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Biofuels and Economic Development in Tanzania

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Contents

Abstract	v
1. Introduction	1
2. The Biofuels Debate	2
3. Options for Producing Biofuels in Tanzania	5
4. Modeling Impacts on Growth and Poverty	10
5. Model Results	15
6. Conclusions	27
References	29

List of Tables

1. Food and Agriculture Organization's biofuel production options	5
2. Simulated biofuel production scenarios	6
3. Production cost estimates for biofuel scenarios	7
4. Biofuel production technologies under alternative scenarios	9
5. Structure of Tanzania's economy, 2007	10
6. Core model equations	11
7. Core macroeconomic assumptions and results, 2007–2015	16
8. Agricultural production results, 2007–2015	18
9. Sector growth results, 2007–2015	20
10. Employment results, 2007–2015	22
11. Household per capita equivalent variation results, 2007–2015	24
12. Poverty results, 2007–2015	27

List of Figures

1. Conceptual framework	14
2. Change in per capita equivalent variation from baseline scenario by quintile, 2007–2015	25

ABSTRACT

Biofuels provide a new opportunity to enhance economic development in Tanzania. Drawing on detailed cost estimates, we develop a dynamic computable general equilibrium model to estimate the impact of different biofuel production scenarios on growth and poverty. Our results indicate that maximizing the poverty-reducing effects of a biofuels industry in Tanzania requires engaging and improving the productivity of smallholder farmers. Evidence shows that cassava-based ethanol production is more profitable than other feedstock options. Our findings also indicate that cassava generates higher levels of pro-poor growth than do sugarcane-based systems. However, if smallholder yields can be improved rather than expanding cultivated land, then sugarcane and cassava outgrower schemes can produce similar pro-poor outcomes. We conclude that in so far as the public investments needed to establish a biofuels industry in Tanzania are in accordance with national development plans, producing biofuels will contribute to achieving the country's overall development objectives.

Keywords: biofuels, growth, poverty, Tanzania, Africa

1. INTRODUCTION

Tanzania's economy performed well over the last half-decade, with economic growth exceeding 5 percent per year. However, poverty has not declined significantly; the national headcount rate fell only slightly, from 35.7 to 33.6 percent, during 2001–2007 (World Bank 2009). This persistence in poverty is at least partly explained by slower growth in agricultural incomes (Pauw and Thurlow, 2010). Indeed, agriculture's performance is particularly important for economic development in Tanzania, given that four-fifths of the labor force work on farms and a similar share of the poor population live in rural areas. Supporting the establishment of a biofuels industry may therefore offer Tanzania an opportunity to reinvigorate agricultural growth, create new jobs in rural areas, and strengthen efforts to reduce poverty.

Evidence from other countries suggests that optimism about biofuels may be justified. In Mozambique, for example, Arndt et al. (2009) find that proposed biofuel investments will increase economic growth by half a percent each year over the coming decade, causing the national poverty rate to fall by 5 percentage points. This supports the view held by some that biofuels permit low-income countries to overcome their dependence on foreign oil while increasing farmers' participation in the growth process (see Hausmann 2007). This optimism, however, is countered by uncertainty over possible trade-offs between biofuels and food production, and the effects that declining food supplies may have on poverty and food insecurity. This concern has received considerable attention in the biofuels debate (see Oxfam International 2007). Indeed, shifting resources away from food production could increase households' reliance on marketed foods, and biofuels may not generate sufficient incomes for poorer households to offset rising food prices. Concerns over food security are therefore equally justified.

Possible trade-offs between development objectives have prompted low-income countries such as Tanzania to consider a range of biofuel production scenarios. For example, in evaluating proposals from foreign investors, governments must decide which feedstocks are both economically viable and contribute to achieving national development objectives. Similarly, many governments are encouraging foreign investors to combine smallholder outgrower schemes with larger-scale plantation systems in order to reduce poverty while still ensuring reliable feedstock supplies.

Understanding the consequences of different scenarios is crucial to maximizing the social benefits of biofuel investments. Accordingly, this paper uses a dynamic computable general equilibrium (DCGE) model of Tanzania to estimate the impact of alternative biofuel production scenarios on economic growth and employment. The model is also linked to a survey-based microsimulation module that estimates impacts on income poverty. Section 2 reviews the current debate surrounding biofuels. Section 3 presents the biofuel production scenarios that Tanzania's government is considering, and Section 4 describes the DCGE model and how the various biofuel production scenarios are simulated. Section 5 presents the results, and the final section concludes with recommendations for policy.

2. THE BIOFUELS DEBATE

Biofuel production has enjoyed tremendous growth in recent years.¹ During 2000–2007 global production tripled in volume (Coyle 2007). In 2007–2008 alone, the share of ethanol in global gasoline increased from 3.8 to 5.5 percent, while the share of biodiesel in diesel increased from 0.9 to 1.5 percent (UNEP 2009). More and more countries are adopting or setting higher biofuel consumption mandates (for example, 10 percent of transport energy in the European Union member states must come from biofuels by 2020), leading to consensus that the biofuels industry will grow even further. The interest in biofuels reflects two important shifts in countries' energy policies. The first is a concerted effort by countries to reduce dependence on crude oil as an energy source, a policy prompted by the recent oil price instability and prospects of a steadily rising crude oil price (IEA 2009). The second reflects growing concerns about global warming and the environment. Ethanol, for example, emits about 70 percent less carbon dioxide than fossil fuels during combustion (UNEP 2009), which suggests that there are environmental benefits associated with a switch to biofuels.

Biofuel growth, however, is not without controversy. There are at least three major ongoing debates concerning biofuels. The first concerns the true environmental impacts of biofuels. Comparing fossil fuel and biofuel emissions only during the end-use stage is shortsighted; what really matters are the emissions over the entire life cycle of the fuel. Thus, emissions at the farm level (for example, due to land use and cultivation of feedstock) and emissions associated with the processing and transportation of biofuels should also be considered. Some of these emissions may be offset as carbon is captured by plant biomass grown as biofuel feedstock, and hence many life-cycle analyses show that biofuels (sometimes only minimally) reduce greenhouse gases (Cohen et al. 2008; Coyle 2007). Furthermore, these life-cycle analyses reveal that certain feedstocks are more efficient; for example, a United Nations study shows that Brazil's sugarcane ethanol process has net negative emissions, while America's corn ethanol can sometimes be more polluting than gasoline, depending on how the feedstock is grown and processed (UNEP 2009).

An area of contention, though, is land and fertilizer use. When increased feedstock production requires forest or grassland to be cleared, indirect emissions are higher, often pushing the emissions balance into positive territory (Fargione et al. 2008; Searchinger et al. 2009). Fertilizer is an important source of another greenhouse gas, nitrous oxide, which is sometimes ignored in life-cycle analyses (Melillo et al. 2009). When land clearing and fertilizer impacts are not accounted for in life-cycle analyses, the environmental benefits of biofuels vis-à-vis fossil fuels are overstated. Arndt et al. (2009) argue that these observations are particularly pertinent from a development perspective since optimism about the potential of biofuels as a driver of growth in developing countries is often based on the notion that these countries have surplus land available that can be cleared and cultivated for the production of biofuel feedstock (see further discussion below).

A second debate concerns biofuels and their implications for food security. Certain biofuel feedstocks such as cassava or corn (in the United States) are also used as food and/or animal feed, and hence an increase in biofuel production may directly impact the supply and/or consumer prices of agricultural produce and meats. Food production may also be hampered by growth in biofuel feedstock production via indirect competition for resources such as land or labor. There is little doubt that increased biofuel production was a major driver of the sharp increases in the prices of corn, wheat, and soybean observed in 2006 (see Rosegrant 2008; Headey and Fan 2008). The ensuing "food crisis" had serious implications for poor consumers worldwide and their ability to satisfy basic consumption needs. Food security concerns are quelled somewhat by the prospects of second- and third-generation biofuels replacing first-generation biofuels within the next decade or so, once they become commercially viable due to technological gains and oil price increases. These next-generation technologies not only offer environmental advantages over existing technologies, but will also reduce competition for food and

¹ The term biofuels in this study refers to bioalcohols such as ethanol (produced mostly from starch crops and sugarcane or molasses) and biodiesel (produced from vegetable or other plant oils and fats).

natural resources given their use of biomass waste, wheat stalks, algae, and so on as feedstocks (IEA 2008).

A recent study by the Food and Agriculture Organization of the United Nations (FAO 2008) claims that only about one-quarter of land in Sub-Saharan Africa with potential for rainfed crop production is currently cultivated. This, together with the widely held perception that African agriculture has considerable scope for raising productivity (Diao et al. 2007), means that biofuel feedstocks may not necessarily displace food crops, and even where they do, food production can be maintained on less land through productivity enhancements. In this regard, the FAO (2008) argues that cash-crop production for markets does not necessarily come at the expense of food crops and that it may actually contribute to improving food security by raising household incomes. Of course, surplus land supplies are not unlimited everywhere in Africa. For example, in their study of Mozambique, Arndt et al. (2009) assume that only about half of planned biofuel crop production will take place on new land, while the other half will displace existing crops.

A third issue concerns the potential for developing countries to benefit from the increased global demand for biofuels. Optimists believe that the Sub-Saharan African region, with its land endowments and relatively cheap labor, is particularly well placed to become a global biofuels player (Hausmann 2007). The FAO (2008) believes that growing demand for biofuels and the resulting rise in agricultural commodity prices can present an opportunity to promote agricultural growth and rural development in developing countries. Compared with the natural resource extraction industries that often dominate investments in Africa, biofuel production (and particularly upstream production of feedstocks) is more labor-intensive and hence pro-poor (Arndt et al. 2009). The region already grows many of the major biofuel feedstocks in abundance, while existing first-generation biofuel technologies that can now be adopted are well matured and profitable at current oil prices. For example, new entrants into the ethanol industry can benefit from productivity gains realized in Brazil, which have caused production costs there to decline by between 3.8 and 5.7 percent every year for the past three decades (Moreira 2006).

However, there are some pitfalls. First, with respect to land, it is pertinent that the “vast majority” of land in Africa is operated under customary (informal) tenure (Deininger 2003). This means that biofuel projects that require additional land to be cleared would need to have a strong local community element and political buy-in. This poses some challenges for biofuel investors, particularly with respect to the business model opted for. Feedstocks can either be supplied by local smallholders or grown on plantations. An outgrower approach will be more pro-poor since land rents accrue to the smallholders, while other crops grown by the smallholders could benefit from technology spillovers (Arndt et al. 2009). However, Arndt et al. and Caminiti et al. (2007) argue in favor of a mix of outgrower and estate production to ensure a steady supply of feedstocks. Plantation schemes, however, mean that benefits accrue to agribusiness or even foreign investors rather than local smallholders.

A second concern is the long-term sustainability of the industry. When land clearing is necessary in order to establish new industries, the biofuels produced may seem less attractive to European and U.S. importers who demand sustainability and environmental compliance from suppliers. The future profitability of biofuels is also uncertain, with producers facing a cost price squeeze as feedstock prices rise and oil extraction technologies improve. African biofuel producers further face the challenge of competing against subsidized U.S. and European enterprises. Thus, even though market access is eased by free trade agreements, there are still various nontrade barriers to entry that need to be overcome.

Similarly, there are concerns that volatility in world oil and commodity markets will undermine the profitability of biofuels, while also exposing developing countries to heightened risk in world markets. However, as of this writing, futures prices for oil start at US\$70 per barrel in 2010 and rise continuously to more than US\$100 per barrel by 2018. Thus, while concerns over market price volatility are legitimate, futures markets indicate high and rising prices. In short, there are substantial incentives to produce biofuels and these look to become even more pronounced over time. Sophisticated investors can also lock in prices favorable to biofuels production out to 2018.

In summary, the opportunities for investing in biofuels in Africa abound. However, very few case studies exist that consider the true potential and the extent of the trade-offs, which is why studies such as

this are important. Among these trade-offs, the most important is the issue of competition for land and labor. Where biofuel feedstocks do end up displacing other crops (particularly food crops), the implications should be carefully weighed. Ultimately, however, food security is not only about producing sufficient quantities of food within countries. Household income effects and the advantages of increased trade and lower dependence on oil imports may yield net nutritional benefits. Given the complexity of the impacts and the fact that they need to be understood at both national and international levels, global or national ex ante general equilibrium approaches provide the best tools for understanding the potential gains and losses (Kretschmer and Peterson, 2010).

3. OPTIONS FOR PRODUCING BIOFUELS IN TANZANIA

Identifying Biofuel Production Scenarios

The FAO and the Government of Tanzania have identified a number of biofuel production scenarios using different feedstock crops and different types of downstream processing plants (see Cardona et al. 2009). In our analysis we focus on a subset of these options in order to capture their core differences. The options identified by the FAO and examined in this study are summarized in Table 1.

Table 1. Food and Agriculture Organization's biofuel production options

Feedstock	FAO option	Description
Sugarcane juice (ethanol)	1	Single large-scale ethanol processing plant with a capacity of 160,000 liters per day using juice from new sugarcane cultivars produced by smallholders. Production and sale of by-products included.
	2	Single large-scale ethanol processing plant with a capacity of 236,000–277,000 liters per day using juice from new sugarcane produced on 12,000 hectares of large-scale commercial land and 3,000 hectares of smallholder outgrower land. Production and sale of by-products included.
	3	Single large-scale ethanol processing plant with a capacity of 160,000 liters per day using juice from new sugarcane produced by increasing smallholders' crop yields rather than expanding cropland area. Production and sale of by-products included.
	4	Four small-scale ethanol processing plants with individual capacities of 44,000–52,000 liters per day using juice from new sugarcane produced by smallholders. Production and sale of by-products included.
Molasses (ethanol)	5	Single large-scale ethanol processing plant with a capacity of 80,000–85,000 liters per day using existing molasses produced and currently exported by sugar refineries.
Cassava (ethanol)	8	Single large-scale ethanol processing plant with a capacity of 160,000 liters per day using dry cassava chips produced by increasing smallholders' crop yields.
	9	Single large-scale ethanol processing plant with a capacity of 303,030 liters per day using dry cassava chips, 40% of which are produced by increasing smallholders' crop yields and 60% are from on-site large-scale commercial production.
Jatropha (biodiesel)	10	Single large-scale biodiesel processing plant with a capacity of 70,000 liters per day using jatropha produced by smallholders.

Source: Cardona et al. (2009).

The FAO scenarios differ in terms of four characteristics: (1) the type of feedstock used and biofuel produced, (2) the scale of feedstock production (that is, smallholder versus estate), (3) the way in which feedstock production is expanded (meaning increasing yields or harvested area), and (4) the scale of downstream biofuel processing plants. These differences are presented in Table 2, which shows the various scenarios simulated in this paper.

Table 2. Simulated biofuel production scenarios

Feedstock	Scenarios		Scale of feedstock production	Feedstock yield level	Land expansion (% of land from displacement)	Scale of biofuel processing
	DCGE model	FAO option				
Sugarcane (ethanol)	Sugar 1	1	Small	Low (43 mt/ha)	Yes (50%)	Large (69 l/mt)
	Sugar 2	2	Small/large mix	Low (43/84 mt/ha)	Yes (50%)	Large (69 l/mt)
	Sugar 3	-	Large	Low (84 mt/ha)	Yes (50%)	Large (69 l/mt)
	Sugar 4	3	Small	High (70 mt/ha)	No (0%)	Large (69 l/mt)
	Sugar 5	4	Small	Low (43 mt/ha)	Yes (50%)	Small (69 l/mt)
Molasses (ethanol)	Molasses	5	Imported	-	-	Large (166 l/mt)
Cassava (ethanol)	Cassava 1	-	Small	Low (10 mt/ha)	Yes (50%)	Large (183 l/mt)
	Cassava 2	8	Small	High (20 mt/ha)	No (0%)	Large (183 l/mt)
	Cassava 3	9	Small/large mix	High (20 mt/ha)	Yes (30%)	Large (183 l/mt)
Jatropha (biodiesel)	Jatropha	10	Small	High (4 mt/ha)	Yes (50%)	Large (350 l/mt)

Source: Authors' calculations using information from Cardona et al. (2009).

The first five scenarios (Sugar 1–5) refer to ethanol produced from sugarcane juice. In the first scenario (Sugar 1), all feedstock is produced by smallholder farmers through an outgrower scheme and is supplied to a single large processing plant. This is equivalent to the first FAO production option presented in Table 1. The second scenario is similar to the second FAO option in that it adopts a mixed production system in which one-fifth of the feedstock is produced by smallholders and the rest is produced by large-scale estates or plantations. The third scenario does not correspond to a particular FAO option since it assumes that all feedstock is produced on large-scale farms. This additional scenario allows us to contrast the impacts of purely small- and large-scale production systems.

The remaining two sugarcane scenarios are variations on Sugar 1, where all feedstock is produced by smallholders through an outgrower scheme. In the Sugar 4 scenario, sugarcane production is increased by raising smallholders' land yields (from 43 to 70 tons per hectare) rather than by expanding the amount of land under sugarcane cultivation. This reduces the amount of land currently used for agriculture that is displaced by biofuel production. The final sugarcane scenario (Sugar 5) still uses low yields but now assumes that downstream processing takes place using a number of small-scale plants. As shown later in this section, using small-scale processing plants increases the amount of labor required for biofuel production.

Molasses is another feedstock that could be used to produce ethanol in Tanzania. Molasses is a by-product of sugarcane refining, and all the molasses currently being produced is exported. Producing ethanol from molasses would thus redirect exports for use as feedstock in the domestic biofuels industry. This means that no additional feedstock needs to be produced. Only one molasses scenario is considered in our analysis, and it is equivalent to the fifth FAO production option.

We also consider the use of cassava as a biofuel feedstock. In each scenario we assume that production is by smallholders through an outgrower scheme and that processing is performed by large-scale processing plants. The first two scenarios differ in that Cassava 1 assumes that cassava production is achieved through extensification (meaning land expansion) while Cassava 2 assumes that crop yields are increased (from 10 to 20 tons per hectare), thereby limiting the amount of land displaced by the new biofuels industry. The Cassava 3 scenario assumes a mixed production system, with 40 percent of feedstock obtained from smallholders through yield improvements (as in Cassava 2) and the rest produced by large-scale commercial farmers situated close to a large-scale processing plant. Finally, we consider the use of jatropha oilseeds to produce biodiesel. Jatropha has received considerable attention from governments in developing countries, since it is inedible and should thus only indirectly affect food production. Jatropha is already grown in India and production trials are being conducted in African countries, such as Mozambique (Arndt et al. 2009). In our Jatropha scenario, production is via a smallholder outgrower scheme linked to a large-scale biodiesel processing plant, with high crop yields of 4 tons per hectare.

The FAO options in Table 1 produce different volumes of ethanol or biodiesel. This complicates direct comparisons of the scenarios. For example, if the Sugar 2 scenario generates more economic growth than Sugar 1, this may be due either to the larger volume of biofuel being produced or to inclusion of more larger-scale farmers. Therefore, to make scenarios comparable we simulate the same volume of biofuels under all scenarios rather than modeling the varying amounts identified in Table 1. More specifically, we model the establishment of a biofuels industry capable of producing one billion liters of ethanol or biodiesel per year (that is, three million liters per day).

Estimating Production Costs and Technologies

The biofuel scenarios in Table 2 contrast the economic impacts of different feedstocks and types of processing plants. These scenarios will produce different outcomes because they use different technologies (meaning factor and intermediate inputs) and generate different profit rates for farmers and downstream processing plants. Cardona et al. (2009) estimate itemized production costs when they assess the economic viability of the various biofuel scenarios. These cost estimates are shown in Table 3 below.

Table 3. Production cost estimates for biofuel scenarios

	Sugar 1 FAO 1	Sugar 2 FAO 2	Sugar 4 FAO 3	Sugar 5 FAO 4	Mo- lasses FAO 5	Cassava 2 FAO 8	Cassava 3 FAO 8	Jatro- pha FAO 10
Cost per liter (US\$)	0.567	0.434	0.529	0.632	0.735	0.469	0.369	0.828
Raw materials	0.416	0.310	0.393	0.393	0.514	0.252	0.190	0.700
Service fluids	0.039	0.025	0.027	0.025	0.082	0.086	0.079	0.001
Labor	0.001	0.001	0.001	0.003	0.001	0.000	0.000	0.002
Maintenance	0.014	0.014	0.015	0.025	0.014	0.025	0.020	0.006
Operating charges	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001
General plant costs	0.007	0.007	0.008	0.014	0.007	0.013	0.010	0.004
Administrative costs	0.038	0.029	0.035	0.037	0.050	0.030	0.024	0.057
Capital depreciation	0.063	0.063	0.070	0.150	0.067	0.064	0.045	0.085
Coproducts	-0.011	-0.016	-0.019	-0.016	0.000	0.000	0.000	-0.028

Source: Cardona et al. (2009).

The cost of producing ethanol in Tanzania ranges from US\$0.43 per liter under a mixed small- and large-scale production system (that is, Sugar 2) to US\$0.74 per liter using molasses as a feedstock. The low-cost scenarios (that is, Sugar 2, Cassava 2, and Cassava 3) compare favorably with current

ethanol production costs in countries such as Brazil (US\$0.47), the United States (US\$0.46), and India (US\$0.52). However, the estimated costs of producing ethanol from smallholder-based sugarcane and from molasses suggest that Tanzania is not competitive given current crop yields and the proposed processing technologies. In our analysis we assume that the domestic ethanol price received by processing plants is US\$0.56 per liter, implying that processing plants in some of our scenarios run at a loss. Similarly, the biodiesel production cost is US\$0.83 per liter in Tanzania, which is above the landed price at Dar es Salaam harbor (US\$0.77) (Johnson and Holloway 2007). If ethanol prices were higher than US\$0.56 per liter then the profits earned by foreign investors would increase. Since these profits are, by assumption, repatriated, changing the price of ethanol does not greatly affect the welfare outcomes of biofuels expansion for Tanzanian households.

Using the above processing costs and farm crop budgets, we estimate the production technologies for the 10 biofuel scenarios modeled in this paper. These are summarized in Table 4. The top half of the table shows the inputs required and outputs generated for 100 hectares of land allocated to feedstock production. From the first three columns we see that smallholder crop yields (that is, Sugar 1) are lower than larger-scale farmers' yields (meaning Sugar 3), implying that 100 hectares of small-scale farmland produces half the output of plantations on the same amount of land (that is, 4,280 versus 8,400 tons). Small-scale farms are also more labor-intensive (meaning 0.4 hectares per worker compared to 2.4 hectares per worker on larger farms). Increasing smallholders' sugarcane yields significantly increases production levels per 100 hectares of land (that is, to 7,000 tons) but requires additional labor for weeding and harvesting. Cassava production is also labor-intensive and requires more land per liter of ethanol than sugarcane. The mixed cassava production system (that is, Cassava 3) is more labor-intensive than the equivalent smallholder scenario (that is, Cassava 2) since new commercial farms require additional laborers whereas smallholders increase production by raising yields on their existing farmland. Finally, the Jatropha scenario is also labor-intensive, albeit less so than smallholder cassava and sugarcane.

The lower half of Table 4 shows the inputs required to produce 100,000 liters of ethanol or biodiesel. The first four columns refer to large-scale processing plants and so the technologies are the same. The Sugar 1–4 scenarios differ with respect to the scale of feedstock production and, hence, the required amount of land and number of farmworkers. The number of workers used in processing biofuels is much smaller than the number of farmworkers used in producing the feedstock (for example, 1 processing worker is needed for every 121 farmworkers in the more labor-intensive Sugar 1 scenario). The labor-intensity of biofuels processing is, however, higher in the Sugar 5 scenario, which uses small-scale processing plants. Finally, cassava processing is more labor-intensive, although the large amount of land required to produce the feedstock makes it the most labor-intensive option overall.

In summary, 10 biofuel production scenarios are considered in this analysis. These scenarios compare different feedstocks, small- and large-scale production structures, and intensive and extensive feedstock production options. The study draws on detailed estimates of production costs based on the specific technologies used in each scenario. In the next section we integrate these technologies within an economywide model of Tanzania in order to estimate their impacts on growth and poverty.

Table 4. Biofuel production technologies under alternative scenarios

Production characteristics for biofuels (inputs and outputs per 100 ha)	Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Mo- lasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatro- pha (FAO 10)
Land employed (ha)	100.0	100.0	100.0	100.0	100.0	n/a	100.0	100.0	100.0	100.0
Crop production (mt)	4,280	7,575	8,399	6,999	4,280	n/a	1,000	2,000	2,000	400
Farmworkers employed (people)	225.2	78.4	41.8	81.5	209.5	n/a	215.7	66.6	153.3	130.2
Land yield (mt / ha)	42.8	75.8	84.0	70.0	42.8	n/a	10.0	20.0	20.0	4.0
Farm labor yield (mt / person)	19.0	96.6	201.1	85.9	20.4	n/a	4.6	30.0	13.0	3.1
Land per farmworker (ha / person)	0.44	1.27	2.39	1.23	0.48	n/a	0.46	1.50	0.65	0.77
Capital per hectare (cap. units / ha)	1.76	3.54	3.98	n/a	1.64	n/a	0.72	n/a	1.4	1.3
Labor–capital ratio (people / cap. unit)	1.28	0.22	0.10	n/a	1.28	n/a	2.99	n/a	1.10	1.01
Biofuel produced (liters)	297,078	525,819	582,999	485,847	297,078	n/a	183,328	366,636	366,636	140,008
Processing workers employed (people)	2.33	3.15	3.36	4.18	10.33	n/a	0.45	0.91	0.91	1.36
Production characteristics for biofuels (inputs and outputs per 10,000 liters)	Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Mol- asses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatro-pha (FAO 10)
Biofuel produced (liters)	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Feedstock inputs (mt)	1,441	1,441	1,441	1,441	1,441	600	546	546	546	286
Feedstock yield (liters / mt)	69.41	69.41	69.41	69.41	69.41	166.7	183.31	183.31	183.31	349.92
Land employed (ha)	33.66	19.02	17.15	20.58	33.66	n/a	54.55	27.28	27.28	71.42
Farmworkers employed (people)	75.81	14.92	7.16	16.77	70.51	n/a	117.66	18.17	41.82	92.97
Processing workers employed (people)	0.78	0.60	0.58	0.86	3.48	0.33	0.25	0.25	0.25	0.97
Capital employed (capital units)	105.2	315.8	342.6	183.6	144.9	133.5	214.5	214.5	373.7	40.3

Source: Authors' calculations using data from Cardona et al. (2009); Coles (2009); Kapinga et al. (2009); Rothe, Görg, and Zimmer (2007); and the DCGE model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

4. MODELING IMPACTS ON GROWTH AND POVERTY

Structure of the Tanzanian Economy

Table 5 shows the structure of the Tanzanian economy in 2007, which is the base year of the economic model. Agriculture generates one-third of national gross domestic product (GDP) and 80 percent of total employment. Most farmers are smallholders, with average landholdings of 1.6 hectares. They produce most of the country's food, which dominates both the agricultural and manufacturing sectors. However, Tanzania as a whole relies on imported foods (mainly cereals), which account for 15 percent of total imports and 20 percent of all processed foods in the country. This dependence on food imports stems in part from the low crop yields achieved by smallholders due to their reliance on traditional rainfed farming technologies. Larger-scale commercial farmers are more heavily engaged in nonfood export crops, such as coffee, tobacco, and tea, which together account for almost a third of total merchandise exports.

Table 5. Structure of Tanzania's economy, 2007

	Share of total (%)				Export intensity (%)	Import penetration (%)
	GDP	Employment	Exports	Imports		
Total GDP	100.00	100.00	100.00	100.00	9.44	22.01
Agriculture	31.82	82.46	34.89	6.11	13.23	7.28
Food crops	19.06	39.97	2.57	5.83	1.64	10.05
Traditional exports	3.20	12.22	21.50	0.28	63.45	7.08
Biofuel crops	0.00	0.00	0.00	0.00	0.00	13.74
Other agriculture	9.56	30.27	10.81	0.00	14.98	0.00
Mining	3.94	0.17	25.06	4.61	82.26	72.26
Manufacturing	8.84	1.46	12.83	87.88	8.26	61.42
Food processing	5.62	1.12	2.13	10.01	2.00	20.80
Biofuel processing	0.00	0.00	0.00	0.00	100.00	0.00
Other manufacturing	3.22	0.35	10.69	77.87	21.79	83.87
Other industries	10.35	0.99				
Private services	32.36	13.45	27.22	1.40	8.76	1.06
Government services	12.69	1.47	0.00	0.00	0.00	0.00

Source: Tanzania 2007 social accounting matrix.

Nonagriculture is dominated by gold mining, which accounts for a third of total merchandise earnings. Mining does not, however, create much employment or value added, and most nonfarm workers in the country are employed in construction ("other industries") and private services. Incomes in many of these nonfarm sectors, such as trade, are on average only slightly higher than those in agriculture. This partly reflects the low levels of education and shortage of skilled labor in the country. Indeed, most of Tanzania's workforce has not completed primary schooling.

The economywide model captures Tanzania's initial conditions and its detailed economic structure. This class of economic models is often used to examine external shocks and policies in low-income countries. The strength of these models is their ability to measure linkages between producers, households, and the government, while also accounting for resource constraints and their role in determining product and factor prices. These models are, however, limited by their underlying assumptions and the quality of the data used to calibrate them. The remainder of this section explains the workings of the DCGE model.

Core General Equilibrium Model

Table 6 presents the equations of a simple DCGE model illustrating how biofuel investments affect economic outcomes in our analysis. Producers in each sector s produce a level of output Q by employing the factors of production F under constant returns to scale (exogenous productivity α) and fixed production technologies (fixed factor input shares δ) (eq. [1]). Profit maximization implies that factor payments W are equal to average production revenues (eq. [2]). Labor, land, and capital supply s are fixed, implying full employment and intersector mobility (eq. [10]). This means that as new biofuel sectors expand they generate additional demand for factor inputs, which then affect economywide factor returns and production in other sectors by increasing resource competition.

Table 6. Core model equations

Production function	$Q_{st} = \alpha_{st} \cdot \prod_f F_{fst}^{\delta_{fs}}$	(1)
Factor payments	$W_{ft} \cdot \sum_s F_{fst} = \sum_s \delta_{fs} \cdot P_{st} \cdot Q_{st}$	(2)
Import supply	$P_{st} \leq E_t \cdot w_s^m \perp M_{st} \geq 0$	(3)
Export demand	$P_{st} \geq E_t \cdot w_s^e \perp X_{st} \geq 0$	(4)
Household income	$Y_{ht} = \sum_{fs} \theta_{hf} \cdot W_{ft} \cdot F_{fst}$	(5)
Consumption demand	$P_{st} \cdot D_{hst} = \beta_{hs} \cdot (1 - v_h) \cdot Y_{ht}$	(6)
Investment demand	$P_{st} \cdot I_{st} = \rho_s \cdot \left(\sum_h v_h \cdot Y_{ht} + E_t \cdot b \right)$	(7)
Current account balance	$w_s^m \cdot M_{st} = w_s^e \cdot X_{st} + b$	(8)
Product market equilibrium	$Q_{st} = \sum_h D_{hst} + I_{st}$	(9)
Factor market equilibrium	$\sum_s F_{fst} = s_{ft}$	(10)
Land and labor expansion	$s_{ft} = s_{t-1} \cdot (1 + \varphi_f)$	f is land and labor (11)
Capital accumulation	$s_{ft} = s_{t-1} \cdot (1 - \eta) + \sum_s \frac{P_{st-1} \cdot I_{st-1}}{\kappa}$	f is capital (12)
Technical change	$\alpha_{st} = \alpha_{st-1} \cdot (1 + \gamma_s)$	(13)

Table 6. Continued

<u>Subscripts</u>		<u>Exogenous variables</u>	
f	Factor groups (land, labor, and capital)	b	Foreign savings balance (foreign currency units)
h	Household groups	s	Total factor supply
s	Economic sectors	w	World import and export prices
t	Time periods	<u>Exogenous parameters</u>	
<u>Endogenous variables</u>		α	Production shift parameter (factor productivity)
D	Household consumption demand quantity	β	Household average budget share
E	Exchange (local/foreign currency units)	γ	Hicks neutral rate of technical change
F	Factor demand quantity	δ	Factor input share parameter
I	Investment demand quantity	η	Capital depreciation rate
M	Import supply quantity	θ	Household share of factor income
P	Commodity price	κ	Base price per unit of capital stock
Q	Output quantity	ρ	Investment commodity expenditure share
W	Average factor return	v	Household marginal propensity to save
X	Export demand quantity	ϕ	Land and labor supply growth rate
Y	Total household income		

Source: Authors' compilation.

Foreign trade is determined by comparing domestic and world prices, where the latter are fixed under a small-country assumption. The simple model implements trade as a complementarity problem. If domestic prices exceed world import prices w_m (adjusted by exchange rate E), then the quantity of imports M increases (eq. [3]). Conversely, if domestic prices fall below world export prices w_e , then export demand X increases (eq. [4]). To ensure macroeconomic consistency, a flexible exchange rate adjusts to maintain a fixed current account balance b (measured in foreign currency units) (eq. [8]). This implies that as biofuel exports rise (or petroleum imports decline) the exchange rate will appreciate, thus affecting the competitiveness of nonbiofuel exports and imports.

Factor incomes are distributed to households using fixed income shares θ based on households' initial factor endowments (eq. [5]). Incomes Y are then saved (based on marginal propensities to save v) or spent on consumption C (according to marginal budget shares β) (eq. [6]). Household savings and foreign capital inflows are collected in a national savings pool and used to finance investment demand I (meaning a savings-driven investment closure) (eq. [7]). Finally, prices P equilibrate product markets so that demand for each commodity equals supply (eq. [9]). The model therefore links production patterns to household incomes through changes in factor employment and returns.

The model's variables and parameters are calibrated to observed data from a national social accounting matrix that captures the initial equilibrium structure of the Tanzanian economy in 2007. Parameters are then adjusted over time to reflect demographic and economic changes and the model is resolved for a series of new equilibriums for the eight-year period 2007–2015. Between periods the model is updated to reflect exogenous rates of land and labor expansion ϕ (eq. [11]). The rate of capital accumulation is determined endogenously, with the level of investment I from the previous period converted into new capital stocks using a fixed capital price κ (eq. [12]). This is added to previous capital stocks after applying a fixed long-term rate of depreciation π . Finally, the model captures total factor productivity through the production function's shift parameter α , with the rate of technical change γ determined exogenously (eq. [13]).

Extensions in the Full Tanzania Model

The above model illustrates how economic growth and household incomes are linked in our analysis. However, the full model drops certain restrictive assumptions (see Thurlow 2005). Constant elasticity of substitution production functions allow factor substitution based on relative factor prices (meaning δ is no

longer fixed). The model identifies 58 sectors (that is, 26 in agriculture, 22 industries, and 10 services). Intermediate demand in each sector, which was excluded from the simple model, is now determined by fixed technology coefficients (Leontief demand). Based on the 2000/01 Household Budget Survey (HBS) (Tanzania, NBS 2001), labor markets are segmented across three skill groups: (1) workers with less than primary education, (2) workers with primary and possibly some secondary schooling, and (3) workers who have completed secondary or tertiary schooling. Agricultural land is divided across small- and large-scale farms based on the 2002/03 Agricultural Sample Survey (Tanzania, MINAG 2004). All factors are still assumed to be fully employed, but capital is immobile across sectors. New capital from past investment is allocated to sectors according to profit rate differentials under a “putty-clay” specification. This means that once capital stocks have been invested it is difficult to transfer them to other uses.

International trade is captured by allowing production and consumption to shift imperfectly between domestic and foreign markets, depending on the relative prices of imports, exports, and domestic goods (inclusive of relevant sales and trade taxes). This differs from the simple model, which assumed perfect substitution between domestic and foreign goods (meaning homogenous products). This extension captures differences in domestic and foreign products and allows for observed two-way trade. Tanzania is still considered a small economy, such that world prices are fixed and the exchange rate (that is, price index of tradable to nontradable goods) adjusts to maintain a fixed current account balance. Production and trade elasticities are drawn from Dimaranan (2006).

Households maximize a Stone-Geary utility function so that a linear expenditure system determines consumption with nonunitary income elasticities (estimated using HBS). Households are disaggregated across rural/urban and farm/nonfarm groups and by per capita expenditure quintiles, giving a total of 15 representative households in the full DCGE model. Households pay taxes to the government based on fixed direct and indirect tax rates. Tax revenues finance exogenous recurrent spending, resulting in an endogenous fiscal deficit. Finally, the model includes a simple consumption-side microsimulation module where each respondent in HBS is linked to their corresponding representative household in the DCGE model. Changes in commodity prices and each household groups’ consumption spending are passed down from the DCGE model to the survey respondents, where their total per capita consumption and poverty measures are recalculated.

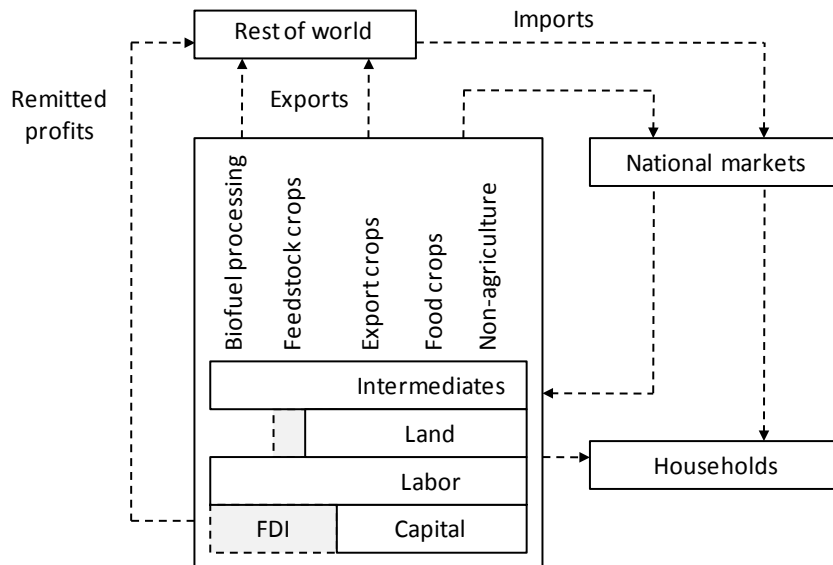
Modeling Biofuel Production

Biofuels are not currently produced in Tanzania and so there is initially no biofuels sector in the 2007 social accounting matrix used to calibrate the DCGE model. However, the production cost information in Table 3 and farm crop budgets provide the intermediate technology vectors needed to create these new sectors in the model. We initially create negligibly small feedstock and processing sectors representing different biofuel technology vectors. The DCGE model is first run forward over the 2007–2015 period assuming no expansion in biofuels production. This produces a baseline “without biofuels” scenario. Then in the biofuel simulations we expand the size of the feedstock and processing subsectors to produce one billion liters of biofuels. A conceptual framework for these simulations is shown in Figure 1.

We smoothly introduce biofuels production over the 2007–2015 period, reflecting the likely gradual establishment of the industry. Biofuel expansion is assumed to be driven entirely by foreign direct investment (FDI), and all profits generated in the biofuel sectors are remitted abroad (after applying average corporate tax rates). The decision to invest is thus resolved exogenously by foreign investors, and we assume that the level of investment remains consistent with necessary profitability. Biofuel producers must, however, compete with other sectors for intermediate inputs and land and labor resources. In the DCGE model we assume full employment, which means that total labor supplies are fixed and increasing labor demand per unit of land raises workers’ wages. Feedstock production also displaces lands used for existing crops, since these lands will be assigned to new biofuel investments, and smallholder farmers will also reallocate resources toward feedstocks. Thus, although new lands may be available to feedstock producers, we expect that at least some existing lands will be displaced by biofuel crops. Table 2 shows that for most scenarios we assume that half the lands used by biofuel feedstocks come from lands already

in use by smallholder farmers.² There is no land displacement in the *Sugar 4* and *Cassava 2* scenarios since feedstocks are produced entirely through intensification (meaning raising yields). The gray shaded areas in Figure 1 represent new foreign capital and cropland resources, which cause national production to expand in the simulations.

Figure 1. Conceptual framework



Source: Authors' creation.

We assume that all biofuels will be exported. However, it is possible that some of the ethanol produced in Tanzania may be blended with imported petroleum for domestic use (see Cardona et al. 2009). However, if the Government of Tanzania does not subsidize domestic ethanol, the difference between increasing biofuel exports and reducing petroleum imports is small (meaning the effect on the balance of payments is symmetrical). Therefore, assuming all biofuels are exported will not change our findings. Similarly, since molasses production involves redirecting existing exports to biofuel production, we assume that all molasses feedstocks are effectively imported, which offsets the decline in molasses exports required in the Molasses scenario. The model includes coproducts produced during the biofuel production process, the sale of which helps reduce ethanol and biodiesel production costs. We do not, however, explicitly model markets for coproducts, but assume that they are used to reduce fuel and electricity inputs during biofuel processing.

² The assumption of 50 percent land displacement implies that although land is relatively abundant in Tanzania, there is a limit to the availability of large contiguous pieces of land that would be needed for large-scale commercial and small-scale outgrower production approaches. Some displacement is therefore inevitable. Moreover, labor is also a scarce resource in Tanzania, especially during planting and harvesting periods. So expanding feedstock production will force farmers to reallocate their own labor resources or become laborers on large-scale commercial farms, thereby reducing the amount of labor available for cultivating existing crops.

5. MODEL RESULTS

Baseline Scenario

We first calibrate the DCGE model to track observed trends in key demographic and macroeconomic indicators (see Table 7). Population growth is set at 2.5 percent per year during 2007–2015. The skilled labor supply grows faster than unskilled labor in all scenarios, reflecting gradual improvements in educational attainment. Livestock stocks and agricultural land expand by 1 percent each year, capturing rising population density, especially in rural areas. In order to achieve recently observed growth rates in GDP, total factor productivity growth is set at 2.7 percent per year during the simulation period. The baseline scenario also captures the recent poor performance of the agricultural sector (Pauw and Thurlow, 2010).

Table 7. Core macroeconomic assumptions and results, 2007–2015

	Initial, 2007	Baseline scenario	Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Molasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatropha (FAO 10)
Average annual growth rate, 2007–2015 (%)												
Population	31,683	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Total GDP	100.00	4.61	4.86	4.95	4.97	4.98	4.88	4.72	4.86	4.97	4.99	4.87
Labor supply	56.07	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
Primary	42.54	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Secondary	12.17	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Tertiary	1.36	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Capital stock	17.53	2.52	2.62	2.62	2.62	2.63	2.62	2.51	2.59	2.59	2.61	2.55
Livestock stock	2.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Land supply	24.20	1.00	1.24	1.13	1.12	1.29	1.24	1.00	1.38	1.38	1.27	1.50
Small-scale	22.48	1.00	1.26	0.91	0.87	1.00	1.26	1.00	1.41	1.00	0.87	1.54
Large-scale	1.72	1.00	1.00	3.76	4.08	1.00	1.00	1.00	1.00	1.00	3.95	1.00
Final-year value, 2015												
Real exchange rate	1.00	1.07	0.99	1.00	1.00	1.00	1.00	1.05	1.01	1.01	1.02	1.00
Consumer prices	1.00	1.06	1.03	1.03	1.03	1.03	1.04	1.05	1.04	1.04	1.04	1.04
Cereals prices	1.00	1.16	1.13	1.12	1.12	1.12	1.13	1.14	1.15	1.13	1.14	1.16

Source: Results from the Tanzania DCGE and microsimulation model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

Changes in Agricultural Production

In the biofuel simulations we increase the amount of land and FDI allocated to biofuel sectors. We assume that only half of the biofuel land requirements will displace land already being cultivated. We therefore expect an increase in the total amount of land under cultivation. This is shown in the third column of Table 7, where the rate of land expansion for smallholders increases from 1.00 percent under the baseline scenario to 1.26 percent per year under the *Sugar 1* scenario. Conversely, as we shift toward larger-scale feedstock production (in *Sugar 2* and *Sugar 3*), the expansion rate of smallholder lands drops below 1 percent per year. This is because we assume that it is smallholders' lands that are displaced when large-scale plantations expand feedstock production. However, no smallholder land is displaced in the *Sugar 4* and *Cassava 2* scenarios, as production increases are achieved by improving yields. There is some land displacement in the mixed cassava production scenario (*Cassava 3*), because the portion that is produced by commercial farmers requires additional lands, half of which come from smallholders. Finally, the sugarcane needed as feedstock for molasses production is already produced in Tanzania and so there is no change in land expansion rates under the *Molasses* scenario.

Displacing lands to produce biofuel feedstocks causes production of other crops to contract (see Table 8). The debate surrounding biofuels in low-income countries centers on their possible negative effects on food production. Our findings suggest that, in the case of Tanzania, it is export crops that experience the largest declines in production. This is because in our simulations biofuels eventually account for almost a third of total merchandise export earnings by 2015. Since we assume that the current account balance is fixed in foreign currency, the increase in exports causes the real exchange rate to appreciate relative to the baseline scenario (see Table 7). This reduces the competitiveness of traditional export crops, such as coffee, tobacco, and tea, and these exports decline. For example, the amount of land allocated to export crops falls by 191,000 hectares in the *Sugar 1* scenario. In the same scenario the land allocated to food crops increases slightly, as farmers reallocate land away from export crops and rising incomes raise food demand. Food crop production therefore increases under most biofuel production scenarios. The only exception is the *Cassava 1* scenario, in which a large amount of land is needed to produce the same amount of biofuel, causing food production to fall. However, even in this scenario, the trade-off between food production and biofuels remains small, with export crops more severely affected.

Table 8. Agricultural production results, 2007–2015

	Initial value, 2007	Baseline value, 2015	Deviation from baseline scenario final value, 2015									
			Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Molasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatropha (FAO 10)
<u>Biofuel</u> (1,000 l)	0	0	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
<u>Cropland</u> (1,000 ha)	8,207	8,887	168	95	86	0	168	0	273	0	50	357
Biofuel crops	0	0	337	190	172	0	337	0	545	0	99	714
Food crops	7,236	7,711	23	60	65	163	20	42	-85	142	45	-155
Maize	2,690	2,812	22	32	33	67	21	17	-14	59	24	-33
Rice	546	592	1	6	6	15	1	4	-12	12	3	-20
Cassava	660	671	4	7	7	17	3	4	-6	15	4	-9
Export crops	970	1,175	-191	-155	-150	-163	-188	-42	-187	-142	-127	-202
<u>Production</u> (1,000 mt)												
Biofuel feedstock			14,407	14,407	14,407	14,407	14,407	1,000	5,455	5,455	5,455	2,857
Food crops												
Maize	2,354	2,713	18	38	41	60	18	15	-16	52	21	-14
Rice	1,084	1,268	-1	13	15	19	0	5	-18	15	4	-16
Cassava	5,284	5,873	26	68	73	137	26	35	-56	123	33	-65

Source: Results from the Tanzania DCGE and microsimulation model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

The same amount of ethanol exports is produced under *Sugar 1* and *Sugar 3*, causing a similar appreciation of the real exchange rate in these two scenarios (see Table 7). This suggests that moving to larger-scale feedstock production does not remove the negative impacts for nonbiofuels exporters. Larger-scale feedstock production technologies do, however, favor food crop production, since the higher yields of large-scale farmers mean that less land is needed for biofuel feedstocks and hence more land previously used by traditional export crops is reallocated to food crops rather than being used to produce biofuels. This finding suggests that any trade-offs that do exist between biofuels and food production are likely to be smaller when feedstocks are produced by larger-scale farmers.

Alternatively, when smallholders' yields are increased there is no displacement of land and so traditional export crop lands are reallocated entirely to food crops (see *Sugar 4* and *Cassava 2*). The same is true in the *Molasses* scenario, in which no additional lands are needed to produce feedstocks. These scenarios clearly indicate that the exchange rate effect is more important than heightened resource competition when determining the overall effect of biofuel investments on food production in Tanzania. Arndt et al. (2009) reported similar findings for Mozambique, although biofuel investments reduced food crop production because Mozambique does not have a large export crop sector and so at least some lands under food crops are displaced by biofuel feedstocks.

Impacts on Economic Growth and Employment

Table 9 shows the impact of biofuel investments on the various sectors' real GDP growth rates. FDI in the biofuel sectors expands agriculture's capital stock and also brings new lands under cultivation. This expansion in resources causes agriculture's growth rate to increase in all the biofuel scenarios. Larger-scale production of sugarcane feedstocks (that is, *Sugar 3*) generates larger gains in agricultural GDP than does production through smallholder outgrower schemes (that is, *Sugar 1*). There are also larger gains in the manufacturing sector under the *Sugar 3* scenario, due to its smaller impact on food crops and downstream food processing. However, all sugarcane scenarios reduce processed-food production because the appreciated exchange rate heightens competition in this import-intensive sector (see Table 5). Ultimately, the trade-offs from biofuel production are smaller than the gains from new investments in the biofuels industry. As a result, national GDP growth rates increase in all the biofuel scenarios.

Table 9. Sector growth results, 2007–2015

	GDP share, 2007 (%)	Baseline growth (%)	Deviation from baseline scenario growth rate (%-point)									
			Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Molasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatropha (FAO 10)
Total GDP	100.00	4.61	0.25	0.34	0.35	0.37	0.27	0.11	0.25	0.35	0.37	0.26
Agriculture	31.82	2.20	0.21	0.33	0.34	0.50	0.19	0.00	0.25	0.55	0.38	0.67
Food crops	19.06	1.88	0.00	0.13	0.15	0.22	0.01	0.06	-0.17	0.19	0.04	-0.16
Traditional exports	3.20	2.49	-1.49	-0.97	-0.90	-1.11	-1.45	-0.23	-1.61	-0.97	-0.92	-1.61
Biofuel crops	0.00	0.00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other agriculture	9.56	2.71	-0.27	-0.14	-0.12	-0.10	-0.26	-0.03	-0.33	-0.08	-0.14	-0.28
Mining	3.94	7.17	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01	-0.02	-0.02	-0.01	-0.02
Manufacturing	8.84	5.49	0.00	1.11	1.25	0.53	0.24	0.51	0.57	0.71	1.52	-0.27
Food processing	5.62	3.82	-0.12	-0.05	-0.04	0.03	-0.12	-0.01	-0.18	0.03	-0.03	-0.14
Biofuel processing	0.00	0.00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other manufacturing	3.22	8.03	-1.16	-1.07	-1.05	-1.03	-1.13	-0.40	-1.01	-0.94	-0.71	-0.98
Other industries	0.31	8.03	-0.97	-0.91	-0.91	-0.87	-0.95	-0.34	-0.79	-0.77	-0.57	-0.73
Private services	45.05	5.35	0.32	0.18	0.16	0.28	0.32	0.08	0.16	0.17	0.14	0.17
Government services	0.45	5.18	0.03	0.02	0.02	0.11	0.03	-0.02	0.06	0.12	0.10	0.12

Source: Results from the Tanzania DCGE and microsimulation model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

Generally, the more profitable the biofuel processing technology is, the larger its impact on national economic growth. For example, the scenarios with the largest positive gains in total GDP are *Sugar 2/3* and *Cassava 2/3*, which are among the more profitable ethanol technologies in Tanzania (see Table 3). Improving crop yields rather than displacing existing cultivated lands also generates large economywide gains. This is because these sectors enhance the returns to agricultural resources without greatly reducing food production. By contrast, producing ethanol using molasses has little effect on national GDP since there are no growth linkages to the agricultural sector and only small gains in manufacturing. Moreover, growth effects under the mixed cassava production approach (that is, *Cassava 3*) are not as large as those under the mixed sugarcane approach. This is because cassava is a land-intensive crop and so establishing new large-scale commercial cassava farms displaces more land from other crops than does sugarcane. Similarly, obtaining cassava feedstock solely by increasing smallholders' yields (that is, *Cassava 2*) generates larger growth effects, since no displacement of land for other crops is necessary. Finally, the *Jatropha* scenario has smaller growth effects since the sector is less profitable and so generates lower levels of value added, especially for downstream processors.

Table 10 reports impacts on employment. The number of new jobs created in the biofuels sector varies greatly across scenarios. The low labor-intensity of large-scale sugarcane production means that only 72,000 farm jobs are created in the *Sugar 3* scenario. Conversely, outgrower schemes employ far more farmers (see Table 4), with 758,000 additional workers producing sugarcane in the *Sugar 1* scenario.³ Sugarcane is less labor-intensive than cassava production, and it is the *Cassava 1* and *Jatropha* scenarios that engage the most workers in feedstock production. Moreover, although improving crop yields among smallholders does not require additional lands in the *Sugar 4* and *Cassava 2* scenarios, it still requires additional workers, especially during harvesting. For example, doubling cassava yields in the *Cassava 2* scenario draws an additional 182,000 farmers into cassava production. This result emphasizes an often overlooked dimension of the biofuels debate, which has typically focused on land displacement (especially for food crops) and ignored labor “displacement.” Thus, even if all feedstock production were to take place on new lands (meaning no land displacement), nonfeedstock crop production would still decline due to increased competition over nonland resources (meaning labor).

³ Note that employment numbers do not adjust for underemployment and include unpaid family members.

Table 10. Employment results, 2007–2015

	Employment, 2007	Baseline employment, 2015	Deviation from baseline scenario final employment, 2015									
			Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Molasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatropha (FAO 10)
Total (1,000s workers)	19,010	22,487	0	0	0	0	0	0	0	0	0	0
Agriculture	15,675	18,565	-95	-78	-76	-103	-101	-37	-23	-68	-50	-9
Food crops	7,597	8,977	-76	188	221	178	-55	54	-269	146	-4	-83
Traditional exports	2,323	2,901	-535	-351	-327	-403	-520	-92	-573	-356	-342	-559
Biofuel crops	0	0	758	149	72	168	705	0	1,177	182	418	930
Other agriculture	5,754	6,686	-243	-65	-42	-46	-231	2	-358	-39	-122	-296
Mining	33	54	-5	-5	-5	-5	-5	-1	-4	-4	-3	-4
Manufacturing	278	320	-20	-16	-16	-14	-17	-4	-21	-13	-12	-18
Food processing	212	209	-2	0	0	2	-2	1	-4	2	-1	-3
Biofuel processing	0	0	1	1	1	1	3	0	0	0	0	1
Other manufacturing	66	111	-19	-17	-17	-17	-18	-5	-17	-15	-12	-16
Other industries	188	240	11	14	14	12	10	3	9	11	12	3
Private services	2,557	2,981	107	84	81	109	111	38	37	72	53	27
Government services	280	327	2	2	1	2	2	1	1	1	1	1

Source: Results from the Tanzania DCGE and microsimulation model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

The downstream processing of biofuels creates very few jobs, with almost all employment effects from biofuel investments coming from feedstock production.⁴ Moreover, unlike those in feedstock production, jobs in processing plants are largely reserved for semiskilled and skilled workers, most of whom must be sourced from other manufacturing subsectors as the biofuels sector grows. Lower-skilled feedstock farmers or laborers mainly come from within the agriculture sector itself. However, both sugarcane and cassava have lower-than-average labor–land ratios. This means that reallocating land to these crops effectively reduces demand for agricultural labor. Excess farmworkers therefore migrate to the nonfarm sector, especially into less skill-intensive trade and transport services. Establishing a biofuels industry in Tanzania will therefore create new job opportunities for some farmers but will also impose significant adjustment costs on other workers, especially those in export agriculture.

Changes in Household Incomes and Poverty

Biofuel investments increase national GDP and factor returns, causing household incomes to rise. Although this is true in all the biofuel scenarios, there are significant differences in the distributional impacts across household groups. Table 11 reports changes in households' equivalent variation, which is a welfare measure that controls for changes in prices. All rural quintiles benefit from the introduction of a biofuels industry in Tanzania. However, higher-income rural households benefit more under larger-scale production scenarios, such as Sugar 3 and Cassava 3, since most large-scale farmers fall into the higher expenditure quintiles. Lower-income households, in contrast, benefit more under smallholder outgrower schemes, especially when these schemes are combined with improvements in crop yields.

⁴ About 620 biofuel processing jobs are created in *Sugar 1–3*; 860 in *Sugar 4*; 1,600 in *Sugar 5*; 333 in *Molasses*; and 248 in *Cassava 1–3*.

Table 11. Household per capita equivalent variation results, 2007–2015

	Per capita consumption, 2007 (US\$)	Baseline growth, 2015 (%)	Deviation from baseline scenario growth rate (%-point)									
			Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Molasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatropha (FAO 10)
Rural	372.4	1.32	0.41	0.57	0.59	0.53	0.41	0.11	0.27	0.45	0.49	0.34
Quintile 1	109.8	0.82	0.31	0.19	0.18	0.58	0.30	0.06	0.29	0.59	0.22	0.53
Quintile 2	198.6	0.97	0.32	0.21	0.19	0.56	0.32	0.06	0.29	0.54	0.22	0.49
Quintile 3	283.7	0.99	0.37	0.25	0.24	0.60	0.36	0.07	0.32	0.59	0.25	0.53
Quintile 4	433.7	1.17	0.40	0.30	0.28	0.59	0.39	0.09	0.32	0.55	0.26	0.48
Quintile 5	967.4	1.31	0.44	0.57	0.59	0.55	0.44	0.12	0.28	0.45	0.47	0.33
Urban	903.2	1.94	0.38	0.38	0.38	0.41	0.38	0.11	0.16	0.28	0.21	0.13
Quintile 1	120.6	1.22	0.35	0.28	0.27	0.43	0.35	0.08	0.22	0.25	0.22	0.15
Quintile 2	211.3	1.28	0.44	0.43	0.42	0.50	0.45	0.14	0.23	0.33	0.26	0.17
Quintile 3	307.6	1.38	0.54	0.53	0.53	0.58	0.54	0.17	0.26	0.41	0.31	0.21
Quintile 4	470.3	1.52	0.52	0.52	0.52	0.56	0.52	0.17	0.25	0.40	0.30	0.20
Quintile 5	1,614.2	2.08	0.34	0.35	0.35	0.37	0.34	0.10	0.13	0.25	0.19	0.11

Source: Results from the Tanzania DCGE and microsimulation model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

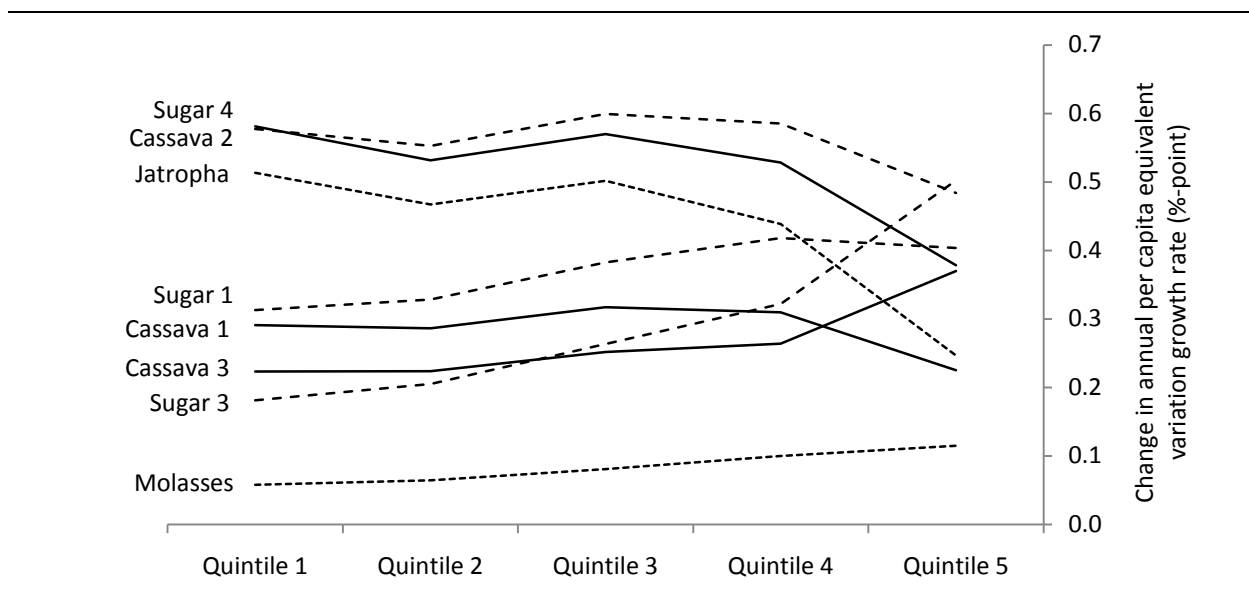
Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

Urban households also benefit from an increase in the economywide returns to labor and capital, and from the higher overall level of economic growth in the country. However, it is typically the middle of the urban income distribution that benefits the most, since these quintiles rely more heavily on labor wages for their incomes. Moreover, these households are typically endowed with semiskilled labor, which is used fairly intensively in the biofuel processing sectors (meaning as operators and technicians).

The national distributional effects of biofuel investments on households' equivalent variation are shown in Figure 2. Molasses generates very little additional value added in the economy and so its effects on household welfare are small. Although larger-scale sugarcane-based biofuel production is far more beneficial for households, it is higher-income households that benefit far more than lower-income households (meaning the curve for Sugar 3 is upward sloping). By contrast, the welfare gains are more evenly distributed across expenditure quintiles when outgrower schemes are used to produce sugarcane (meaning Sugar 1). Increasing smallholders' crop yields produces the most pro-poor welfare outcomes. This is reflected in the figure by the higher and downward sloping curves for the Sugar 4 and Cassava 2 scenarios. The mixed cassava production approach (meaning Cassava 3) is the least effective of the cassava scenarios in raising household welfare, with higher-income households benefiting the most in this scenario. This is because the displacement of existing farmland in order to establish commercial farms to produce this land-intensive crop is particularly severe for smallholders. Finally, the Jatropha scenario produces large welfare gains for lower-income households since it assumes high crop yields and engages a large number of smallholder farmers.

Figure 2. Change in per capita equivalent variation from baseline scenario by quintile, 2007–2015



Source: Results from the Tanzania DCGE and microsimulation model.

Note: Equivalent variation is a measure of household welfare that controls for changes in commodity prices. Expenditure quintiles are based on per capita consumption spending.

Table 12 reports changes in national poverty rates for the various biofuel scenarios. The headcount rate, which measures the share of the population under the poverty line, declines the most under the two yield-improvement scenarios. Poverty reduction is also more pronounced for technologies that more heavily engage smallholder farmers. There is little difference in poverty outcomes, however, between the purely large-scale sugarcane scenario (meaning *Sugar 3*) and the scenario that produces 20 percent of feedstock using smallholders (meaning *Sugar 2*). Similarly, the poverty effects of the mixed cassava production approach (meaning *Cassava 3*) are also fairly modest compared to the purely smallholder-based approaches. This suggests that increasing the participation of smaller-scale farmers generates significant gains in poverty reduction, especially when additional investments enhance crop productivity.

Table 12. Poverty results, 2007–2015

	Poverty rate, 2007 (%)	Baseline poverty, 2015 (%)	Deviation from final baseline scenario poverty rate, 2015 (%-point)									
			Sugar 1 (FAO 1)	Sugar 2 (FAO 2)	Sugar 3 -	Sugar 4 (FAO 3)	Sugar 5 (FAO 4)	Molasses (FAO 5)	Cassava 1 -	Cassava 2 (FAO 8)	Cassava 3 (FAO 9)	Jatropha (FAO 10)
Headcount (P0)	40.00	36.77	-1.36	-1.07	-1.05	-2.18	-1.33	-0.30	-1.28	-2.21	-1.15	-1.81
Rural	44.72	41.34	-1.37	-1.08	-1.05	-2.32	-1.33	-0.29	-1.34	-2.36	-1.20	-1.97
Urban	20.18	17.52	-1.32	-1.07	-1.05	-1.60	-1.32	-0.38	-1.00	-1.57	-0.94	-1.17
Gap (P1)	13.23	12.00	-0.54	-0.36	-0.34	-1.00	-0.53	-0.11	-0.52	-1.04	-0.44	-0.82
Rural	15.01	13.70	-0.60	-0.39	-0.36	-1.12	-0.59	-0.12	-0.58	-1.18	-0.49	-0.93
Urban	5.76	4.89	-0.32	-0.25	-0.25	-0.48	-0.32	-0.08	-0.27	-0.46	-0.25	-0.33
Squared gap (P2)	6.10	5.49	-0.27	-0.18	-0.17	-0.52	-0.27	-0.06	-0.27	-0.54	-0.23	-0.43
Rural	6.97	6.31	-0.31	-0.20	-0.18	-0.59	-0.30	-0.06	-0.30	-0.63	-0.25	-0.50
Urban	2.46	2.07	-0.13	-0.10	-0.10	-0.21	-0.13	-0.03	-0.12	-0.20	-0.11	-0.15

Source: Results from the Tanzania DCGE and microsimulation model.

Notes: Sugar 1/2/3: Small-scale / mixed / large-scale sugarcane production (land expansion) with large-scale ethanol processing

Sugar 4: Small-scale sugarcane production (yield improvements) with large-scale ethanol processing

Sugar 5: Small-scale sugarcane production (land expansion) with small-scale ethanol processing

Molasses: Large-scale ethanol processing using imported molasses

Cassava 1: Small-scale cassava production (land expansion) with large-scale ethanol processing

Cassava 2/3: Small-scale / mixed cassava production (yield improvements) with large-scale ethanol processing

Jatropha: Small-scale jatropha production with large-scale biodiesel processing

6. CONCLUSIONS

Considerable uncertainty exists concerning the potential gains from establishing biofuel industries in low-income countries. Particular concern is raised over possible trade-offs between biofuel and food production. It is therefore essential that governments in countries such as Tanzania understand how different biofuel technologies can contribute to achieving national development objectives. Drawing on detailed production cost estimates, this study developed a dynamic economywide model of Tanzania to estimate the growth and distributional implications of alternative biofuel production scenarios. These scenarios differed in the feedstocks used to produce biofuels (sugarcane, molasses, and cassava), the scale of feedstock production (small-scale outgrowers versus larger-scale plantations), and the way in which feedstock production is increased (yield improvements versus land expansion).

Model results indicate that although some individual farmers may shift resources away from producing food crops, there is no national-level trade-off between biofuel and food production in Tanzania. Rather, it is traditional export crops that will be adversely affected by a sizable appreciation of the real exchange rate. Indeed, it is the large size of Tanzania's agricultural export sector that prevents food production from contracting. This is because the amount of land displaced by biofuel feedstock is smaller than the lands released by declining traditional export crops. As a result, food production increases slightly under most biofuel investment scenarios. Overall, national GDP rises and new employment opportunities are created in biofuel sectors. This leads to welfare gains throughout the income distribution, albeit following a possible period of adjustment in which prices, farmworkers, and nonbiofuel exporters adapt to new market conditions.

Our findings suggest that although all biofuel production scenarios improve household welfare, it is small-scale outgrower schemes, especially for typical smallholder crops such as cassava and jatropha, that are most effective at raising poorer households' incomes. Tanzania should therefore explore opportunities to engage smallholders in the production of biofuels, possibly through mixed small- and large-scale production systems. However, supporting evidence indicates that these mixed systems may reduce the profitability of biofuels in Tanzania and reduce the reliability of feedstock supply for downstream processing. Here our findings confirm the welfare gains achieved by producing feedstock through yield improvements rather than land expansion. Given the strong pro-poor outcomes and greater profitability, our findings favor a cassava-based biofuels industry for Tanzania.

There are, however, a number of limitations to our analysis. First, although the scenarios based on yield improvements generated the highest levels of pro-poor growth, we accounted for only the private costs involved in establishing the biofuels industry. We did not include public-sector costs, such as the provision of irrigation and farm inputs to improve farmers' productivity. Given the difficulties that Tanzania's government has faced in the past in raising smallholders' crop yields, some of the yield-oriented biofuel scenarios may prove overly optimistic.

Second, although the modeled scenarios assume competition for labor inputs (meaning there is no excess labor capacity that can be absorbed by the growing biofuels sector or feedstock producers), most scenarios assume that at least half of the agricultural land required to produce feedstocks will be obtained through the clearing of currently unutilized land (Arndt et al. [2009] adopt a similar assumption for Mozambique). If, in reality, more land is displaced by biofuel feedstock production, the results with respect to domestic food production may be less positive. Even so, some believe that biofuels will displace even less of the land currently utilized for agricultural production in Tanzania (see Cardona et al. 2009), and hence we believe our assumptions are sufficiently conservative.

Third, in all the biofuel scenarios, we did not consider the cost of providing the infrastructure or tax incentives that may be demanded by foreign investors to produce biofuels in Tanzania. If these public investments are not in accordance with the government's national development plan, then they will incur opportunity costs. Finally, our analysis also did not compare the benefits of investing in biofuels vis-à-vis other social and economic sectors. However, excluding public-sector costs, our results indicate that establishing a biofuels industry in Tanzania can contribute to achieving the country's development objectives of enhancing economic growth and reducing poverty.

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