Producing Biodiesel from Soybean in Zambia: An Economic Analysis

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.

Key words: Zambia, Biofuels, Biodiesel, Soybean, Biofuel Policy, Sub-Saharan Africa

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 percent of the nation's energy needs while hydropower contributes about 14 percent 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 percent 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-percent biodiesel (B5) and 10-percent 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

¹ Hydropower in Zambia is estimated to have potential of 6,000 MW, of which less than one third (1,715.5 MW) has been exploited so far.

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 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.

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.

³ World prices are determined endogenously, but we do not model the price formation in our 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 $\bar{P}_{SB}$, $\bar{P}_{SO}$, and $\bar{P}_{SM}$, 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

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

System of equations (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 $\beta_1 = 0.19$ and $\beta_2 = 0.81$ denote metric tons of soybean oil and soybean meal produced

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.

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 through⁶

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

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

$$\hat{P}_{SB} = \hat{\beta}_1 \bar{P}_{SO} + \hat{\beta}_2 \bar{P}_{SM} - \hat{\beta}_1 \hat{c}_{0s}. \quad (3)$$

Because the world soybean price is exogenous to a small country, the price defined by equation (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 $\hat{P}_{SB} \geq \bar{P}_{SB}$,⁷ at least some domestic soybean production is crushed because the crushers are willing to pay as much as $\hat{P}_{SB}$ dollars per metric ton of the feedstock but the market price they have to pay is only $\bar{P}_{SB}$; on the other hand, if $\hat{P}_{SB} < \bar{P}_{SB}$, 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 $\beta_3 = 990.1$ 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

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 equation (2) because the prices are endogenous in world markets.

⁷ Notice that because $\hat{P}_{SB} \geq \bar{P}_{SB}$ 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} .

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)

$$P_{SO} = \beta_3 (P_B - c_{ob}). \quad (4)$$

Letting $\hat{P}_{SO}$ 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

$$\hat{P}_{SO} = \hat{\beta}_3 (\bar{P}_B - \hat{c}_{ob}). \quad (5)$$

Biodiesel will be produced as long as $\hat{P}_{SO} \geq \bar{P}_{SO}$; 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 $\bar{P}_D + t$, 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, $\hat{P}_B + t = \lambda (\bar{P}_D + t)$. After dividing this equation by $\lambda = 0.91$ (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)

$$\hat{P}_B = \bar{P}_D - \left(\frac{1}{\lambda} - 1 \right) t . \quad (6)$$

Fuel blenders in a small country compare the world biodiesel price to $\hat{P}_B$. As long as $\hat{P}_B \geq \bar{P}_B$, fuel blenders favor biodiesel over diesel because of a lower cost and will blend domestic and/or imported biodiesel with fossil-based diesel.⁹

Each of the three hypothetical domestic prices (soybean, soybean oil, and biodiesel) in equations (3), (5), and (6) can be either greater (or equal) or smaller than the respective world price, yielding a total of $2 \times 2 \times 2 = 8$ possible price regimes presented in the first column of Table 1. The second column presents the predicted consumption-production patterns for a small country under a given price regime (the trade position can be determined based on specific values of the variables in the second column).

Table 1. Market outcomes for a small country under different price regimes and no biodiesel policy

	Price regime	Market outcome in a small country
1.	$\hat{P}_{SB} \geq \bar{P}_{SB}, \hat{P}_{SO} \geq \bar{P}_{SO}, \hat{P}_B \geq \bar{P}_B$	$C_{SB} > 0, B > 0, C_B > 0$
2.	$\hat{P}_{SB} \geq \bar{P}_{SB}, \hat{P}_{SO} \geq \bar{P}_{SO}, \hat{P}_B < \bar{P}_B$	$C_{SB} > 0, B > 0, C_B = 0$
3.	$\hat{P}_{SB} \geq \bar{P}_{SB}, \hat{P}_{SO} < \bar{P}_{SO}, \hat{P}_B \geq \bar{P}_B$	$C_{SB} > 0, B = 0, C_B > 0$
4.	$\hat{P}_{SB} \geq \bar{P}_{SB}, \hat{P}_{SO} < \bar{P}_{SO}, \hat{P}_B < \bar{P}_B$	$C_{SB} > 0, B = 0, C_B = 0$
5.	$\hat{P}_{SB} < \bar{P}_{SB}, \hat{P}_{SO} \geq \bar{P}_{SO}, \hat{P}_B \geq \bar{P}_B$	$C_{SB} = 0, B > 0, C_B > 0$
6.	$\hat{P}_{SB} < \bar{P}_{SB}, \hat{P}_{SO} \geq \bar{P}_{SO}, \hat{P}_B < \bar{P}_B$	$C_{SB} = 0, B > 0, C_B = 0$
7.	$\hat{P}_{SB} < \bar{P}_{SB}, \hat{P}_{SO} < \bar{P}_{SO}, \hat{P}_B \geq \bar{P}_B$	$C_{SB} = 0, B = 0, C_B > 0$
8.	$\hat{P}_{SB} < \bar{P}_{SB}, \hat{P}_{SO} < \bar{P}_{SO}, \hat{P}_B < \bar{P}_B$	$C_{SB} = 0, B = 0, C_B = 0$

Note. C_{SB} = amount of soybean processed domestically, B = biodiesel production, C_B = biodiesel consumption.

Equilibrium for a Small Country under a Blend Mandate

⁹ In addition to the increasing cost of securing biodiesel, the maximum share of biodiesel is, in this case, the fuel blend which might be determined by a blend wall that determines the upper limit on the share of biodiesel in the fuel blend that is acceptable for the vehicle's engine.

With a blend mandate, domestic fuel suppliers are obliged to blend biodiesel with diesel in a given proportion. Because small developing countries have an interest in producing and consuming biofuels domestically, we assume that the government in a small country requires that the mandated quantity of biodiesel be sourced domestically. Whenever the world market price of soybean oil exceeds the domestic biodiesel producers' willingness to pay for the feedstock, a compensatory payment is required for biodiesel production to occur, else biodiesel producers would incur a loss. In the absence of a biofuel policy, no market agent has an incentive to provide a compensatory payment (if necessary) for domestic biodiesel producers. A blend mandate is a policy instrument that is able to transfer the payment from fuel consumers to biodiesel producers. Because fuel blenders are obliged to comply with the blending mandate, α , they charge consumers a fuel price, P_F ,¹⁰ inclusive of the necessary compensatory payment

$$s_B = (\bar{P}_{SO} - \hat{P}_{SO}) / \hat{\beta}_3$$

$$P_F = \alpha(\bar{P}_B + t/\lambda + s_B) + (1 - \alpha)(\bar{P}_D + t). \quad (7)$$

The compensatory payment acts as an additional fuel tax on consumers, resulting in lower fuel consumption. In this way, blenders collect an exact amount of money to be transferred to domestic biodiesel producers. No biodiesel is exported because only soybean oil used for production of biodiesel consumed domestically is eligible for the compensation.

Data and Model Application for Zambia

Data

To assess the market and welfare impacts of various biodiesel policies, we calibrate a stylized long-run model for Zambia, using the 2010 market data reported in Appendix 1.

¹⁰ The term t/λ represents the tax on biodiesel (in \$/DEEL), reflecting fewer kilometers traveled per liter of biodiesel relative to diesel.

Biodiesel is currently not blended with fossil-based diesel nor does commercial biodiesel production exist in Zambia (Sinkala et al. 2013). Of the several biodiesel feedstocks being considered in Zambia (e.g., jatropha, palm, sunflower), this study focuses on soybean oil. The analysis can, however, be readily extended to other oilseed feedstocks.

In 2010, Zambia produced 41,000 mt of soybean and net exports represented 14,418 mt.¹¹ This leaves 26,582 mt for domestic crushing. To be able to determine the net trade position in soybean oil and meal in the ensuing analysis, we assume a crushing-to-production ratio for soybean of 0.65 that reflects the current state of industry infrastructure in Zambia (we do, however, change the ratio in sensitivity analyses).

Zambia is not self-sufficient in soybean oil production: to meet the demand for non-biodiesel soybean oil of 10,952 mt, net imports of 7,352 mt were required on top of domestic production of 3,600 mt. We use the above values to calculate the implied extraction rates for soybean oil and meal for Zambia in 2010 (noting that these rates very likely vary by year, depending on weather conditions). Thus, we determine the soybean oil extraction rate to be $\hat{\beta}_1 = 0.135 (= 3,600/26,582)$ metric tons of oil per one ton of soybean, while the share of soybean meal is given by the residual, $\hat{\beta}_2 = 0.865 (= 1 - 0.135)$.¹² The production of soybean meal in Zambia, which FAOSTAT does not report, is estimated to be $0.865 \times 26,582 = 22,982$ mt and is assumed to be all consumed domestically due to high transportation cost. Zambia did not trade in soybean meal in 2010. Diesel consumption in Zambia was 597 million liters in 2010.

Because Zambia is a landlocked country remote from the key markets considered in this paper, the market prices in Zambia have to reflect the transportation costs and existing trade

¹¹ Soybean imports of 27 mt are very small relative to exports and most likely represent the seed material for the next year's crop.

¹² The corresponding US values are 0.19 and 0.81, respectively.

barriers. We assume all commodities are traded through Dar-Es-Salaam in Tanzania and Durban in South Africa, which are the current traditional ports. Because Zambia is a net exporter of soybean, the local price in Lusaka (\$370.24/mt) is equal to the lowest price in Durban (for soybean originating in Argentina, \$470.24/mt) less the transportation cost (\$100/mt).¹³ On the other hand, because soybean oil is imported, its domestic price (transportation costs and import duties) is equal to \$1,284.35/mt, which is the lowest price for soybean oil in Lusaka, Zambia, that originates in Argentina and is delivered to Zambia through Walvis Bay, Namibia. Zambia did not trade soybean in meal in 2010 but plans exist to export the joint product if soybean-based biodiesel is produced. In that case, the price in Lusaka would be equal to the price at Durban, Mozambique (\$487.20/mt) less the transportation cost (\$100/mt), that is, \$387.20/mt.

Zambia imports petroleum products through Tanzania. The diesel market price in Zambia (excluding the tax) was \$0.921/liter and the diesel tax was \$0.299/liter in 2010. Because the observed retail price of diesel fuel was \$1.459/liter, we ascribe the difference to a (fixed) marketing margin of \$0.239/liter. In 2010, the world biodiesel price was determined in the European Union (Germany) (de Gorter et al. 2011; Rajcaniova et al. 2013). We therefore take the German biodiesel price of \$1.636/liter to be the price faced by Zambian biodiesel exporters in the EU market. Consistent with the relationship between transportation costs and prices of other studied commodities, we set the market price of biodiesel to be 20 percent below the price in the European Union, that is, \$1.31/liter.

Econometric estimates of market elasticities for Zambia are not available. Therefore, to calibrate our constant price elasticity demand and supply curves, we use elasticities found in the literature as well as the elasticities used for similar developing countries in the FAPRI model.

¹³ The data on prices and transportation costs come from http://www.unitedsoybean.org/wp-content/uploads/MarketPotential_SubSaharanAfrica2.pdf

We use Hamilton's (2009) estimate of fuel demand elasticity of -0.26. The demand for soybean oil for human consumption, demand for soybean meal for feed, and supply of soybean, have price elasticity of -0.15, -0.35, and 0.34, respectively.¹⁴

The Persistence of the Observed Production and Trade Patterns

The objective of this section is to provide rough bounds on the key market prices and parameters for which one might expect the observed production, consumption, and trade patterns to be preserved. The observed patterns suggest that the price regime 4 in Table 1 prevailed in Zambia in 2010. This price regime implies that in order for domestic biodiesel production to begin, Zambia's biodiesel producers need to be compensated for the difference between the market price of soybean oil and their willingness to pay for the feedstock to break even. The determination of this compensatory payment is crucial for modeling the effects of alternative biodiesel policies.

Sinkala et al. (2013) reports a processing cost of soybean-based biodiesel in Zambia of \$0.22/liter. Because the local market price of biodiesel in Zambia is \$1.31/liter, using equation (5) we estimate the Zambian biodiesel producers' willingness to pay for soybean oil to be \$1,180/mt. The difference between the market price of soybean, \$1,284/mt, and the willingness to pay then determines the compensatory payment which is equivalent to \$0.10/liter of biodiesel.

In addition to the constellation of world commodity prices relative to hypothetical domestic prices (Table 1), the stability of the observed production and trade patterns also depends on the processing cost for soybean oil and biodiesel. The maximum processing cost of soybean oil that would preserve the observed Zambia's production/consumption, for given market prices, can be obtained from equation (3) as

¹⁴ The FAPRI elasticities database does not provide elasticities specifically for Zambia. We therefore use the elasticities reported for Brazil as both countries are developing countries.

$$\max \hat{c}_{0s} = \frac{\hat{\beta}_1 \bar{P}_{SO} + \hat{\beta}_2 \bar{P}_{SM} - \hat{P}_{SB}}{\hat{\beta}_1}, \quad (10)$$

which upon substitution of the 2010 market prices and parameters gives $\max \hat{c}_{0s} = \$1,022/\text{mt}$.

Notice that a corresponding processing cost in Argentina, an important exporter of soybean and soybean products to southern African countries, is estimated to be \$355/mt.¹⁵ If Zambia's soybean oil processing facilities required the same crushing margins as in Argentina, the maximum price for soybean that would preserve the current production/trade pattern in Zambia would be \$460/mt.

In a similar manner, we can determine an approximation of the bounds for biodiesel production. We have shown that under the current biodiesel processing cost, biodiesel producers in Zambia are unlikely to produce if the price of the feedstock (soybean oil) is more than \$1,180/mt. To begin production at the 2010 biodiesel and soybean oil prices, their processing cost would have to be no more than \$0.12/liter, which is almost 80 percent less than the current level.

But biodiesel production does not automatically imply biodiesel consumption unless an appropriate policy is in place or if the biofuel is competitive vis-à-vis diesel (e.g., due to a high diesel price or a low fuel tax). Invoking equation (6), the maximum price that makes biodiesel competitive with diesel is \$0.82/liter. Contrast this with the current biodiesel market price of \$1.31/liter in Zambia.

Results from Model Simulations

No binding biofuel policy is currently implemented in Zambia. However, in April 2011, the government issued a 5-percent blending target for biodiesel (B5) that is to be achieved by

¹⁵ This cost is calculated as per equation (2), using the market prices and parameters pertaining to the Argentinian market in 2010: $(0.19 \times 936 + 0.81 \times 336 - 382)/0.19$.

2015. It is therefore of interest to analyze the potential market and welfare impacts of this policy as well as the impacts of a possible expansion of the mandatory biodiesel blending to 10 or 20 percent. The upper panel of Table 2 gives market effects for individual scenarios, whereas the bottom panel presents welfare changes associated with each scenario relative to the no policy (i.e., status quo) baseline. We assume that the government requires blending of biodiesel produced domestically; otherwise all biodiesel would be imported because no biodiesel production currently exists due to a high soybean oil price that does not allow biodiesel producers to break even. The mandate on consumption of domestic biodiesel represents an instrument to initiate biodiesel production in Zambia.

By implementing a 5-percent mandate, the government requires fuel blenders to blend diesel with more costly biodiesel, which results in an increase in the consumer price of fuel by 3 cents per liter (from \$1.46 to \$1.49/liter). The reduction in the consumer surplus of fuel consumers is by far the most significant welfare effect across all scenarios in Table 2, and for the 5-percent mandate represents a decrease of \$17.6 million. The mechanism through which the mandate secures domestic biodiesel production is shown in equation (7). To reiterate, blenders charge consumers a fuel price that includes the compensatory payment necessary for biodiesel producers to produce biodiesel. Blenders then transfer the collected money to biodiesel producers in the form of purchasing biodiesel at the world market price of biodiesel. This compensatory payment equals \$0.10/liter (as per the definition above equation (7)) and costs \$2.9 million ($= \$0.10/\text{liter} \times 30 \text{ million liters}$) under the 5 percent mandate (and increases with higher blend ratio scenarios). Because biodiesel replaces diesel (although not one-to-one as there is market leakage in the fuel market—see Drabik et al., 2010)¹⁶ the revenue from taxing diesel decreases by \$9.1 million but the loss is partially recouped by raising revenues from taxing

¹⁶ This has implications for carbon offsets.

Table 2. Market and welfare effects of various simulation scenarios

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Mandate							
	No policy	5%	10%	20%	5% mandate & 80% crushing rate	5% mandate & 100% crushing rate	5% mandate & no land constraint	No mandate & no land constraint	Biodiesel price below diesel price; max. share of biodiesel 20%
Fuel price (\$/liter)	1.46	1.49	1.52	1.58	1.49	1.49	1.49	1.46	1.43
Compensatory payment to domestic biodiesel producers (\$/liter)	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00
Diesel consumption (mil. liters)	597	566	536	476	566	566	566	597	489
Biodiesel consumption (mil. liters)	0	30	60	119	30	30	30	0	122
Fuel consumption (mil. liters)	597	596	596	595	596	596	596	597	611
Trade in soybean (metric tons)	14,418	14,418	14,418	14,418	8,200	0	107,693	107,693	14,418
Trade in soybean oil (metric tons)*	-7,352	-34,861	-62,326	-117,147	-34,019	-32,909	-11,572	15,938	-120,088
Trade in soybean meal (metric tons)	0	0	0	0	5,376	12,465	148,679	148,679	0
		Change relative to no policy (million dollars)							
Fuel consumer surplus		-17.6	-35.3	-70.9	-17.6	-17.6	-17.6	0.0	19.5
Soybean oil consumer surplus		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soybean meal consumer surplus		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soybeans producer surplus		0.0	0.0	0.0	0.0	0.0	56.2	56.2	0.0
Tax revenues									
Diesel		-9.1	-18.1	-36.1	-9.1	-9.1	-9.1	0.0	-32.3
Biodiesel		8.9	17.8	35.6	8.9	8.9	8.9	0.0	36.5
<i>Total change in welfare</i>		-17.8	-35.6	-71.5	-17.8	-17.8	38.4	56.2	23.7
Foreign exchange earnings									
Oil (diesel)		27.9	55.8	111.3	27.9	27.9	27.9	0.0	99.5
Soybean oil		-35.3	-70.6	-141.0	-34.3	-32.8	-5.4	24.4	-144.8
Soybean meal		0.0	0.0	0.0	1.8	4.2	50.0	50.0	0.0
<i>Total foreign exchange earnings</i>		-7.4	-14.8	-29.8	-4.5	-0.7	72.5	74.3	-45.3
Compensatory payment from fuel consumers to biodiesel producers		2.9	5.7	11.5	2.9	2.9	2.9	0.0	0.0

* A negative value denotes imports.

Source: calculated

biodiesel of \$8.9 million.

While the mandate has no impact on soybean production (the soybean price as well as soybean supply is unaffected),¹⁷ it does affect the allocation of soybean oil. Additional soybean oil is now needed for biodiesel production, expanding soybean oil imports expand considerably: from 7,352 mt to 34,861 mt. Recall that the total amount of soybean oil extracted does not change because we assume a fixed share of oil extracted from soybean crushed. As a result, trade in soybean meal does not respond to the introduction of the mandate either. Overall, the 5-percent biodiesel mandate reduces social welfare by \$17.8 million¹⁸ and the loss increases with higher blend requirements. Note, however, that the welfare index measured here is an average index throughout the population.

Although not a component of the total welfare change, foreign exchange earnings can be an interesting indicator for Zambia (and other countries) as to how appropriate a biofuel policy is; especially because small Sub-Saharan countries import petroleum products which cause an outflow of foreign exchange. Our simulations indicate that as much as \$27.9 million is saved on reduced imports of oil (in the form of diesel).¹⁹ However, due to much higher imports of soybean oil triggered by domestic biodiesel production, Zambia loses \$35.3 million, which yields an overall foreign exchange deficit of \$7.4 million. This gap widens with higher mandate levels.

Despite deterioration of societal welfare, especially because of a relatively negative impact on fuel consumers, which seems to be characteristic of all biodiesel blending levels, can there be a situation under which at least foreign exchange earnings would improve with the

¹⁷ As an anonymous reviewer correctly pointed out, a higher biodiesel mandate in Zambia is likely to affect the local soybean prices. Production of soybean oil is linked to soybean production and although there may not be perfect pass through of biofuel shocks through the supply chain, some impact would be observed. However, because of the small country assumption for Zambia and because we do not model local markets but only the national market, the soybean price is fully determined in the world market in this paper.

¹⁸ $-17.8 = -17.6 - 9.1 + 8.9$.

¹⁹ This does, of course, not include the value associated with the reduction in energy dependency.

mandate? To see this, the fifth column in Table 2 presents a scenario where we increase the soybean crushing-to-production ratio from 65 percent in the baseline to 80 percent and keep the mandate at 5 percent. While this change has a sizable effect on exports of soybean (down from 14,418 mt to 8,200 mt) the improvement in the soybean oil trade balance is very small – imports decrease by only 842 mt ($= -34,019 - (-34,864)$). The same holds even when all soybean production is crushed domestically (column 6). The reason is that the baseline amount of soybean (and hence soybean oil) is very small relative to the new demand created by biodiesel. Therefore, a biodiesel mandate is likely to worsen the soybean trade balance and reduce foreign exchange earnings for Zambia unless a corresponding expansion of soybean production occurs.

The expansion of soybean production is possible because Zambia has vast areas of available arable land that could be used for biodiesel feedstock production. We simulate this scenario (column 7) by increasing (doubling) the soybean supply elasticity, holding the crushing rate at its baseline level (0.65) and the blend mandate at 5 percent. As a result, soybean producers' surplus increases by \$56.2 million as compared to the 5-percent mandate alone scenario, and the country exhibits net foreign exchange gains coming especially from a reduction in outlays on imports of soybean oil and receipts from exports of soybean meal.

The results in column 7 in Table 2 suggest that increasing soybean (and hence biodiesel) production on the abandoned land in Zambia appears to be beneficial under a binding biodiesel mandate. However, how does the situation change if there is no mandate? We have shown that under the baseline constellation of international feedstock prices, no biodiesel production is expected in a free market environment. This is reflected in column 8 of Table 2. The direct effect of the absence of a mandate under the expanded soybean production (column 8 vs column 7) is an improvement in the trade balance for soybean oil: Zambia changes from an importer (11,572

mt) into an exporter (15,938 mt) of oil. The trade in meal and soybean is not affected by the mandate because of the unchanged world price of meal and the crush-to-production ratio.

Fuel consumers benefit from no biodiesel mandate as they do not have to pay a higher price to finance the policy. The net government fuel tax revenues also increase by \$0.2 million (= 0 - (-9.1) - 8.9) because of a greater tax base. In terms of foreign exchange earnings, expanding soybean production and imposing no mandate is also beneficial, as the total foreign exchange earnings increase by 1.8 million relative to scenario 7 due to much higher soybean oil exports.

Technological progress is likely to reduce the biodiesel production cost as new technologies become available. In fact, Sinkala et al. (2013) estimate that the production cost in Zambia for soybean-based biodiesel is \$0.655/liter, which is below the current diesel price. Although currently there is no large scale biodiesel production in Zambia, it is useful to investigate the implications of such a biodiesel-to-diesel price scenario.

Clearly, when biodiesel is less expensive than diesel, fuel blenders have an incentive to blend as much biodiesel as possible.²⁰ The US Environmental Protection Agency (2007) recommends that biodiesel blends containing more than 20 percent of biodiesel should be evaluated on a case-by-case basis because of possible damage to the vehicle's engine. Therefore, we set the share of biodiesel in the fuel blend to 20 percent in this scenario (the last column in Table 2). The consumer fuel price, as per equation (7), decreases by 3 cents relative to the no-policy baseline because of two effects: (i) biodiesel is less expensive than diesel and (ii) blenders do not charge fuel consumers the compensatory payment as it was the case in the previous scenarios (i.e., $s_B = 0$ in equation (7)). The reduction in the fuel price has considerable and

²⁰ Our sensitivity analysis shows that if the biodiesel production cost in Zambia is below \$0.84/liter (for the current diesel price and fuel tax), the blending of biodiesel will increase the total social welfare relative to the no-biodiesel baseline. Moreover, for a biodiesel production cost below \$0.815/liter, fuel blenders will blend the maximum share of biodiesel that is technologically allowed.

positive effects on fuel consumers whose welfare increases by \$19.5 million. Diesel tax revenues decrease by \$32.3 million, but this fiscal loss is more than offset by the revenues from taxing biodiesel, \$36.5 million. Overall, therefore, the social welfare increases by \$23.7 million ($= 19.5 - 32.3 + 36.5$). The foreign exchange balance worsens, however, relative to all previous scenarios because of a substantial increase in imports of soybean oil.

The scenario above is likely to underestimate the positive welfare effects and overestimate the negative foreign exchange balance, however. With increasing efficiency of biodiesel production in Zambia in the long run, especially if the industry is able to keep biodiesel production costs below the diesel price, one could expect more land to be converted into soybean production which would result in more soybean oil and soybean meal produced, both of which have positive effects on the trade balance. Moreover, the welfare of soybean producers would increase as well.

Conclusions

The objective of this paper was to analyze the economics of producing biodiesel from soybeans in Zambia and to investigate alternative scenarios for biodiesel market developments. We find that the market impacts of biofuel policies in a small open economy, such as Zambia, are much more nuanced than an analogous analysis for a large country. The reason for this is the exogeneity of world prices the small country is facing. Because the world prices of biodiesel and diesel on the one hand and of soybean oil, soybean meal, and soybean on the other are linked internationally, a small country biodiesel producers face a zero–one situation: they will produce biodiesel only if the constellation of the world prices of biodiesel and soybean oil and the processing cost for biodiesel in the small country result in non-negative profits. In the opposite situation, no biodiesel production occurs.

To induce biodiesel production in a small country when the market conditions imply negative profits in the industry, a biodiesel blend mandate can necessitate a compensatory payment to biodiesel producers. Under the mandate, the transfer is financed by fuel consumers and all biodiesel produced is consumed domestically.

Our sensitivity analyses show that the welfare impacts are very sensitive to the assumptions about the future developments in the soybean/biodiesel sector in Zambia. For example, if land can be converted into soybean production at a low cost and/or biodiesel be produced at a lower cost than diesel, then biodiesel production in Zambia is likely to yield significant welfare benefits. We find that even higher welfare gains could be achieved (at the current world commodity prices) if soybean production (and crushing) were expanded but no biodiesel mandate imposed. It is to be noted, however, that our welfare analysis ignores other potentially important welfare components, such as the marginal burden of taxation, negative traffic-related externalities (e.g., air pollution and traffic congestion) and benefits from domestic biofuel production if there are spillover effects in reducing wood consumption and thereby air pollution and deforestation.

The structure and the level of detail of our model does not allow for a detailed analysis of the effects of expanding soybean cultivation for biodiesel in Zambia on the rural soybean growers. For a given price, expansion of soybean production triggered by increasing demand for domestically produced biodiesel is, however, expected to increase income of local soybean growers. However, it is reasonable to assume that different parts of the population will be affected by higher incomes differently. All in all, facing world prices of soybean, rural growers will be better-off with biodiesel production because this creates another demand channel for their production.

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