

Ethanol for an agriculture-based developing economy: A computable general equilibrium assessment for Uganda

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ABSTRACT

This study uses a static computable general equilibrium (CGE) model to examine the potential economic impacts of ethanol production in Uganda. We introduce an ethanol sector in the 2016/17 Uganda's social accounting matrix (SAM) using maize, cassava, sugarcane, and molasses as feedstocks. Furthermore, we evaluate the suitability of each feedstock. By simulating a 10% blending mandate, we find that factor employment and total output would increase, with a sluggish rise in commodity prices. Real GDP would grow moderately, and household income increase, mostly for the rural households. Household welfare would decline because of a counter-financing tax on gasoline. A reduction in gasoline imports is likely to improve the trade balance, and despite the ensuing decline in import tax revenues, government income would still rise. Our results are suggestive of ethanol production as a potential pro-poor project for Uganda. Both sugarcane and maize are more growth-enhancing compared to cassava. The use of only molasses from the sugar industry may result in negative impacts since it is already an input in other activities. We also observe that using an average of multiple feedstocks would be more sustainable. Moreover, it would allow a more balanced growth while reducing upward price pressures.

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Introduction and motivation

Ethanol is one of the conventional liquid biofuels mainly used in transport and industrial processes. Biofuels production started as early as the 1970s in Brazil and the US, and later in the EU (Runge & Senauer, 2007). It has been motivated by concerns for energy security, rural development rural, and the reduction of greenhouse gas emissions. The attempt to promote renewable energy in Uganda was first spelled out in the provisions of the Energy Policy (Ministry of Energy and Mineral Development (MEMD), 2002) and the Renewable Energy Policy (REP) (MEMD, 2007). One of the policy objectives in the latter is to promote the production and utilization of biofuels by setting a requirement of at least a 20% blend level. The biofuels Act was signed in 2018 to provide a supportive regulatory framework that would regulate the production, distribution, and use of biofuels. The Act, however, is yet to be operationalized.

The promotion of biofuels in Uganda is anticipated to reduce the country's trade deficit. Uganda imports all its petroleum products, and these constitute the largest share (18.2%) of the total import budget (Uganda Bureau of Statistics (UBOS), 2018). While substituting some

of these products may result in significant foreign exchange savings, there are concerns about the subsequent losses in import tax revenues.

For an agriculture-based economy, a bioeconomy¹ provides a competitive advantage and opportunities to achieve several sustainable development goals (goals 1, 2, 7, 8, 9, and 13). The prospective benefits of biofuels cannot be overemphasized, especially for a country like Uganda, where over 70% of the population derive their livelihood from agriculture. These benefits range from employment and rural income enhancement to trade and economic growth (Mitchell, 2010). As biofuels production expands, factor demand in this sector and other related industries is expected to rise. This can boost the income of households by supplying factors of production. Al-Riffai and Laborde (2010) find that ethanol and biodiesel would improve the income of households in Peru. The increase in household income could potentially dampen poverty levels and even improve food security. For example, Arndt, Benfica, Tarp, Thurlow, and Uaiene (2010), Arndt, Pauw, and Thurlow (2010), and Boccanfuso, Coulibaly, Savard, and Timilsina (2018) assess the expansion of biofuels production using computable general equilibrium (CGE) models, which are linked to microsimulation modules. Their findings suggest a decline in the poverty rates, especially

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¹ Activities involving the use of bio-based resources to produce food, energy and materials.

for the rural households. In this regard, biofuels production could be perceived as a strategic route to escape from poverty (Peskett, Slater, Stevens, & Dufey, 2007).

Since the pre-independence period, the Ugandan government has made efforts toward enhancing agriculture through extension services and value addition. Nonetheless, the lack of a reliable market for agricultural commodities remains a big challenge. Majority of studies have confirmed a positive correlation between biofuels and feedstock (and food) prices (see Elizondo & Boyd, 2017; Timilsina, Beghin, Van der Mensbrugghe, & Mevel, 2010; Wianiwat & Asafu-Adjaye, 2013). It is, therefore, logical to expect that promoting biofuels would strengthen crop markets, especially in periods of excess harvest, during which prices usually plummet. The rise in feedstock/food prices may, however, lead to food insecurity, particularly in lean seasons (Mitchel, 2008). Nonetheless, the magnitude of this price increase is quite debatable, as reflected by the variations in findings across studies. Some studies have found a weak relationship between biofuels and food prices; for example, in the work by Wianiwat and Asafu-Adjaye, the prices of food and other products increase marginally both in the short and long run.

The choice of an appropriate feedstock is also crucial, and it heavily depends on the available technologies. The current technology in Uganda supports production of ethanol from molasses and crops. Policymakers should, however, act with prudence to ensure that the supply of feedstocks does not compromise food availability, and the choice of feedstock crops may have a significant bearing on this. Some crops employ more labor and other factor inputs, others have higher crop yields, yet others have stronger linkages with other sectors in the economy. Arndt et al. (2010) observe that even without any yield improvements, cassava is more profitable, and it generates higher levels of pro-poor growth than sugarcane. Similarly, Hartley, van Seventer, Samboko, and Arndt (2018) find that in Zambia, cassava would generate substantial gains relative to sugarcane and sweet sorghum because it has the highest value-added.² Nonetheless, sugarcane is identified to have stronger linkages with the rest of the sectors in the economy.

There is a large body of literature on biofuels at the global level, and this is mainly focused on production in developed countries (see Calzadilla, Delzeit, & Klepper, 2014; Taheripour, Levano & Tyner, 2017; Timilsina et al., 2010; Tyner, Taheripour, Zhuang, Birur, & Baldos, 2010). These studies provide useful insights and an essential basis for research in developing countries. There is also a growing strand of research on this subject in developing countries, but this is still in its early stage (see Arndt, Benfica, et al., 2010; Arndt, Pauw, & Thurlow, 2010; Boccanfuso et al., 2018; Hartley et al., 2018; Hartley, van Seventer, Tostão, & Arndt, 2019). Moreover, biofuels are a new development; they are still understudied, particularly in developing countries.

Our main research question is: what impacts might ethanol production and mandatory blending have on Uganda's economy? We address this question by explicitly examining the economic impacts on (i) employment, output, and prices, (ii) household income and welfare, (iii) the trade balance, government income, and overall economic growth. We also evaluate the suitability of the feedstocks. We carry out our empirical analysis using a static CGE model calibrated to the 2016/17 Uganda's social accounting matrix (SAM). All the simulations assume a 10% blending mandate, which is achieved through a consumption subsidy. Despite the ministerial document (the REP) that aims for at least a 20% blending level, we find a 10% level to be more realistic. Currently, at least all modern cars can run on such a fuel mixture without any engine or fuel system modifications. Besides, this is a less ambitious target for an infant industry. The novelty of our study is the introduction of an ethanol sector in Uganda's SAM and the explicit simulation of a 10% blending mandate. To our knowledge, this is the first study in Uganda to empirically examine the likely impact of ethanol production with an explicit displacement of gasoline. This is a time when knowledge and

information are needed for investors and policymakers to make informed decisions. Our study, therefore, sheds light on the possible impacts of ethanol by presenting general predictive considerations. It also provides policy recommendations and a basis for further research.

The rest of the paper is organized as follows: Section 2 briefly introduces biofuels and the background of Uganda's biofuels sector. Section 3 outlines the methods and data, while Section 4 presents and discusses results. In Section 5, we conclude and provide policy implications.

Biofuels and the state of the biofuels sector in Uganda

Biofuels are biomass-based fuels derived from plant or animal material. These may be solid, liquid, or gaseous. The most common liquid biofuels are ethanol and biodiesel, which are mostly used in transport and industries. Ethanol and biodiesel can be blended with gasoline and diesel, respectively. Biofuels from food crops are referred to as first-generation biofuels. While first-generation biodiesel is obtained from oilseed crops, first-generation ethanol is produced from feedstocks that contain sugar; for example, sugar beet, sugarcane, and molasses. It can also be obtained from starch crops such as maize, cassava, banana, and sweet sorghum.

Uganda's biofuels sector is at its initial stage, but companies like Kakira Sugar Works Limited (KSWL) in Jinja and the Sugar Corporation of Uganda Limited (SCOUL) in Lugazi already have installed capacity to produce 35,000 l and 60,000 l of molasses ethanol per day, respectively. SCOUL produces maize ethanol as well. These companies currently process undenatured ethanol known as Extra Neutral Alcohol (ENA), and they have expressed interest to start producing fuel-grade ethanol. A clear regulatory framework and incentives toward the sector are still lacking (MEMD, 2015). This partly explains the slow investment and the delay to commence commercial production. Some small-scale companies like Kamtech logistics in Lira, which was processing 4000 l of cassava ethanol per day, shut down due to lack of a steady market.

The tropical climate in Uganda, with an annual average rainfall of about 1188 mm and temperature of around 25 °C, presents prospects for higher agricultural output. According to the FAO (2020) database, as of 2018, Uganda's sugarcane optimum yield was about 60 t/ha, which compares closely with the 74 t/ha for Brazil. The acreage productivity of maize and cassava were estimated at 2.6 t/ha and 5.3 t/ha, respectively. Although these figures are slightly below the Africa's averages of 2.04 t/ha for maize and 9.08 t/ha for cassava, and the world averages of 5.9 t/ha for maize and 11.3 t/ha for cassava, there is room for productivity improvement. These conditions create a conducive environment for first-generation ethanol. As a preliminary step, the National Environment Management Authority (NEMA) report identifies *Jatropha curcas*, maize, sugarcane, and oil palm as potential biofuels feedstocks (NEMA, 2010).

Materials and methods

Our analysis employs the 2016/17 Uganda's official SAM developed by (Tran, Roos, Asimwe, & Kisaky, 2019). The SAM and the data on gasoline imports were obtained from MEMD. Data on molasses production, its price, and the price of ethanol is from the sugar industry. We got the ethanol conversion rates from the sugar industry and the literature, and the information on how molasses is captured in the national accounts was obtained from UBOS.

The biofuels sector is linked to other sectors like energy, transport, and agriculture, and these have linkages with other industries. CGE is a suitable modeling framework to account for such interlinkages. We, therefore, carry out our analysis in a static CGE model, and calibrate it to the 2016/17 SAM using GAMS.

Kretschmer and Peterson (2010) present a comprehensive discussion of the approaches to modeling biofuels in CGE analyses. These include implicit modeling, the latent approach, and explicit disaggregation. An implicit modeling approach determines the required

² Value-added in this case refers to the contribution of land, capital and labor per unit of output.

amount of biomass to produce a given volume of biofuels (see Banse, van Meijl, Tabeau, & Woltjer, 2008; Dixon, Osborne, & Rimmer, 2007). In contrast, the latent approach introduces a biofuels sector and treats it as unprofitable and inactive in the base year, but it becomes profitable with changes in relative prices or some government support (see Boeters, Veenendaal, van Leeuwen, & Rojas-Romagoza, 2008; Kretschmer, Peterson, & Ignaciuk, 2010). The above two approaches apply when no production exists. If production exists, and it is captured under some other industries, the sector can be modeled by explicitly disaggregating it from the existing database (see Taheripour, Birur, Hertel, & Tyner, 2007).

At the global level, CGE models based on different versions of the Global Trade Analysis Policy database are used in analyzing biofuels (see Calzadilla et al., 2014; Taheripour et al., 2007; Taheripour et al., 2017; Tyner et al., 2010). At the national level, individually built country-specific and generic models, such as the Standard CGE models by the Partnership for Economic Policy (PEP) and the International Food Policy Research Institute (IFPRI) have been directly applied or modified.

In this study, we extend the PEP-1-1 standard single-country static CGE model by Decaluwé, Lemelin, Robichaud, and Maisonnave (2013). Our extensions to the model include (i) the integration of the ethanol sector based on maize, cassava (chips), sugarcane, and molasses (ii) the introduction of a by-product sector (molasses), (iii) the inclusion of factor income from abroad, and (iv) the blending equation (please see Appendix A). The original SAM consists of 186 activities and commodities, which we aggregate into 34 activities and commodities, including the new sectors. Some model parameters are directly calibrated from the SAM, while others (elasticity parameters) are obtained from the literature. The latter are presented in Table A.2 of Appendix A.

The production structure is presented in Fig. A.1, Appendix A. At the top of every production activity, a Leontief production function combines aggregate intermediate inputs and total value-added in fixed proportions. Except for the ethanol collecting and blending sectors, the aggregate intermediate in the rest of the sectors is also a Leontief function of individual intermediate inputs. Total value-added is a constant elasticity of substitution (CES) function of the capital-land and the labor composites. At the bottom of each nest, components of the capital-land composite are also governed by a CES, and so are the components of the labor composite. Profits are maximized when each factor's marginal product equals its price.

Labor is disaggregated into unskilled (incomplete primary), semi-skilled (completed primary), skilled (completed secondary), and highly skilled (completed tertiary). This categorization includes rural and urban for both male and female groups; thus, a total of 16 labor categories. In the original SAM, land is merged with agricultural capital. We extracted it from total agricultural capital, for only the crop sectors, using a share of 75%, which we derived from the 2013 Uganda SAM by Randriamamonjy and Thurlow (2017).

Each feedstock produces a corresponding ethanol type. Both the ethanol-collecting sector (Ethanol) and the blending sector (Blend) have no value-added, and their intermediate inputs are governed by a CES. The Ethanol sector combines all ethanol types as perfect substitutes using a CES function (Eq. (1)). The demand for each type is derived from the first-order conditions for cost minimization, subject to the CES technology (Eq. (2)). Similarly, the Blend sector combines total ethanol and gasoline in a CES function as perfect substitutes (Eq. (3)). The demand for each fuel is a result of cost minimization (Eq. (4)). Please note that for the model to converge, the share of biofuels should vary in the production of the blended product (Woltjer & Kuiper, 2014). To achieve an equal offset of gasoline by the volume of ethanol, we treat the two fuels as perfect substitutes. We simply fix the mandated share exogenously, and consumers make no choice. Moreover, a consumption subsidy equates the purchaser prices for the two fuels.

$$TEHTD_{ec} = B_{ec}^{ed} \left[\sum_{et} \beta_{et,ec}^{ed} ETHD_{et,ec}^{-\rho_{ec}^{ed}} \right]^{-\frac{1}{\rho_{ec}^{ed}}} \quad (1)$$

$$ETHD_{et,ec} = \left[\frac{\beta_{et,ec}^{ed} P(ec)}{P(et,ec)} \right] \left(B_{ec}^{ed} \right)^{\sigma_{ec}^{ed}-1} TEHTD_{ec} \quad (2)$$

$$BLD_b = B_b^{fd} \left[\sum_f \beta_{f,b}^{fd} FUEL_{f,b}^{-\rho_b^{fd}} \right]^{-\frac{1}{\rho_b^{fd}}} \quad (3)$$

$$FUEL_{f,b} = \left[\frac{\beta_{f,b}^{fd} P(b)}{P(f,b)} \right] \left(B_b^{fd} \right)^{\sigma_b^{fd}-1} BLD_b \quad (4)$$

$$-1 < \rho_{ec}^{ed} < \infty; -1 < \rho_b^{fd} < \infty; 0 < \sigma_{ec}^{ed} < \infty; 0 < \sigma_b^{fd} < \infty$$

In the above equations $TEHTD_{ec}$ is total ethanol in the Ethanol sector (ec), $ETHD_{et,ec}$ the type of ethanol (et) into sector (ec), B_{ec}^{ed} the scale parameter, $\beta_{et,ec}^{ed}$ the share parameter, ρ_{ec}^{ed} the elasticity parameter, σ_{ec}^{ed} the elasticity of substitution parameter, $P(et,ec)$ the price for ethanol type (et) into ethanol sector (ec), and $P(ec)$ is the intermediate consumption price index for the Ethanol sector. For the blending sector, BLD_b is total blended fuel, $FUEL_{f,b}$ the fuel (f) (ethanol or gasoline) entering the blend sector (b), B_b^{fd} the scale parameter, $\beta_{f,b}^{fd}$ the share parameter, ρ_b^{fd} the elasticity parameter, σ_b^{fd} the elasticity of substitution parameter, $P(f,b)$ the price of the individual fuel (f) into the blend sector (b), and $P(b)$ is the intermediate consumption price index for the Blend sector.

Activities can produce more than one commodity, and the output from an individual sector is aggregated using a constant elasticity of transformation (CET) function, except for the by-products (molasses). Domestic output is directed to the domestic and export markets under the assumption of imperfect substitutability represented by a CET function. Domestic demand is made up of household consumption demand, public demand, investment demand, intermediate demand, and the demand for margin services. The imperfect substitutability between domestic and imported commodities is captured by a CES function for Armington aggregation. A small country-hypothesis regarding exports and imports is adopted; hence, their world market prices are exogenous. Nonetheless, an exporter can increase his world market share depending on the competitiveness of the free-on-board price relative to the world price, and on the price elasticity of demand for the exports.

Our household sector consists of 32 representative types grouped according to the Central, Eastern, Northern, and Western regions of Uganda. These groupings are further categorized into rural and urban under four income quintiles. The disaggregation allows for a richer analysis of the income distribution and welfare effects. Household income comprises of factor payments and transfers from firms, other households, the government, and the rest of the world. This is spent on consumption, taxes, savings, and transfers (locally and abroad). The consumption demand functions are linear expenditure systems derived from the maximization of a Stone-Geary utility function, subject to a consumption expenditure constraint. Because of the mandate and the consumption subsidy, consumption of the blended fuel is not different from consumption of conventional fuel.³

Under the factor market closure, land is underutilized and mobile in agriculture.⁴ We also assume unemployment in the labor market. The supply of these factors is, therefore, endogenized, while the rent and the wage are fixed. This is a common closure in studies on Uganda, intended to capture idle land and unemployment in the economy (Shinyekwa & Mawejje, 2013). All the unskilled labor can move freely

³ Consumers can only buy the blended product at a price not higher than that of the conventional fuel (gasoline).

⁴ We are using agriculture to refer to only the crop sectors. It therefore excludes fishing, forestry and animal husbandry.

in the agriculture, firewood, charcoal, and the molasses sectors (hereafter “the rural sectors”), but it is immobile in the rest of the sectors (hereafter “the urban sectors”).

Capital is fixed in supply and fully employed. It is sector-specific in agriculture, but mobile across the non-agricultural sectors. Although the capital mobility assumption may not be suitable in this context, we could not invoke the sector-specific assumption because we are introducing new sectors while holding the supply of capital constant. We recognize the limitations of capital transfers for project financing in developing countries (United Nations Conference on Trade and Development, 2018). Moreover, the current production proposals are dependent on installed capacity, and from our interviews, producers claim to have this capacity in place. Therefore, like Boccanfuso et al. (2018), we assume that expansion of the ethanol sector is generated using existing capital in the economy; for example, the annexed distilleries that are already in operation.

For the macroeconomic closure, foreign savings are fixed and the exchange rate is endogenized to clear any imbalances on the current account. This assumption is appropriate since Uganda runs a flexible exchange rate system. We use the GDP deflator as the model numeraire. The savings-investment balances are investment-driven, with savings as the endogenous variable. Total investment is the sum of savings by households, firms, government, and foreign borrowings. It is made up of both gross fixed capital formation and changes in stocks, with the former endogenous and the latter fixed. Government savings is a flexible residual between revenues and expenditures, and all tax (subsidy) rates are fixed.

Modeling ethanol production

Details of all the calculations in this section are presented in Appendix B. Currently, companies produce ENA from maize, cassava, and molasses as they await the government to enforce mandatory consumption and to provide other incentives. This information was obtained from our field visits, and it is the basis for the SAM adjustments. We use maize, cassava, sugarcane, and molasses as the feedstocks. Each feedstock is supplied by its respective sector, except for molasses, which does not exist in the original SAM. We introduce a molasses sector without production of its own, but its output is the by-product molasses from the sugar industry.

From our interviews with the experts in the sugar industry and UBOS, the value of molasses is captured in the value of sugar. We use data on sugar production and the corresponding amount of molasses. Using the monetary values of both, we derive the share of molasses as 2.7% of the value of sugar. We use this to calculate the value of by-product molasses from the sugar industry. It enters the molasses sector through a Leontief functional relationship. The distribution of the final output is that: 86% goes to the ‘food processing’ sector, 13% to the ‘Spirits-alcohol’ sector that makes alcoholic beverages, and 1% enters the ‘prepared animal feed’ sector.⁵ The molasses-ethanol sector only creates an additional demand determined by the input coefficient.

Arndt, Benfica, et al. (2010), Arndt, et al (2010), and Hartley et al. (2018) treat biofuels as a tradable sector, and the entire production is exported. We take a different approach and assume production for domestic use only. This is intended to determine the impact of reducing gasoline imports on the import tax revenues and the trade balance. Since ethanol in our analysis is for transport, we disaggregate the gasoline sector from the aggregate petroleum sector using the share of gasoline (44%) in the total petroleum products imports. The technical structure of this sector is derived from the petroleum sector. Please note that in Uganda, all the gasoline is primarily used for transport.

We follow the latent approach by introducing tiny amounts of ethanol in the SAM (see Taheripour et al., 2017). In this case, ethanol output

is practically zero in the base year because it is more expensive than gasoline, and there is a lack of effective demand. Production occurs only when the sector becomes competitive through government interventions and market incentives. The technical coefficients for the four ethanol sub-sectors are from Zhou and Kojima (2011). We adjusted them to reflect local costs, and the final technical structure is provided in Table B.2. Based on the data from the ethanol-producing companies, the basic price for undenatured ethanol was about USD 0.86 per liter, which is equivalent to Ush. 3000 in 2016/17 prices. We adopt this price as the production cost per liter of fuel-grade ethanol. To avoid the zero problem, we introduce a small quantity of about 0.676 million liters for each ethanol type in the base year. We multiply this quantity by the production cost of Ush. 3000 per liter to obtain a nominal value of Ush. 2.03 billion for each.

We use an ad valorem consumption subsidy to make ethanol competitive. The purchaser prices calculated from the SAM are 2.30⁶ and 1.90 for ethanol and gasoline, respectively. We use the price for gasoline as the reference price and derive a subsidy rate of about 33% per liter of ethanol. The subsidy equates the two prices and makes fuel-ethanol competitive. To maintain a neutral government budget, we impose an initial corresponding tax rate of 0.22% per liter of gasoline, which is quite small, because the large volume of gasoline provides a broader tax base.⁷ Finally, we balance the SAM using the cross-entropy method by Lemelin, Fofana, and Cockburn (2013).

Definition of the baseline model and policy simulations

The baseline model depicts the structure of Uganda's economy with almost zero fuel-grade ethanol. We first run the model without any simulations to make sure it replicates the base year equilibrium. For the simulations, we first identify the volume of gasoline in the base year. The imported volume was approximately 818 million liters (MEMD, 2016). Some of it, however, is re-exported. We calculate a share of 14% as re-exports using the values in the SAM. The remaining 86% (about 703 million liters) makes up domestic consumption. The required ethanol at a 10% blending rate is, therefore, 70.3 million liters. We multiply this volume by the basic price per liter (Ush. 3000) to obtain a nominal value of Ush. 211.05 billion, which we use in all our simulations. All the calculations are provided in Table B.2 Appendix B.

Scenarios and simulations description

We came up with four scenarios, and each is based on the production of ethanol worth Ush. 211.05 billion. In all the scenarios, unless where it is explicitly stated, maize, cassava, and sugarcane ethanol contribute an equal share (33.3%) to the total production.

Scenario 1. This scenario maintains the baseline closures. There is unemployment in the labor market. Skilled labor is mobile across all sectors, while unskilled labor can only move freely across the rural sectors. Land is underutilized and mobile within agriculture. Capital is mobile across the non-agricultural sectors but sector-specific in agriculture.

Scenario 2. In this scenario, we have all the assumptions in scenario 1, except that land is fully employed. It allows us to investigate the impacts of land constraints.

Scenario 3. Under this scenario, the share of sugarcane ethanol in total production is met by molasses. We test the likely outcome of using

⁶ Purchaser prices include commodity taxes (subsidies) and trade margins. The trade margins, and VAT on ethanol are adopted from the gasoline sector. We, however, introduce a product tax of 80% which is the rate on undenatured ethanol according to the current tax regime.

⁷ Please note that the subsidy and tax rates are ad valorem and endogenous; they are allowed to adjust in all simulations.

⁵ This distribution follows closely the initial distribution of sugar and additional explanation is presented in Appendix B.

by-product molasses from the sugar industry. This scenario is crucial because molasses is currently used to produce ENA, and fuel-ethanol is anticipated to come from the same by-product molasses. The purpose is to verify the envisaged benefits, considering that this feedstock is already an input in other activities.

Scenario 4. We assume total production from one feedstock at a time and compare the findings for all ethanol types. We also make a comparison with the main scenario (scenario 1), which assumes an average of feedstocks.

Sensitivity analysis. We carry out a sensitivity analysis to test the robustness of the model by choosing different elasticity of substitution parameters between capital and labor. We also run one test using an unbalanced budget, and another where all the factors of production are mobile and fixed in supply.

Results and discussion

In this section, we present and discuss the findings. All the results are reported as percentage deviations from the base year equilibrium values unless otherwise stated. Our analysis is based on a static model that does not incorporate dynamic effects; hence, the growth effects are not exhaustively captured. The results are, therefore, only suggestive and simply shed light on the possible implications.

Scenario 1

In this scenario, land is underutilized and mobile. Capital is sector-specific in agriculture but mobile in other sectors, and we assume unemployment in the labor market.

Impacts on output, factor employment, and prices

The ethanol sector creates new demand for the crops that serve as feedstocks. This raises the production and prices of these crops, which leads to growth in revenues. Since agricultural capital is sector-specific, the feedstock sectors draw in more land and labor to meet the growing demand. In Table 4.1 under S1 (for scenario 1), employment of land and labor rises in the maize, cassava, and sugarcane sectors, while it declines elsewhere. Because capital is sector-specific, it becomes relatively scarce compared to the supply of land and labor. This raises its marginal product and rental rate in expanding sectors. The labor wage and rent on land remain constant because of the unemployment assumption and the existence of underutilized land (see Table 4.1). Overall, total agricultural output increases. Table 4.2 (S1) shows an expansion of maize and cassava production by over 1%. Sugarcane activity increases with a higher percentage because it has the lowest ethanol conversion rate compared to maize and cassava.⁸ The sectors with declining activities experience a fall in output, prices, and capital rental rates.

Sugar activity contracts not only because of capital reallocation but also because of the competition for sugarcane from the ethanol sector. The higher rental rates on capital, the new demand for feedstocks, and the decline in output of other sectors exert an upward pressure on commodity prices. Ethanol prices also rise despite the subsidy. The price of gasoline increases due to the counter-financing tax, and so does the final fuel price. The CPI rises, and consumption of most commodities falls marginally.

Our findings are consistent with those by (Wianwiwat & Asafu-Adjaye, 2013). In their study, land reallocates to the feedstock sectors; in the short-run, it increases by 3.3 and 33% in the cassava and sugarcane sectors, respectively. They also show that as the demand for ethanol rises, the prices of inputs, such as molasses, cassava,

and tapioca chips increase, but the adverse effects on the food sector are minimal.

Impacts on household income, consumption, and welfare

The growth of mainly capital income and revenue in the feedstock sectors raises household disposable income. This occurs mostly for the rural households (see data series S1 in Fig. 4.1). The percentage change in income ranges from 0.01 to 0.10%. Household welfare, which is measured by equivalent variation (EV), declines across all households (Fig. 4.2). This is mainly because of the tax burden from the counter-financing tax on gasoline. The pattern of EV follows the change in the household real consumption budget (not reported), and the financing tax on gasoline seems more progressive in this context. Fig. 4.2 can be compared with Fig. C.1 in Appendix C under the unbalanced budget case, which excludes the effect of the financing tax.

In the study by Al-Riffai and Laborde (2010), biofuels production enhances rural household income. Arndt, Benfica, et al. (2010) and Arndt, Pauw, and Thurlow (2010) report a potential reduction in poverty levels arising from distributional income effects.

Impacts on the trade balance and economic growth

Exports fall and imports rise across all commodities; the period is too short to allow full adjustment in domestic production. Exports of maize and cassava decline as their imports rise to meet the increasing demand. Sugarcane exports, however, remain almost constant while the imports rise markedly (Table 4.2). As reflected in their respective volume indices, the decrease in total imports exceeds the fall in total exports (Table 4.3). The impact on total imports is exacerbated by the substantial reduction in gasoline. As a response to these movements in the trade balance, the real exchange rate appreciates by 0.29% (see Table 4.3). If export supply could be maintained, this outcome portrays prospects for an improved trade balance.

Gasoline is one of the heavily taxed commodities; hence, its decline reduces import tax revenues. However, since other commodity taxes like value-added and the sales tax increase at the same time, total tax revenue rises. As a result, the change in government income and savings is positive. We, however, notice that this outcome is, to some extent, dependent on maintaining some taxes on ethanol. Overall, the economy grows with real GDP expanding by 0.05%.

Scenario 2

In this scenario, land is fully employed and mobile. Capital is still sector-specific in agriculture but mobile in other sectors, and we assume unemployment in the labor market.

The results from this scenario, referred to as S2 (for scenario 2), are presented with the results from scenario 1 in the same tables and figures. Because both land and capital are fixed in supply, land use increases at a slower pace, while labor demand grows faster to generate the required output. Similar to scenario 1, sector-specificity of capital drives up its marginal product and the rental rate in the feedstock sectors. The sectors whose activity and prices decline record negative rental rates on capital. The growth in household income is slower, and it drops for some households while welfare deteriorates across all.

The reduction in exports and the increase in imports are higher than in scenario 1. Government revenue and savings rise, but real GDP declines. The rise in the cost of production and commodity prices is higher, and the increase in the CPI of 0.12 substantiates this (see Table 4.3). Therefore, in the absence of surplus land or productivity enhancement, short-run benefits may be limited. To a larger extent, we attribute the growth in scenario 1 to the existence of idle land.

Scenario 3

In this scenario, the share of sugarcane ethanol in total ethanol production is met by molasses ethanol.

⁸ A lower conversion rate means more sugarcane input to produce a given volume of ethanol. Furthermore, the initial base year values are relatively small, hence the large percentage deviations.

Table 4.1

Percentage change in factor demand and rental rate on capital.

	Scenario 1				Scenario 2			
	Land demand	Capital demand	Rate on capital ^b	Labor demand	Land demand	Capital demand	Rate on capital ^b	Labor demand
Maize	2.01	^a	1.70	3.31	1.62	^a	2.09	3.43
Cassava	1.80	^a	1.52	2.96	1.51	^a	2.00	3.25
Sugarcane	12.58	^a	11.55	22.20	12.23	^a	11.99	22.44
Grain seeds	−0.07	^a	−0.06	−0.11	−0.47	^a	0.32	−0.02
Other agric	−0.28	^a	−0.23	−0.45	−1.05	^a	−0.16	−0.96

^a Not applicable because capital is activity-specific in agriculture; hence, its demand does not change.^b Refers to the sectoral rental rate of composite capital, which combines land and capital. It declines by 0.06% and 0.14% under S1 and S2, respectively, in the sectors where capital is mobile (not shown). The higher percentage changes in the sugarcane variables are a result of smaller initial values. Other agric. includes all the cash crops like tea, coffee, cotton, vanilla, etc.

The findings in this section are summarized in Table 4.4. A simulation of an average of maize, cassava, and molasses ethanol generates errors if we set no limit to the subsidy budget. We, therefore, fix the subsidy budget for maize and cassava ethanol to their levels in scenario 1 (Ush.28 billion for each). Molasses ethanol adopts the budget for sugarcane ethanol (Ush.32 billion). Only about 52 million liters of the required 70.3 million liters are realized, with molasses ethanol contributing just 10% of this volume. The new demand from the ethanol sector puts an upward pressure on the price of molasses, and it escalates by over 300%. This high price is transmitted to the molasses ethanol price, and it erodes the subsidy budget (by raising the subsidy rate). There are reasons that explain this. First, molasses is currently used to produce products such as ENA, whose purchaser price is as high as USD.1.80 per liter. Second, the recovery rate for molasses is only 4% compared to that of sugar that ranges between 9 and 11% (Ministry of

Tourism, Trade and Industry MTTI (2010). Finally, molasses is extremely cheap compared to sugar. Therefore, the extent to which the demand for molasses prompts the growth in sugar production will be limited. It is untenable for a cheap product (molasses) to drive the growth in an expensive primary product (sugar) in order to generate more by-products (molasses).

From the simulation, the possible additional molasses induces a higher production of sugarcane and sugar. The sugarcane and sugar sectors draw in more resources, and their output increases significantly. Nevertheless, total value-added and real GDP rise moderately.

Sugar production increases and saturates the domestic market, leading to over 20% growth in its exports. This attenuates the decline in total exports. It is also a boon for consumers because of the price fall and the increase in consumption. Nonetheless, the 'processed-food,' 'animal feed,' and the 'spirit and alcohol' sectors that use molasses are

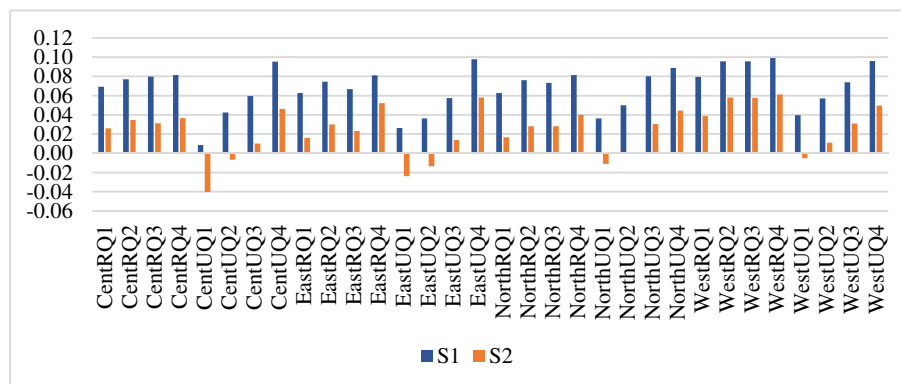


Fig. 4.1. Percentage change in household disposable income. The horizontal axis plots households for the central, eastern, northern and western regions; with R and U representing rural and urban, respectively. The Qs from 1 to 4 represent the four income quintiles. S1 and S2 are scenario 1 and 2, respectively.

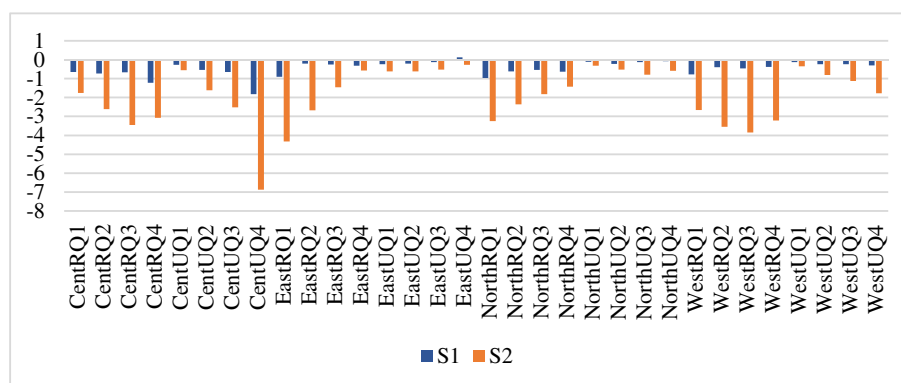


Fig. 4.2. Change in household welfare measured by equivalent variation. The change in equivalent variations is in absolute terms (billions of Uganda shillings).

Table 4.2

Percentage change in output, prices, and consumption.

	Scenario 1					Scenario 2				
	Output	Exports	Imports	Price	Consumption	Output	Exports	Imports	Price	Consumption
Maize	1.73	−1.45	11.59	1.54	−0.72	1.50	−2.26	13.35	1.87	−0.92
Cassava	1.37	−1.82	8.98	1.27	−0.59	1.17	−2.83	10.89	1.66	−0.82
Sugarcane	14.07	0.00	58.18	6.55	−2.94	14.00	−0.50	59.87	6.79	−3.09
Grain-seeds	−0.06	−0.39	0.25	−0.04	0.05	−0.32	−1.27	0.65	0.24	−0.13
Other agric	−0.24	−0.29	0.21	−0.13	0.09	−0.81	−0.94	0.25	−0.07	0.01
Animal farm	−0.04	−0.38	0.29	−0.02	0.04	−0.08	−0.27	0.10	−0.09	0.03
Processed food	−0.26	−1.13	0.67	0.22	−0.11	−0.33	−1.23	0.65	0.24	−0.19
Animal feed	−0.21	−0.88	0.06	0.16	−	−0.24	−0.87	0.01	0.14	−
Sugar	−0.79	−1.46	0.54	0.13	−0.06	−0.84	−1.51	0.48	0.13	−0.12
Spirits + alcohol	−0.15	−0.75	0.46	0.08	−0.01	−0.19	−0.75	0.40	0.06	−0.06
Transport	−0.39	−1.03	0.75	0.15	−0.06	−0.36	−0.91	0.63	0.11	−0.09
Gasoline			−16.73	4.48				−16.73	4.50	
Blended fuel				4.33	−1.90				4.34	−1.95
Molasses				49.83					49.38	
Sugarcane ethanol				1.29					1.30	
Cassava ethanol				1.29					1.30	
Maize ethanol				1.29					1.30	

Table 4.3

Percentage change in key macroeconomic variables.

	Scenario 1	Scenario 2
Real exchange rate	−0.29	−0.3
Import volume index	−0.94	−0.98
Export volume index	−0.70	−0.77
Agricultural output	0.45	0.15
Real GDP at market price	0.05	−0.02
Total value-added	0.07	0.02
Consumer price index (CPI)	0.10	0.12
Government income	0.70	0.64
Government saving	13.57	12.37
Import tax revenue	−0.37	−0.43
Total revenue from all product taxes	1.19	1.14
Total subsidies	89 ^a	90 ^a

^a Refers to absolute values of the subsidy budget in billions of Uganda shillings.

significantly affected. Government income and savings increase, and the pronounced growth in the sugarcane and sugar activities generates a

higher growth in income for most households (Fig. 4.3). Welfare improves for just a few rural households (Fig. 4.4).

Al-Riffai and Laborde (2010) also find that using molasses would be costly, especially if it is already efficiently used in other sectors. However, contrary to our findings, their change in household income and GDP is negative. Our case exhibits strong growth effects from the sugarcane, sugar, molasses, and the ethanol sectors. When we assume full employment of factor inputs, which is applied in their analysis, real GDP declines by 0.001%. Nonetheless, income still rises for the rural households (Fig. C.2 Appendix C), and the impact on welfare remains practically the same (Fig. C.3 Appendix C). Since we use a similar model, the divergence could be attributed to differences in elasticity parameters, the model numeraire, the data, or the general model specification.

Please note that the above findings are conditional on the willingness of the government to offer a higher subsidy rate for molasses ethanol, but this may be economically infeasible.

Table 4.4

Percentage change in factor demand, capital rent, output and price (scenario 3).

	Land demand	Capital demand	Labor demand	Capital rate	Output	Exports	Imports	Price	Consumption
Maize	1.76	^a	2.90	1.49	1.52	−1.49	10.78	1.37	−0.63
Cassava	1.62	^a	2.67	1.37	1.24	−1.84	8.54	1.14	−0.52
Sugarcane	10.26	^a	17.62	9.25	11.43	−0.05	46.00	5.27	−2.40
Grain seeds	−0.17	^a	−0.27	−0.14	−0.14	−0.50	0.18	−0.10	0.07
Other agric	−0.40	^a	−0.64	−0.33	−0.34	−0.40	0.11	−0.21	0.14
Animal farm		−0.28	−0.05	−0.08	−0.26	−0.74	0.19	−0.03	0.03
Processed food		−0.92	−0.19	"	−0.77	−2.76	1.44	0.69	−0.47
Animal feed		−0.55	−0.05	"	−0.52	−1.54	−0.12	0.26	−
Sugar		19.95	2.27	"	12.05	20.65	−4.40	−3.77	2.86
Spirits + alcohol		−0.92	−0.11	"	−0.63	−2.20	1.07	0.44	−0.29
Transport					−0.47	−1.19	0.79	0.11	−0.06
Gasoline							−12.26	4.17	−
Blend								4.06	−1.82
Molasses								338	
Molasses-ethanol								2.30	
Cassava-ethanol								1.04	
Maize-ethanol								1.03	
Exchange rate									
Import volume index									
Export volume index									
Real GDP									
CPI									
Govt income									
Import tax revenue									
Total product tax revenue									
Agricultural output									
Total value-added									
−0.35	−0.65	−0.49	0.02	0.09	0.56	−0.42	0.97	0.31	0.04

^a Not available because agricultural capital is immobile.

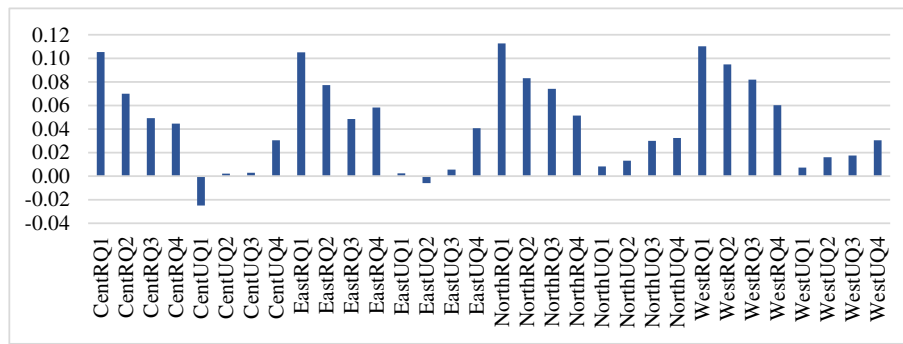


Fig. 4.3. Percentage change in household disposable income.

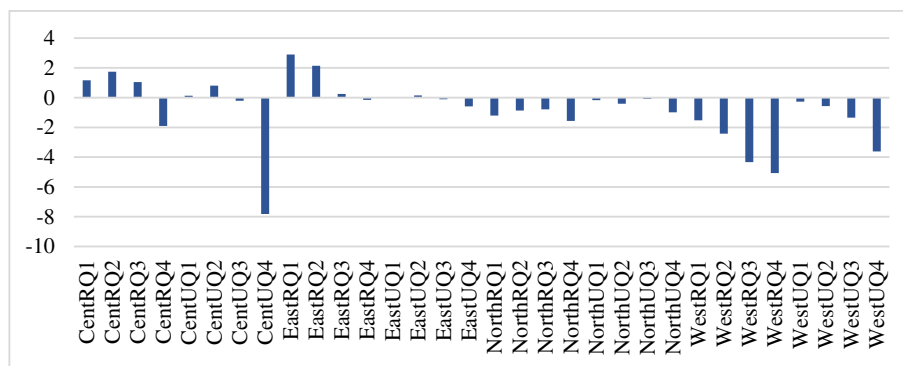


Fig. 4.4. Change in equivalent variation.

Scenario 4

In this scenario, we assume total ethanol is produced from one feedstock at a time. Based on the results from scenario 3, we decided to exclude molasses. The findings are reported in Table 4.5. Both sugarcane and maize seem more promising. They cause higher growth in agricultural output and GDP than cassava does. Sugarcane generates the highest growth in income for all households, but this is moderate under maize, and it declines for some households under cassava (Fig. 4.5).

Sugarcane ethanol takes the highest subsidy budget. This is because it has a lower conversion rate, implying more sugarcane input. This raises the demand and price of sugarcane. The higher price for sugarcane is transmitted to the ethanol price, and it explains why we have the highest increase in the CPI.

Column D presents the results from scenario 1, in which each feedstock contributes an equal share to total production. Despite a slower growth in GDP, a comparison with all the other cases in columns A, B, and C, reveals that a combination of feedstocks is likely to avert price escalations while achieving growth. We, accordingly, concur with the NEMA (2010) report, which supports the hypothesis that a combination of feedstocks would be more efficient and sustainable.

Sensitivity analysis results

Most of the test results under the various elasticity parameters in columns A, B, and C are close to our main findings (see Table 4.6). We also present in column D, a case of an unbalanced government budget. In this case, the growth in GDP is similar to scenario 1, but government income declines. This test allows us to identify the net welfare effect of ethanol production. We observe that in the absence of a financing tax, most rural households have their welfare enhanced. It, however,

Table 4.5

Percentage change in key macroeconomic variables – single feedstock case.

	A	B	C	D
	100% sugarcane ethanol	100% cassava ethanol	100% maize ethanol	Equal share (scenario 1)
Real exchange rate	−0.28	−0.34	−0.28	−0.29
Import volume index	−0.94	−0.96	−0.96	−0.94
Export volume index	−0.69	−0.73	−0.73	−0.70
Agricultural output	0.62	0.29	0.49	0.45
Real GDP at market price	0.09	0.01	0.05	0.05
Total value added	0.11	0.04	0.07	0.07
CPI	0.14	0.11	0.11	0.10
Gov't income	0.94	0.69	0.74	0.70
Tot. product taxes	1.61	1.18	1.27	1.19
Total subsidies	135 ^a	94 ^a	99 ^a	89 ^a
% Change in production from the base equilibrium values				
Maize	−0.15	−0.19	5.57	1.73
Cassava	−0.04	4.25	−0.07	1.37
Sugarcane	44.97	−0.05	−0.01	14.07
Grain seeds	−0.03	−0.09	−0.06	−0.06
Other agriculture	−0.18	−0.29	−0.21	−0.24
Animal farm	−0.05	−0.04	−0.05	−0.04

The size of each budget is determined by the rate of the price increase for the respective feedstock; sugarcane has the fastest growth in price. Column D presents results from scenario 1, in which the three feedstocks contribute an equal share to total ethanol.

^a Refers to absolute values in billions of Uganda shillings.

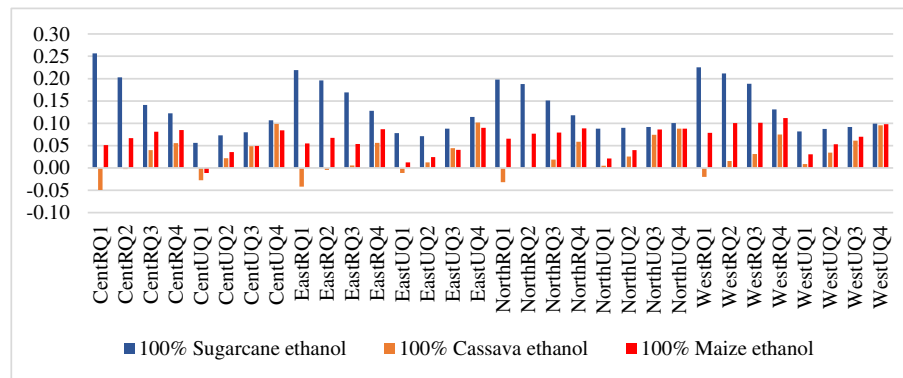


Fig. 4.5. Change in disposable income with total production from one feedstock.

remains constant for many urban households and the rural poor. We attribute this outcome to the increase in food prices, which erodes households' purchasing power, despite the growth in income (see Fig. C.1 in Appendix C).

In Column E, all the factors of production are mobile and fixed in supply. Household income and welfare decline (Figs. C.4 and C.5 in Appendix C). A comparison of these findings with those from scenario 1 shows that without productivity improvement, if all factor inputs are fixed in supply, ethanol production may negatively affect both sectoral and total output.

Conclusion and policy implications

We use a static CGE model to assess the economic impacts of ethanol production by simulating a 10% blending mandate. We introduce an ethanol sector based on maize, cassava, sugarcane, and molasses. To

address our main research question, we specifically examine (i) the impacts on employment, output, and prices, (ii) the impacts on household income and welfare, (iii) the effects on the trade balance, government income, and overall economic growth. We also evaluate the suitability of the feedstocks. In our main scenario (scenario 1), land is underutilized and mobile in agriculture, and labor faces unemployment. Capital is mobile in the non-agricultural sectors but sector-specific in agriculture. We find that factor employment and output increase in the feedstock and ethanol sub-sectors, but they decline in most of the remaining sectors. Prices of most commodities rise, and their consumption drops. Income grows mostly for the rural households, while welfare declines across all. Without a counter-financing tax, the majority of rural households have their welfare enhanced. It, however, remains constant for many urban households and the rural poor. Despite these effects, our results strongly suggest potential growth effects from ethanol. It might, however, require the government to synergize ethanol policies with other pro-poor policies such as encouraging micro-distilleries and the pursuance of an integrated food-fuel system. The growth effects are also conditional on surplus land, which is, to some extent, a valid case in Uganda and most developing countries. The available resources can, therefore, kick off an ethanol program.

If export supply could be maintained, a reduction in gasoline imports presents prospects for an improved trade balance. Although the concern for the loss in import tax revenues is valid, government income rises, and real GDP grows moderately.

Both sugarcane and maize result in higher growth than cassava. The envisaged benefits of using molasses from the sugar industry may be overstated. Its price rises faster and affects other sectors using it as an input. We recommend the use of by-product molasses to be augmented by the direct use of sugarcane juice or additional molasses from jaggery mills. It would also be prudent to use an average of feedstocks, to avoid escalating prices. This would also balance the distribution of income because the cultivation of crops varies with ecological regions.

Our analysis is based on a static model; thus, further research in a dynamic CGE framework would provide additional insight. We also based our findings on a consumption subsidy; therefore, investigations of different policy incentives would also be useful.

Declaration of competing interest

We declare no conflict of interest.

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Table 4.6
Results from the sensitivity analysis tests.

	A	B	C	D	E
	Balanced	Balanced	Balanced	Balanced	Unbalanced
EOS1	0.9	1.5	1.8	1.05	Full
EOS2	0.4	0.8	0.9	0.6	Employment
EOS3	0.3	0.3	0.4	0.3	(Uses EOS of D)
% Change in macroeconomic variables					
Real exchange rate	−0.29	−0.29	−0.28	−0.30	−0.18
Import volume index	−0.93	−0.94	−0.94	−0.94	−1.08
Export volume index	−0.7	−0.71	−0.71	−0.71	−0.87
Agricultural output	0.45	0.45	0.47	0.42	0.07
Real GDP at market price	0.06	0.05	0.06	0.05	−0.01
Total value added	0.08	0.07	0.08	0.07	0.00
CPI	0.10	0.10	0.10	(0.00)	0.09
Gov't income	0.70	0.69	0.69	−0.13	0.62
Tot. product taxes	1.20	1.18	1.18	−0.27	1.11
% Change in production					
Maize	1.72	1.76	1.92	1.69	2.60
Cassava	1.37	1.38	1.49	1.38	1.81
Sugarcane	14.04	14.16	14.32	13.96	15.02
Grain seeds	−0.06	−0.06	−0.06	−0.07	−0.19
Other agriculture	−0.23	−0.25	−0.31	−0.36	−3.31
Animal farm	−0.04	−0.04	−0.02	−0.07	−0.03

Balanced means that the subsidy is counter-financed by the tax on gasoline.

EOS stands for the elasticity of substitution.

EOS1 is for substitution between aggregate capital and aggregate labor.

EOS2 is used to substitute the different labor types. The same would apply to capital substitution in the non-agricultural sectors if there were more than one capital type.

EOS3 is for substitution between capital and land in agriculture.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.esd.2020.10.003>.

References

- Al-Riffai, P., & Laborde, D. (2010). *An economic assessment of alternative production pathways for Peruvian biofuels production*. Bioenergy and Food Security Project Retrieved from <http://www.fao.org/bioenergy/2309502215cec02075bcee09948f18e0932afa.pdf>.
- Arndt, C., Benfica, R., Tarp, F., Thurlow, J., & Uaiene, R. (2010). Biofuels, poverty, and growth: a computable general equilibrium analysis of Mozambique. *Environment and Development Economics*, 15(1), 81–105. <https://doi.org/10.1017/S1355770X09990027>.
- Arndt, C., Pauw, K., & Thurlow, J. (2010). *Biofuels and economic development in Tanzania* (No. 966). International Food Policy Research Institute (IFPRI).
- Banse, M., van Meijl, H., Tabeau, A., & Woltjer, G. (2008). Will EU biofuel policies affect global agricultural markets? *European Review of Agricultural Economics*, 35(2), 117–141.
- Boccanfuso, D., Coulibaly, M., Savard, L., & Timilsina, G. (2018). Macroeconomic and distributional impacts of Jatropha based biodiesel in Mali. *Economies*, 6(4), 63. <https://doi.org/10.3390/economies6040063>.
- Boeters, S., Veenendaal, P., van Leeuwen, N., & Rojas-Romagoza, H. (2008, June). The potential for biofuels alongside the EU-ETS. *CPB Netherlands Bureau for Economic Analysis. Paper presented at the GTAP conference in Helsinki*.
- Calzadilla, A., Delzeit, R., & Klepper, G. (2014). *DART-BIO: Modeling the interplay of food, feed and fuels in a global CGE model* (No. 1896). Kiel working paper.
- Decaluwé, B., Lemelin, A., Robichaud, V., & Maisonnave, H. (2013). *PEP-1-1 the PEP standard single-country, static CGE model*. Partnership for Economic Policy-PEP Retrieved from <https://www.pep-net.org/pep-standard-cge-models#1-1>.
- Dixon, P. B., Osborne, S., & Rimmer, M. T. (2007). The economy-wide effects in the United States of replacing crude petroleum with biomass. *Energy & Environment*, 18(6), 709–722.
- Elizondo, A., & Boyd, R. (2017). Economic impact of ethanol promotion in Mexico: A general equilibrium analysis. *Energy Policy*, 101, 293–301. <https://doi.org/10.1016/j.enpol.2016.11.017>.
- FAO (2020). Food and Agricultural Organization of the United Nations (FAO). FAOSTAT database. Retrieved from <http://www.fao.org/faostat/en/#compare>.
- Hartley, F., van Seunter, D., Samboko, P. C., & Arndt, C. (2018). Economy-wide implications of biofuel production in Zambia. *Development Southern Africa*, 36(2), 213–232. <https://doi.org/10.1080/0376835x.2018.1485552>.
- Hartley, F., van Seunter, D., Tostão, E., & Arndt, C. (2019). Economic impacts of developing a biofuel industry in Mozambique. *Development Southern Africa*, 36(2), 233–249. <https://doi.org/10.1080/0376835x.2018.1548962>.
- Kretschmer, B., & Peterson, S. (2010). Integrating bioenergy into computable general equilibrium models—A survey. *Energy Economics*, 32(3), 673–686.
- Kretschmer, B., Peterson, S., & Ignaciuk, A. M. (2010). *Integrating biofuels into the DART model: Analysing the effects of the EU 10% biofuel target* (pp. 63–74). Münster: Landwirtschaftsverlag.
- Lemelin, A., Fofana, I., & Cockburn, J. (2013). *Balancing a social accounting matrix: Theory and application* (revised edition). (Available at SSRN 2439868).
- MEMD (2002). *The energy policy for Uganda*. Kampala, Uganda: Kampala Uganda: Ministry of Energy and Mineral Development.
- MEMD (2007). *Renewable energy policy for Uganda*. Kampala, Uganda: Ministry of Energy and Mineral Development.
- MEMD (2015). *Sector development plan 2015/16–2019/20*. Kampala, Uganda: Ministry of Energy and Mineral Development.
- MEMD (2016). *Statistical abstract*. (Kampala, Uganda).
- Mitchel, D. (2008). *A note on rising food prices*. The World Bank.
- Mitchell, D. (2010). *Biofuels in Africa: Opportunities, prospects, and challenges*. The World Bank.
- MTTI (2010). *National sugar policy. A framework for enhancement of competitiveness, public – private partnerships, and social transformation the Ministry of Tourism, Trade and Industry*. (Kampala, Uganda).
- NEMA (2010). *The potential of bio-fuel in Uganda. An assessment of land resources for bio-fuel feedstock suitability*. (Kampala, Uganda. Retrieved from <https://wedocs.unep.org/bitstream/handle/20.500.11822/9199/The%20Potential%20of%20Bio-fuel%20in%20Uganda%3a%20An%20assessment%20of%20land%20resources%20for%20bio-fuel%20feedstock%20suitability-2010Bio%20fuels%20in%20Uganda.pdf?sequence=3&isAllowed=y>).
- Peskett, L., Slater, R., Stevens, C., & Dufey, A. (2007). Biofuels, agriculture and poverty reduction. *Natural resource perspectives*, 107, 1–6.
- Randriamamonjy, J., & Thurlow, J. (2017). *2013 Social accounting matrix for Uganda: A Nexus Project SAM*. Washington DC, USA: International Food Policy Research Institute <https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/XDNIGO> (Accessed 19 March 2019).
- Runge, C. F., & Senauer, B. (2007). How biofuels could starve the poor. *Foreign Affairs*, 86, 41.
- Shinyekwa, I., & Mawejje, J. (2013). *Macroeconomic and sectoral effects of the EAC regional integration on Uganda: A recursive computable general equilibrium analysis*.
- Taheripour, F., Birur, D., Hertel, T., & Tyner, W. (2007). *Introducing liquid biofuels into the GTAP data base*.
- Taheripour, F., Levano, L. M. P., & Tyner, W. (2017). *Introducing first and second generation biofuels into GTAP data base version 9*.
- Timilsina, G. R., Beghin, J. C., Van der Mensbrugghe, D., & Mevel, S. (2010). *The impacts of biofuel targets on land-use change and food supply: A global CGE assessment*. The World Bank.
- Tran, N., Roos, E. L., Asiimwe, W., & Kisakyi, P. (2019). (No. g-302) *Constructing a 2016/17 Social Accounting Matrix (SAM) for Uganda*. Victoria University, Centre of Policy Studies/IMPACT Centre.
- Tyner, W., Taheripour, F., Zhuang, Q., Birur, D., & Baldos, U. L. (2010). *Land use changes and consequent CO2 emissions due to US corn ethanol production: A comprehensive analysis*. UBOS (2018). *Statistical abstract*. Kampala Uganda: Uganda Bureau of Statistics.
- United Nations Conference on Trade and Development (2018). *World investment report 2018: Investment and new industrial policies*. New York and Geneva: UNCTAD.
- Wianwiwat, S., & Asafu-Adjaye, J. (2013). Is there a role for biofuels in promoting energy self sufficiency and security? A CGE analysis of biofuel policy in Thailand. *Energy Policy*, 55, 543–555. <https://doi.org/10.1016/j.enpol.2012.12.054>.
- Woltjer, G.B. and M.H. Kuiper, 2014. The MAGNET model: Module description. Wageningen, LEI Wageningen UR (University & Research Centre), LEI report 14-057. 146 pp.; 18 fig.; 45 tab.; 39 ref.
- Zhou, X., & Kojima, S. (2011). Biofuels data and social accounting matrices prepared for policy assessment models based on the GTAP 7 data base. Technical report February, Institute for Global Environmental Strategies, Arlington, VA.