Policy Research Working Paper 6498

Should Zambia Produce Biodiesel from Soybeans?

Some Insights from an Empirical Analysis

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The World Bank
Development Research Group
Environment and Energy Team
June 2013

Policy Research Working Paper 6498

Abstract

Facing a huge fiscal burden due to imports of entire petroleum despite the availability of a surplus of agricultural land to produce biofuels, Zambia, a country in Sub-Saharan Africa, has recently introduced a biofuel mandate. But, 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 through soybean feedstock. The study finds that meeting the biodiesel mandate with biodiesel from soybeans would reduce social welfare because the country's soybean imports would cost more than the expected reduction in petroleum imports. However, if Zambia increases its domestic soybean supply along with its capacity to convert soybean to biodiesel, as well as oil yield, soybean based biodiesel is likely to be welfare-beneficial, even if biodiesel prices are above diesel prices. The study also finds that under current market prices and transportation costs and constraints, the same amount of biodiesel can be produced most cost-effectively with a tax exemption. A blend mandate would be less cost effective, while a biodiesel production subsidy represents the least efficient policy option.

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Key words: Zambia, Biofuels, Biodiesel, Soybeans

JEL Classification: Q18, Q28, Q42, Q48

Sector: Energy and Mining, Agriculture and Rural Development

Should Zambia Produce Biodiesel from Soybeans?
Some Insights from an Empirical Analysis [1]

1. Introduction

Zambia is a Sub-Saharan country which 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.[2] 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 (ZDA, 2011) of the total land area of the country), 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 the role 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 a Sub-Saharan African country, 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

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[2] 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.

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 feedstocks (e.g., sugar instead of ethanol in the case of sugarcane)? A further question is what type of policies would be appropriate to support biofuels? Production subsides for the feedstock or biofuel? Or consumption subsidies for the biofuel in the form of a tax exemption at the fuel pump? Or simply implement mandates or a combination of policy instruments?

This paper seeks to provide a framework of analysis to assess such options by deriving a unique economic model of biodiesel production in Zambia, a small[3] developing country, given world soybean oil and biodiesel prices. We also develop an empirical model of Zambia's soybean oil/biodiesel sector as an example. The two most important policy relevant results derived from our analysis are (*i*) will Zambia produce and export biodiesel in the absence of government policy interventions? And if not, what level of government intervention is required? and (*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 costs depend on two key factors: the supply/demand conditions for soybeans, soybean meal and soybean oil (the supply curve 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 in our case) tax/subsidy.

The paper is outlined as follows. The next section develops a market equilibrium for the oilseed/fuel market for small country in international markets while section 3 augments the model by looking at the market impacts of various biodiesel policies. In section 4, we empirically illustrate our theoretical findings for Zambia. The final section provides some concluding remarks.

2. 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. In this paper, we focus on the markets for soybean, soybean oil, and soybean meal, and also allow

[3] In trade literature a 'small' country refers to a country without a capacity to influence world price of an commodity of interest, for example, biodiesel in this study.

for biodiesel production (with soybean oil as the feedstock). We aim to determine the production, consumption, and trade pattern for a small country under various combinations of domestic *versus* world prices for each of soybean, soybean oil and biodiesel. To simplify the theoretical analysis, we assume that transportation costs are zero and that trade barriers are absent. We relax these assumptions in the empirical part of the paper.

Soybean, soybean oil, soybean meal, and biodiesel are internationally traded commodities. Denote world prices of the first three commodities as $\bar{P}_{SB}$, $\bar{P}_{SO}$ and $\bar{P}_{SM}$, respectively, where the bar indicates that the prices are exogenous to the small country. The trade position, T_i, $i = \{SB, \text{ SO, SM, B}\}$, in each commodity is given by

$$\begin{aligned} T_{SB} &= S_{SB}\left(\bar{P}_{SB}\right) - C_{SB} \\ T_{SO} &= \beta_1' C_{SB} - D_{SOH}\left(\bar{P}_{SO}\right) - \frac{B}{\beta_3'} \\ T_{SM} &= \beta_2' C_{SB} - D_{SM}\left(\bar{P}_{SM}\right) \\ T_B &= B - C_B \end{aligned} \tag{1}$$

where $T_i > 0$ ($T_i < 0$) denotes exports (imports) of a commodity *i*. The parameters β_1'[4] and β_2' represent metric tonnes (mt) of soybean oil and soybean meal, respectively, extracted from one mt of soybeans (i.e., $\beta_2' = 1 - \beta_1'$) in a small country, and β_3' denotes diesel energy-equivalent liters (DEEL) of biodiesel produced from one mt of soybean oil. The variable C_{SB} represents the amount of soybeans crushed domestically; D_{SOH} and D_{SM} denote domestic demand for edible soybean oil and soybean meal, respectively; and B and C_B denote biodiesel production and consumption, respectively.

System (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 will be crushed domestically, and how much biodiesel will be produced and consumed, given a constellation of world commodity prices (above or below domestic prices of soybeans, soybean oil, soybean meal and biodiesel).

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[4] The prime 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. This has important implications in our analyses to follow.

De Gorter et al. (forthcoming) show that the world market prices of soybean, soybean oil, and soybean meal are linked through[5]

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

where $\beta_1 = 0.19$ and $\beta_2 = 0.81$ denote mt of soybean oil and soybean meal, respectively, produced from one mt of soybeans in a representative large country (FAPRI 2012),[6] and c_{0s} denotes the (fixed) processing cost per mt of soybean oil (the crushing margin).

An analogous price link for a small country, which follows from the zero profit condition for soybean crushing, can be written as

$$P_{SB}' = \beta_1' \overline{P}_{SO} + \beta_2' \overline{P}_{SM} - \beta_1' c_{0s}' \tag{3}$$

Because the world soybean price is exogenous to a small country, the price defined by the right-hand side of equation (3) does not represent the market price but rather a small country crushers' willingness to pay for soybeans. Thus, if $P_{SB}' \geq \overline{P}_{SB}$,[7] at least some domestic soybean production is crushed because the crushers are willing to pay as much as P_{SB}' dollars per metric tonne of the feedstock but the market price they have to pay is only $\overline{P}_{SB}$; on the other hand, if $P_{SB}' < \overline{P}_{SB}$, 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. The world soybean oil and biodiesel (P_B) prices are linked through a zero profit condition for biodiesel production (de Gorter et al., forthcoming):

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

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[5] We do not use bar signs in equation (2) because the prices are endogenous in world markets.

[6] These extraction coefficients are reflective of the U.S. market conditions in 2012 and vary over time to a certain extent due, for example, to weather.

[7] Notice that because $P_{SB}' \geq \overline{P}_{SB}$ implies positive marginal profits, it is possible that not only could all domestic soybean supply be crushed but the commodity could also be imported. While this scenario is theoretically possible under the assumptions we make, in reality, the fixed processing cost is likely to increase (e.g., because of the expansion of the crushing capacity), thus eliminating the gap for positive profits. Alternatively, in competing for the feedstock, the soybean processors could bid up the domestic soybean price above the world price until they earn zero marginal profits (especially when it pays to procure the feedstock domestically as opposed to import it, e.g., due to transportation cost originating from geographical constraints). In this case, the competition for soybeans would result in an implicit soybean production subsidy and would represent a welfare transfer from processors to soybean producers.

where β_3 = 990.1 and denotes DEELs of biodiesel extracted from one mt of soybean oil, and c_{0b} denotes the processing cost per DEEL of biodiesel.[8] A corresponding (hypothetical) price link for a small country is given by

$$P_{SO}' = \beta_3'\left(\overline{P}_B - c_{0b}'\right) \qquad (5)$$

where P_{SO}' denotes the willingness to pay for soybean oil by biodiesel producers in a small country. Biodiesel will be produced as long as $P_{SO}' \geq \overline{P}_{SO}$; in this case, domestic producers are willing to pay more for soybean oil than is 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 biodiesel's lower kilometers travelled per gallon compared to a gallon 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 $P_D + t$, that is, the diesel price plus the fuel tax regardless of the biodiesel content (consumers' value kilometers traveled per liter of fuel, not its volume). Fuel blenders in a small country compare the world biodiesel price $\overline{P}_B$ (expressed in \$/DEEL) to the consumers' willingness to pay for biodiesel in the absence of a biofuel policy (de Gorter et al., forthcoming)

$$P_B' = P_D - \left(\frac{1}{\lambda} - 1\right)t \qquad (6)$$

where λ = 0.91 denotes miles traveled per liter of biodiesel relative to a liter of diesel. As long as $P_B' \geq \overline{P}_B$, 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 (soybeans, 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 2x2x2 = 8 possible price regimes presented in the first column of Table 1. The second column presents the consumption-production patterns for a small country under a

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

[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 which determines the upper limit on the share of biodiesel in the fuel blend that is acceptable for the vehicle engine.

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

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

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

3. Equilibrium for a Small Country under Biofuel Policies

The determination of one of the price regimes listed in Table 1 is crucial for modeling the market and welfare impact of various biofuel policies in a small country.

Blend Mandate

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. 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 mandate, they charge consumers a fuel price, P_F,[10] inclusive of the necessary compensatory payment

[10] The term t/λ represents the tax on biodiesel, reflecting fewer kilometers traveled per liter of biodiesel relative to diesel.

$$P_F = \alpha\left(\overline{P}_B + t/\lambda + s_B\right) + (1-\alpha)\left(\overline{P}_D + t\right) \tag{7}$$

where $s_B = \left(\overline{P}_{SO} - P'_{SO}\right)/\beta_3'$ denotes the compensatory payment in dollars per DEEL and 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 as compensation to domestic biodiesel producers. No biodiesel is exported because only soybean oil used for production of biodiesel consumed domestically is eligible for the compensation.

Tax exemption

Under a tax exemption, the competition among fuel blenders will bid up the biodiesel price, $\hat{P}_B$, until the blender's marginal revenue, $\hat{P}_B + t/\lambda - t_e/\lambda$, is equal to consumer's willingness to pay $P_D + t$. Setting the marginal revenue equal to the willingness to pay, one obtains the market price of biodiesel under a binding tax exemption (see also de Gorter and Just, 2009)

$$\hat{P}_B = P_D - \left(\frac{1}{\lambda} - 1\right)t + \frac{t_e}{\lambda} \tag{8}$$

The right-hand side of equation (8) determines the maximum biodiesel price to ensure blenders will blend biodiesel with regular diesel. If the price in equation (8) is greater than the world biodiesel price (i.e., $\hat{P}_B \geq \overline{P}_B$), then blenders make positive marginal profits and so will blend biodiesel and diesel. To rule out (infinite) imports of biodiesel from the rest of the world to the small country, we assume the tax exemption only applies to domestic biodiesel. Because in this case the tax exemption favors biodiesel, biodiesel is blended to the maximum limit, $\overline{\alpha}$ that is, the blend wall, representing the maximum technologically allowed. The fuel price is then given by

$$P_F = \overline{\alpha}\left(\overline{P}_B + t/\lambda + t_e/\lambda\right) + (1-\overline{\alpha})\left(\overline{P}_D + t\right) \tag{9}$$

If $\hat{P}_B < \overline{P}_B$, then blending biodiesel at world prices is not economical for fuel blenders.

Biodiesel Production Subsidy

A biodiesel production subsidy can be used when the domestic willingness to pay for soybean oil for biodiesel production is smaller than the world price. In this case, the subsidy equals the compensatory payment analyzed above. However, provision of the subsidy *per se* does not guarantee domestic biodiesel consumption because the subsidy does not mandate consumers to buy biodiesel. Whether or not domestic consumers will buy biodiesel under the subsidy depends on the relative magnitudes of consumers' willingness to pay for biodiesel and its world price[11]. For example, if the consumer willingness to pay is lower than the world price, no biodiesel will be consumed domestically, and the biodiesel production subsidy acts as an export subsidy for biodiesel.

Soybean Production Subsidy

This policy instrument by itself does not generate any biodiesel production provided a compensatory payment is required. It is because soybean producers are independent of biodiesel producers and respond only to the prevailing (world) market prices of soybean.

4. A Numerical Illustration for Zambia

Data

To assess the market and welfare impacts of various biodiesel policies, we calibrate a stylized model for Zambia, using the 2010 market data reported in Appendix 1. Biodiesel is currently not blended with fossil-based diesel nor does commercial biodiesel production exist in Zambia (Sinkala, 2011). Of the several biodiesel feedstocks being considered in Zambia (e.g., jatropha, palm, sunflower), this study focuses on soybeans and soybean oil. The analysis can, however, be readily extended to other oilseed feedstocks.

In 2010, Zambia produced 41,000 mt of soybeans and net exports represented 14,418 mt.[12] 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 constant crushing-to-production ratio for soybeans 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,

[11] See discussion on equation (6).

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

depending on weather conditions). Thus, we determine the soybean oil extraction rate to be $\beta_1' =$ 0.135 (= 3,600/26,582) metric tonnes of oil per one tonne of soybean, while the share of soybean meal is given by the residual, $\beta_2' = 0.865$ (=1 – 0.135).[13] Then the production of soybean meal in Zambia, which FAOSTAT does not report, is estimated to be 0.865 x 26,582 = 22,982 mt and is assumed to be all consumed domestically due to high transportation cost and bulkiness, Zambia did not trade in this commodity 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 be reflective of the transportation costs and existing trade 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 soybeans, the local price in Lusaka ($370.24/mt) is equal to the lowest price in Durban (for soybeans originating in Argentina, $470.24/mt) less the transportation cost ($100/mt).[14] On the other hand, because soybean oil is imported, its domestic price (inclusive of 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 (exclusive of 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., forthcoming). 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

[13] Contrast these with the corresponding U.S. rates of 0.19 and 0.81, respectively.
[14] The data on prices and transportation costs come from http://www.unitedsoybean.org/wp-content/uploads/MarketPotential_SubSaharanAfrica2.pdf

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. We use Hamilton's (2009) estimate of fuel demand elasticity of -0.26.[15] The demand for soybean oil for human consumption, demand for soybean meal for feed, and supply of soybeans, has price elasticities -0.15, -0.35, and 0.34, respectively.[16]

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 (2011) 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 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 leaves the observed Zambia's production/consumption pattern unchanged, for given market prices, can be obtained from equation (3) as

$$\max c_{0s}' = \frac{\beta_1' \bar{P}_{SO} + \beta_2' \bar{P}_{SM} - P_{SB}'}{\beta_1'} \tag{10}$$

[15] This value is close to the average long-run elasticity obtained reported in a meta-analysis by Havránek et al. (2012).

[16] 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.

which upon substitution of the 2010 market prices and parameters gives max $c_{0s}' = \$1,022$/mt. Notice that a corresponding processing cost in Argentina, an important exporter of soybeans and soybean products to southern African countries, is estimated to be \$355/mt.[17] If Zambia's soybean oil processing facilities required the same crushing margins as in Argentina, the maximum price for soybeans 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., because of 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.

Policy 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 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

[17] This cost has been calculated as per equation (2), using the market prices and parameters pertaining to the Argentinean market in 2010: (0.19 x 936 + 0.81 x 336 – 382)/0.19.

producers to break even. The mandate on consumption of domestic biodiesel represents an instrument to initiate biodiesel production in Zambia.[18]

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).

Biodiesel blend (%)	5	10	20
Decrease in energy content (%)	14	14	14
Decreased mileage (%)	0.7	1.4	2.8
Mileage covered (%)	99.3	98.6	97.2
Effective blended fuel cost ($)	1.470	1.481	1.502
Unblended diesel cost ($)	1.460	1.460	1.460

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

[18] See the discussion on equation (7).

Table 2. Market and welfare effects of various biodiesel mandates

	No policy	Mandate 5%	Mandate 10%	Mandate 20%	5% mandate & 80% crushing rate	5% mandate & 100% crushing rate	5% mandate & no land constraint	5% mandate and price of biodiesel below price of diesel
Fuel price ($/liter)	1.46	1.49	1.52	1.58	1.49	1.49	1.49	1.43
Compensatory payment to domestic biodiesel producers ($/liter)	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.00
Diesel consumption (mil. liters)	597	566	536	476	566	566	566	489
Biodiesel consumption (mil. liters)	0	30	60	119	30	30	30	122
Fuel consumption (mil liters)	597	596	596	595	596	596	596	611
Net trade in soybean (tonnes)	14,418	14,418	14,418	14,418	8,200	0	107,693	14,418
Net trade in soybean oil (tonnes)	-7,352	-34,861	-62,326	-117,147	-34,019	-32,909	-11,572	-120,088
Net trade in soybean meal (tonnes)	0	0	0	0	5,376	12,465	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	19.5
Soybean oil consumer surplus		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
Soybeans producer surplus		0.0	0.0	0.0	0.0	0.0	498	0.0
Tax revenues								
Diesel		-9.1	-18.1	-36.1	-9.1	-9.1	-9.1	-32.3
Biodiesel		8.9	17.8	35.6	8.9	8.9	8.9	36.5
Foreign exchange earnings								
Oil (diesel)		27.9	55.8	111.3	27.9	27.9	27.9	99.5
Soybean oil		-35.3	-70.6	-141.0	-34.3	-32.8	-5.4	-144.8
Soybean meal		0.0	0.0	0.0	2.1	4.8	57.6	0.0
Compensatory payment (from fuel consumers to biodiesel producders)		2.9	5.7	11.5	2.9	2.9	2.9	0.0

Source: calculated

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 is inclusive of 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 from producers at the biodiesel's world market price. This compensatory payment equals $0.10/liter and costs $2.9 million under the 5 percent mandate (and increases proportionally 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)[19] the revenue from taxing diesel decreases by $9.1 million but the loss is partially recouped by raising revenues of $8.9 million from taxing biodiesel.

While the mandate has no impact on soybean production (the soybean price as well as soybean supply is unaffected), 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 soybeans 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 million[20] and the loss increases with higher blend requirements. Note however that the welfare index measured here is an average index throughout the population, if we consider welfare of only soybean and biodiesel producers, it will increase. This study does not breakdown the welfare impacts by economic agent instead reports an aggregated welfare of both producers and consumers.

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).[21] 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.

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[19] This has implications for carbon offsets.
[20] 19.4 = – 17.6 – 9.1 + 8.9.
[21] This does, of course, not include the value associated with the reduction in energy dependency.

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 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 soybeans (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. The same holds even when all soybean production is crushed domestically (column 6). The reason is that the baseline amount of soybeans (and hence soybean oil) is very small relative to the new demand created by biodiesel. It follows therefore, that in the short run, a biodiesel mandate is likely to reduce the trade balance and foreign exchange earnings for Zambia.

However, the situation does not have to be so pessimistic in the long run when Zambia could adjust and produce more soybeans and/or expand its crushing capacity. This is possible because of Zambia's vast areas of available arable land that could be used for biodiesel feedstock production. We simulate this scenario (column 7) by increasing (doubling)[22] the soybean supply elasticity, holding the crushing rate at its baseline level. As a result, the welfare of soybean producers increases by $498 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.

In the long run, it is also possible that the biodiesel production costs will decline; for example, producers will not incur investment costs related to building of new production infrastructure, and the production process is likely to become more efficient as new technologies become available. In fact, Sinkala (2011) estimates 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 long run implications of such a biodiesel-to-diesel price scenario.

[22] From 0.34 to 0.68.

Clearly, when biodiesel is less expensive than diesel, fuel blenders have an incentive to blend as much biodiesel as possible.[23] The U.S. 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 (column 8 in Table 2). The consumer fuel price 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. The reduction in the fuel price has considerable and 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. 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 soybeans 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.

Comparison of the Welfare Efficiency of Alternative Biofuel Policies in Zambia

While the blend mandate is currently the most debated biodiesel policy in Zambia, it is of interest to also analyze other policy options that could be used to produce the same amount of biodiesel. Thus, in this section we compare the market effects and efficiency, as measured by the societal welfare, of three alternative biofuel policies: a blend mandate, a biodiesel production subsidy, and a tax exemption,[24] for the same quantity of biodiesel production. The exogenous

[23] 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.

[24] A soybean production subsidy is not considered because it cannot directly affect biodiesel production (especially when a compensatory payment is required to induce biodiesel production).

prices of all traded commodities are held constant at their baseline levels. We assume a 5 percent blend mandate, but unlike the previous section, we impose a biodiesel excise tax that is on parity (in kilometers achieved per gallon terms) with diesel, that is, the volumetric biodiesel tax is equal to 0.86 times the tax on diesel. This allows us to model the effect of the mandate alone because the tax exemption is absent.

The market effects of the three policies are summarized in Table 3. The biodiesel production subsidy that generates the required quantity of biodiesel, 30 million liters, is equal to the compensatory payment of $0.10/liter. Such a subsidy exactly covers the gap between the local market price of soybean oil in Zambia, which is linked to the world price, and the biodiesel producers' willingness to pay for soybean oil. Note, however, that all biodiesel is exported, as domestic consumers would not purchase biofuel that is more expensive (on the kilometer-traveled basis) than biodiesel. The consumer fuel price is lower than under the binding mandate because with the production subsidy, as well as with the tax exemption later, biodiesel has to be priced on par with diesel for consumers to buy it.

Table 3. Market effects of various biofuel policies (for the same biodiesel production)

	Mandate	Biodiesel production subsidy	Tax exemption
Blend mandate	0.05	0.00	0.00
Biodiesel production subsidy ($/liter)	0.00	0.10	0.00
Tax exemption ($/liter)	0.00	0.00	0.49
Fuel price ($/liter)	1.49	1.46	1.46
Compensatory payment to domestic biodiesel producers ($/liter)	0.10	0.10	0.10
Diesel consumption (mil. liters)	567	597	570
Biodiesel consumption (mil. liters)	30	0	30
Biodiesel production (mil. liters)	30	30	30
Fuel consumption (mil liters)	596	597	599
Net trade in soybean oil (tonnes)	-34,868	-34,868	-34,868
Net trade in soybean meal (tonnes)	0	0	0

Source: calculated

The third column in Table 3 presents market effects of a tax exemption that would by itself result in biodiesel production of 30 million liters. Such a tax exemption has to generate biodiesel market price equal to the world biodiesel price under the mandate and has to be eligible only for biodiesel produced domestically. Invoking equation (8), the tax exemption can be expressed as

$$t_e = \lambda\left(\overline{P}_B - P_D\right) + \left(1-\lambda\right)t \tag{11}$$

which for given values gives t_e = $0.49/liter.

Unlike under the biodiesel production subsidy, all biodiesel is consumed because the tax exemption is assumed to be earmarked for domestic market only.

Table 4 gives welfare effects of the biodiesel production subsidy and the tax exemption as compared to the mandate alone. Under both policies, fuel consumers are better-off (up by $16.7 mil.) because of a lower fuel price (Table 3). Tax revenues from diesel increase in both cases ($9.0 million with the production subsidy and $0.9 million with the tax exemption) as more diesel is consumed; the increase is much more significant for the biodiesel production subsidy, however, because in that situation no biodiesel is consumed domestically but is all exported. This causes the tax revenue from biodiesel to dwindle as compared to the mandate.

Table 4. Comparison of welfare effects of a biodiesel production subsidy and a tax exemption relative to the mandate only for Zambia (mil. dollars)

	Biodiesel production subsidy*	Tax exemption
Fuel consumer surplus	16.86	16.86
Soybean producer surplus	0.00	0.00
Soybean meal consumer surplus	0.00	0.00
Soybean oil consumer surplus	0.00	0.00
Tax revenues		
Diesel	9.03	0.89
Biodiesel	-8.92	0.00
Expenditures on biodiesel production subsidy	-2.88	0.00
Expenditures on tax exemption	0.00	-14.72
Compensatory payment	0.00	0.00
Total welfare change relative to mandate	**14.10**	**3.04**
Foreign exchange earnings		
Oil (diesel)	-27.82	-2.74
Biodiesel	39.02	0.00

Source: calculated

* Assuming all biodiesel can be exported.

Fiscal expenditures on the biodiesel production subsidy ($2.9 million) are significantly lower than on the tax exemption ($14.7 million). Intuitively, the tax exemption has to be high enough not only to generate biodiesel production but also to make fuel consumers indifferent between biodiesel and diesel. Notice that the tax exemption already encompasses the compensatory payment as blenders bid up the domestic price of biodiesel while biodiesel producers bid up the domestic price of soybean oil until it is equal to the world price.

Under both subsidies, Zambia spends more money on oil imports as compared to the mandate, but earns more foreign exchange on biodiesel exports under the production subsidy. Overall, the numerical exercise presented in Table 4 indicates, that the most efficient biofuel policy from the welfare perspective is the biodiesel production subsidy, followed by the tax exemption, and the mandate.

However, these results hinge on the assumption that the country is able to export all its biodiesel production if needed. But in reality that might not hold because of logistic problems, such as insufficient quantity of biodiesel produced that would fill up the tanks quickly enough to deliver the product smoothly to the overseas markets. Therefore, it is necessary to also consider a situation where Zambia does not export any biodiesel under the production subsidy. How can a policy be designed to achieve domestic consumption of all produced biodiesel?

One option is to provide a tax exemption along with the production subsidy such that the tax exemption makes consumers indifferent between purchasing diesel and biodiesel. Such a tax exemption is defined by equation (11) and equals $0.49/liter. But associated with this tax exemption are additional fiscal expenditures of $14.7 million (as per column 2 in Table 4) which more than offsets the net benefits of the production subsidy alone of $14.1 million (column 1). Hence, the consideration of possible logistic problems with biodiesel exports and addressing these problems with an additional tax exemption changes makes the tax exemption alone be the most preferred policy option, followed by a mandate.

Interestingly, our numerical analysis shows that for the same biodiesel production, a tax exemption yields higher welfare than a mandate. This contradicts the theoretical and empirical results by Lapan and Moschini (2012) and de Gorter and Just (2010), and is due to the unique situation here of a small country and the soybean oil-biodiesel-diesel market.

5. Conclusions

The objective of this paper is to analyze the economics of producing biodiesel from soybeans in Zambia and also to investigate alternative policies for biodiesel market development. We find that the analysis of market impacts of biofuel policies in a small open economy, such as Zambia, is much more nuanced than an analogous analysis for a large country, such as Argentina. The reason for this is the exogeneity of world prices faced by the small country. Because the world prices of biodiesel and soybean oil on the one hand and of soybean oil, soybean meal, and soybeans 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, an appropriate policy measure needs to be taken. A biodiesel blend mandate and a biodiesel production subsidy both necessitate a compensatory payment to biodiesel producers. Under the mandate, the transfer is financed by fuel consumers and all biodiesel produced is consumed domestically. On the other hand, the compensatory payment under (and in addition to) the production subsidy comes from tax payers and all biodiesel produced is exported. The third policy option is a tax exemption on the pump level that makes fuel consumers indifferent between the purchase of diesel and biodiesel; as with the mandate, all biodiesel is consumed in the small country.

Our empirical analysis of the efficiency of alternative biofuel policies for Zambia (holding the level of biodiesel production constant) as measured by their associated welfare levels indicates the following policy ordering (starting from the best): biodiesel production subsidy, biodiesel tax exemption, and blend mandate. This result, however, ignores possible logistical problems with biodiesel exports. We show that when these problems are accounted for, the tax exemption is likely to be the best policy, while the production subsidy becomes the least efficient policy option. Our sensitivity analyses also show that the results 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 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. It is to be noted, however, that the current welfare analysis ignores other potentially important welfare components, such as the marginal burden of taxation and negative traffic-related externalities (e.g., air pollution and traffic congestion).

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Appendix 1.Observed and calculated values for 2010 used to calibrate the model for Zambia

Variable/Parameter	Symbol	Value	Unit	Source/explanation
Quantity of soybeans crushed (consumption)	C_{SB}	26,582	metric tonnes	$=Q_{SB} + M_{SB} - X_{SB}$
Production of soybeans	Q_{SB}	41,000	metric tonnes	Faostat[a]
Imports of soybeans	M_{SB}	27	metric tonnes	Faostat[b]
Export of soybeans	X_{SB}	14,445	metric tonnes	Faostat[b]
Diesel consumption	D	596.84	mil. liters	Energy Sector Report[c]
Diesel price	P_D	0.92	$/liter	Energy Sector Report[c]
Diesel tax	t	0.30	$/liter	Report of the Status of Petroleum Industry[d]
MPG biodiesel/MPG diesel	λ	0.91		de Gorter et al. (2011)
Local price of soybeans at Beira linked to Argentian price	P_{SB}	370.24	$/metric tonne	HighQuest Partners (2011)
Local soybean oil price at Lusaka linked to Argentinian price	P_{SO}	1284.35	$/metric tonne	HighQuest Partners (2011)
Local price of soybeans at Beira linked to the world price	P_{SM}	387.20	$/metric tonne	HighQuest Partners (2011)
Biodiesel price in Germany	P_B	1.64	$/liter	UFOP[e]
World price of biodiesel (in $/DEEL)	P_B^E	1.79	$/DEEL	$=P_B/\lambda$
Marketing marging for diesel fuel	m	0.24	$/DEEL	$=P_F - P_D - t$
Consumer price of diesel fuel	P_F	1.46	$/DEEL	Energy Sector Report[c]
Consumption of soybean oil for human consumption	D_{SOH}	10,952	metric tonnes	$=Q_{SO} + M_{SO} - X_{SO}$
Production of soybean oil	Q_{SO}	3,600	metric tonnes	Faostat[f]
Imports of soybean oil	M_{SO}	7,459	metric tonnes	Faostat[g]
Exports of soybean oil	X_{SO}	107	metric tonnes	Faostat[g]
Production of soybean meal	Q_{SM}	22,982	metric tonnes	$=\beta_2 * C_{SB}$
Consumption of soybean meal	D_{SM}	22,982	metric tonnes	$=Q_{SM}$
Tonnes of soybean oil from one tonne of soybeans	β_1	0.135		$=Q_{SO}/C_{SB}$
Tonnes of soymeal from one tonne of soybeans	β_2	0.865		$=1 - \beta_1$
DEEL of biodiesel extracted from one metric tonne of soyoil	β_3	990.025	DEEL/metric tonne	FAPRI[h]
Processing cost of soybeanoil	c_{0s}	1022.38	$/metric tonne	$=(\beta_1 P_{SO}+\beta_2 P_{SM}-P_{SB})/\beta_1$
Processing cost of biodiesel	c_{0b}	0.24	$/DEEL	Sinkala (2011)
Elasticities				
Fuel demand	η^D_F	-0.26	Hamilton (2009)	
Demand for soybean oil for human consumption	η^D_{SOH}	-0.15	FAPRI	
Demand for soymeal	η^D_{SM}	-0.35	FAPRI	
Supply of soybeans	η^S_{SB}	0.34	FAPRI	

[a] http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

[b] http://faostat.fao.org/site/535/DesktopDefault.aspx?PageID=535#ancor

[c] http://www.erb.org.zm/reports/ERBeNergySectorReport2010.pdf

[d] http://www.erb.org.zm/reports/ERBStatusReportPetroleumSector.pdf

[e] http://www.ufop.de/medien/downloads/agrar-info/marktinformationen/

[f] http://faostat.fao.org/site/636/default.aspx#ancor

[g] http://faostat.fao.org/site/535/default.aspx#ancor

[h] http://www.fapri.missouri.edu/outreach/publications/2006/biofuelconversions.pdf