over time to a certain extent due, for example, to weather.

[6] We do not use the bar sign in of Eq. (2) because the prices are endogenous in world markets.

[7] Notice that because $\widehat{P}_{SB} \geqslant \overline{P}_{SB}$ implies positive marginal profits, it is possible that not only could all domestic soybean supply be crushed but the commodity could also be imported. In competing for the feedstock, the soybean processors could bid up the domestic soybean price above the world price until they would earn zero marginal profits (especially when it pays to procure the feedstock domestically as opposed to import it, for example, due to transportation cost originating from geographical constraints).

[8] The value of by-products, for example, glycerin, of biodiesel production is small and declining (even negative in Europe); hence, we incorporate this value into c_{0b}.