CHAPTER 7

ECONOMY WIDE EFFECTS OF BIOENERGY DEVELOPMENTS

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7. 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, with the national headcount rate falling only slightly from 35.7 to 33.6 percent during 2001-2007 (World Bank, 2010). This persistence in poverty is at aleast partly explained by slower growth in agricultural incomes (Pauw and Thurlow, forthcoming). Indeed, agriculture's performance is particularly important for economic development in Tanzania, given that four-fifths of the labour 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 regarding biofuels may be justified. In Mozambique, for example, Arndt *et al.* (2009) find that proposed biofuel investments will increase economic growth by 0.5 percent each year over the coming decade, causing the national poverty rate to fall by five 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 Hausman, 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 critical to maximizing the private and 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 micro-simulation module that estimates impacts on income poverty. Section 2 reviews the biofuel production scenarios that the Government of Tanzania is considering. Section 3 describes the economic model and how the various biofuel production scenarios are simulated. Section 4 then presents the results, and Section 5 concludes with recommendations for policy.

7.1 OPTIONS FOR PRODUCING BIOFUELS IN TANZANIA

7.1.1 IDENTIFYING BIOFUELS PRODUCTION SCENARIOS

The Food and Agriculture Organization (FAO) of the United Nations has, together with the Government of Tanzania, identified a number of biofuel production scenarios using different feedstock crops and 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 FAO and examined in this study are summarized in Table 7.1.

TABLE 7.1

FAO biofuel production options

Feedstock	FAO option	Description
Sugar-cane juice (ethanol)	1	Single large-scale ethanol processing plant with a capacity of 160 000 litres per day using juice from new sugar-cane cultivars produced by smallholders. Production and sale of by-products included.
	2	Single large-scale ethanol processing plant with a capacity of 236-277 000 litres per day using juice from new sugar cane 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 litres per day using juice from new sugar cane produced by increasing smallholders' crop yields rather than expanding crop land area. Production and sale of by-products included.
	4	Four small-scale ethanol processing plants with individual capacities of 44-52 000 litres per day using juice from new sugar cane produced by smallholders. Production and sale of by-products included.
Molasses (ethanol)	5	Single large-scale ethanol processing plant with a capacity of 80-85 000 litres 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 litres 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 litres 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 litres per day using jatropha produced by smallholders.

Source: Cardona et al. (2009)

The FAO scenarios differ on four characteristics: (1) the type of feedstock used and biofuel produced; (2) the scale of feedstock production (i.e. smallholder versus estate); (3) the way in which feedstock production is expanded (i.e. increasing yields or harvested area). and (4) the scale of downstream biofuel processing plants. These differences are presented in Table 7.2, which shows the various scenarios simulated in this paper.

TABLE 7.2
Simulated biofuels 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: Own calculations using information from Cardona et al. (2009).

The first five scenarios (*Sugar 1-5*) refer to ethanol produced from sugar-cane 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 7.1. 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 sugar-cane scenarios are variations on *Sugar 1*, where all feedstock is produced by smallholders through an outgrower scheme. However, in the *Sugar 4* scenario, sugar-cane production is increased by raising smallholders' land yields (from 43 to 70 tons per hectare) rather than by expanding the amount of land under sugar-cane cultivation. This reduces the amount of land currently used for agriculture that is displaced by biofuel production. The final sugar-cane scenario (*Sugar 5*) still uses low yields but now assumes that downstream processing is done using a number of small-scale plants. As shown later in this section, using small-scale processing plants increases the amount of labour required for biofuel production.

Molasses is another feedstock that could be used to produce ethanol in Tanzania. Molasses is a by-product from sugar-cane refining and all of the molasses currently being produced is exported. Producing ethanol from molasses would thus redirect exports for use as feedstock in the domestic biofuel 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.

The use of cassava is also considered as a biofuel feedstock. In each scenario we assume that production is by smallholders through an outgrower scheme and that processing is done by large-scale processing plants. The first two scenarios differ in that *Cassava 1* assumes that cassava production is achieved through extensification (i.e. 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 biofuel industry. The *Cassava 3* scenario assumes a mixed production system, with 40 percent of feedstock obtained from smallholders through yield improvements (i.e. 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). Production is via a smallholder outgrower scheme linked to a large-scale biodiesel processing plant, with high crop yields of 4 tons per ha.

The FAO options in Table 7.1 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* then this may be due to either the larger volume of biofuel ethanol being produced or inclusion of more larger-scale farmers. Therefore, to make scenarios comparable we simulate the same volume of biofuels under all scenarios rather than model the varying amounts identified in Table 7.1. More specifically, we model the establishment of a biofuel industry capable of producing 1 000 million litres of ethanol or biodiesel per year (i.e. 3 million litres per day).

7.1.2 ESTIMATING PRODUCTION COSTS AND TECHNOLOGIES

The biofuel scenarios in Table 7.2 contrast the economic impacts of different feedstocks and processing plants. These scenarios will produce different outcomes because they use different technologies (i.e. 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 7.3 below.

The cost of producing ethanol in Tanzania ranges from USD0.43 per litre under a mixed small- and large-scale production system (i.e. *Sugar 2*) to USD0.74 per litre using molasses as a feedstock. The low-cost scenarios (i.e. *Sugar 2, Cassava 2 and Cassava 3*) compare favourably with current ethanol production costs in countries such as Brazil (USD0.47), India (USD0.52) and the USA (USD0.46). However, the estimated costs of producing ethanol from smallholder-based sugar cane 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 USD0.56 per litre, implying that processing plants in some of our scenarios run at a loss. Similarly, biodiesel production costs are USD0.83 per litre in Tanzania and are above the landed price at Dar es Salaam harbour (USD0.77) (Johnson and Holloway, 2007).

TABLE 7.3
Production cost estimates for biofuels scenarios

	Sugar 1	Sugar 2	Sugar 4	Sugar 5	Molasses	Cassava 2	Cassava 3	Jatropha
	FAO 1	FAO 2	FAO 3	FAO 4	FAO 5	FAO 8	FAO 9	FAO 10
Cost per litre (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
Labour	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
Co-products	-0.011	-0.016	-0.019	-0.016	0.000	0.000	0.000	-0.028

Source: Cardona et al. (2009).

Using the above processing costs and farm crop budgets, we estimate the production technologies for the ten biofuels scenarios modelled in this paper. These are summarized in Table 7.4. 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 (i.e. *Sugar 1*) are lower than larger-scale farmers' yields (i.e. *Sugar 3*), implying that 100 ha of small-scale farm land produces half the output of plantations on the same amount of land (i.e. 4 280 versus 8 400 tons). Small-scale farms are also more labour-intensive (i.e. 0.4 hectares per worker compared to 2.4 ha per worker on larger farms). Increasing smallholders' sugar-cane yields significantly increases production levels per 100 ha of land (i.e. to 7,000 tons), but requires additional labour for weeding and harvesting. Cassava production is also labour-intensive and requires more land per litre of ethanol than sugar cane. The mixed cassava production system (i.e. *Cassava 3*) is more labour-intensive than the equivalent smallholder scenario (i.e. *Cassava 2*) as new commercial farms require additional labourers whereas smallholders increase production by raising yields on their existing farm land. Finally, the jatropha scenario is also labour-intensive, albeit less so than smallholder cassava and sugar cane.

The lower half of Table 7.4 shows the inputs required to produce 100 000 litres 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 farm workers. The number of workers used in processing biofuels is much smaller than the number of farm workers used in producing the feedstock (e.g. one processing worker is needed for every 121 farm workers in more labour-intensive *Sugar 1* scenario). The labour-intensity of biofuel processing is, however, higher in the *Sugar 5* scenario, which uses small-scale processing plants. Finally, cassava processing is more labour-intensive, although the large amount of land required to produce the feedstock makes it the most labour-intensive option overall.

In summary, ten biofuel production scenarios are considered in this analysis. These scenarios compare different feedstocks; small/large-scale production structures and intensive/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 economy-wide model of Tanzania in order to estimate their impacts of growth and poverty.

7.2 MODELLING IMPACTS ON GROWTH AND POVERTY

7.2.1 STRUCTURE OF THE TANZANIAN ECONOMY

Table 7.5 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 land holdings of 1.6 hectares. They produce most of the country's food, which dominates

TABLE 7.4

Biofuels production technologies under alternative scenarios

Production characteristics for biofuels (inputs and outputs per 100ha)	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)
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
Farm workers 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 labour 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 farm worker (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
Labour-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
Biofuels produced (litres)	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 litres)	**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)**
Biofuels production (litres)	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 (litres / 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
Farm workers 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: *Own calculations using information from Cardona et al. (2009), Coles (2008), Kapinga et al., (2009), Rothe (2007) and the Tanzania DCGE model.*

Notes: *Sugar 1: Small-scale sugar-cane production (land expansion) with large-scale ethanol processing*
Sugar 2: Mixed small- and large-scale sugar-cane production (land expansion) with large-scale ethanol processing
Sugar 3: Large-scale sugar-cane production (land expansion) with large-scale ethanol processing
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane production (land expansion) with large-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: Small-scale cassava production (yield improvements) with large-scale ethanol processing

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 rainfall and traditional farming technologies. Larger-scale commercial farmers are more heavily engaged in traditional export crops, such as coffee, tobacco and tea, which together account for almost a third of total merchandize exports.

TABLE 7.5
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
Govt. services	12.69	1.47	0.00	0.00	0.00	0.00

Source: Tanzania 2007 social accounting matrix.

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

The economy-wide 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 its 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.

7.2.2 CORE GENERAL EQUILIBRIUM MODEL

We use a DCGE model, details of which are included in Appendix 7A. The DCGE model illustrates how biofuels investments affect economic outcomes in our analysis and how economic growth is linked to household incomes.

7.2.3 MODELLING BIOFUELS PRODUCTION

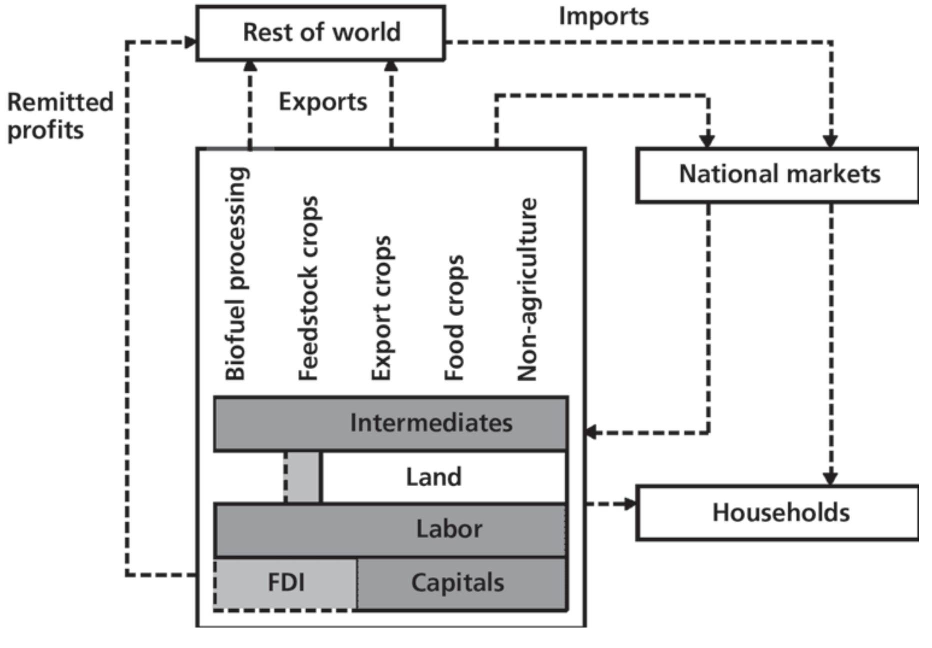
Biofuels are not currently produced in Tanzania and so there is initially no biofuel sector in the 2007 social accounting matrix used to calibrate the DCGE model. However, the production cost information in Table 7.3 and farm crop budgets provide the intermediate technology vectors needed to create these new sectors in the model. Negligibly small feedstock and processing sectors representing different biofuel technology vectors were initially created. The DCGE model is first run forward over the 2007-2015 period assuming no expansion in biofuel 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 1 000 million litres of biofuels. A conceptual framework for these simulations is shown in Figure 7.1.

Biofuel expansion is assumed to be driven by foreign direct investment (FDI) and all profits generated in the biofuel sectors are remitted abroad (after applying average corporate tax rates). Biofuel producers must, however, compete with other sectors for intermediate inputs and land and labour resources. In the DCGE model we assume full employment, which means that total labour supplies are fixed and increasing labour 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 towards feedstock. Thus, while new lands may be available to feedstock producers, it is expected that at least some existing lands will be displaced by biofuel crops. Table 7.2 shows that for most scenarios it is assumed that half of the lands used by biofuel feedstock come from lands already in use by smallholder farmers. There is no land displacement in the *Sugar 4* and *Cassava 2* scenarios as feedstock is produced entirely through intensification (i.e. raising yields). The grey shaded areas in the figure represent new capital and land resources, which cause national production to expand in the simulations.

It is assumed 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 then the difference between increasing biofuel exports or reducing petroleum imports is small (i.e. the effect on the balance of payments is symmetrical). Therefore assuming all biofuels are exported will not change the findings. Similarly, it is assumed that all molasses feedstocks are imported, which offsets the decline in molasses exports required in the molasses scenario. The model includes co-products 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 co-products, but assume that they are used to reduce fuel and electricity inputs used during biofuel processing.

Figure 7.1

Conceptual framework



7.3 MODEL RESULTS

7.3.1 BASELINE SCENARIO

First the DCGE model is calibrated to track observed trends in key demographic and macroeconomic indicators (see Table 7.6). Population growth is set at 2.5 percent per year during 2007-2015. Skilled labour supply grows faster than unskilled labour in all scenarios, reflecting gradual improvements in educational attainment. Livestock stocks and agricultural land expand at 1 percent each year, capturing rising population density, especially in rural areas. In order to achieve observed growth rates in gross domestic product, 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.

7.3.2 CHANGES IN AGRICULTURAL PRODUCTION

In the biofuel simulations the amount of land and foreign direct investment allocated to biofuel sectors is increased. It is assumed that only half of biofuels' land requirements will displace land already being cultivated. An increase is therefore expected in the total amount of land under cultivation. This is shown in the third column of Table 7.6, where the rate of land expansion for smallholders increases from 1 000 percent under the Baseline scenario to 1.26 percent per year under the *Sugar 1* scenario. Conversely, as there is a shift towards larger-scale feedstock production (in *Sugar 2* and *Sugar 3*) the expansion rate of smallholder lands drops below one. 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 since production 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 comes from smallholders. Finally, the molasses needed as feedstock is already produced in Tanzania and so there is no change in land expansion rates under the molasses scenario.

Displacing lands to produce biofuel feedstock causes production of other crops to contract (see Table 7.7). The debate surrounding biofuels in low-income countries centres on their possible negative effects on food production. 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 merchandize export earnings by 2015. It can be assumed that the current account balance is fixed in foreign currency, the increase in exports causes the real exchange rate to appreciate relative to Baseline (see Table 7.6). 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 ha 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, where 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.

Comparing *Sugar 1* with *Sugar 3* suggests that moving to larger-scale feedstock production does not remove the negative impacts on export crops. This is because the same amount of ethanol exports are produced causing a similar appreciation of the real exchange rate (see Table 7.6). This means that non-biofuel exporters are adversely affected in both scenarios. Larger-scale production technologies do, however, favour food crop production, since the higher yields of large-scale farmers means that less land is needed for biofuel feedstock. This implies that 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 feedstock is 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, where no additional lands are needed to produce feedstock. 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 in this country. This difference arises because Mozambique does not have a large export crop sector so at least some lands under food crops are displaced by biofuel feedstock.

7.3.3 IMPACTS ON ECONOMIC GROWTH AND EMPLOYMENT

Table 7.8 shows the impact of biofuel investments on sectors' real GDP growth rates. Foreign direct investment 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 of the biofuel scenarios. Larger-scale production of sugar-cane feedstock (i.e. *Sugar 3*) generates larger gains in agricultural GDP than production through smallholder outgrower schemes (i.e. *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 sugar-cane scenarios reduce processed food production because the appreciated exchange rate heightens competition in this import-intensive sector (see Table 7.6). Ultimately, the trade-offs from biofuel production are smaller than the gains from new investments and, as a result, national GDP growth rates increase in all biofuel scenarios.

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 amongst the more profitable ethanol technologies in Tanzania (see Table 7.3). Improving crop yields rather than displacing existing cultivated lands also generates large economy-wide 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

TABLE 7.6

Core macroeconomic assumptions and results, 2007-2015

	Initial, 2007	Baseline scenario	Sugar 1	Sugar 2	Sugar 3	Sugar 4	Sugar 5	Molasses	Cassava 1	Cassava 2	Cassava 3	Jatropha
			(FAO 1)	(FAO 2)	-	(FAO 3)	(FAO 4)	(FAO 5)	-	(FAO 8)	(FAO 9)	(FAO 10)
		Average annual growth rate, 2007-15 (%)										
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
Labour 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 micro-simulation model.*

Notes: *Sugar 1/2/3: Small-scale / mixed / large-scale sugar-cane production (land expansion) with large-scale ethanol processing*
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane 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

TABLE 7.7

Agricultural production results, 2007-2015

	Initial value, 2007	Baseline value, 2015	Deviation from Baseline scenario final value, 2015									
			Sugar 1	Sugar 2	Sugar 3	Sugar 4	Sugar 5	Molasses	Cassava 1	Cassava 2	Cassava 3	Jatropha
			(FAO 1)	(FAO 2)	-	(FAO 3)	(FAO 4)	(FAO 5)	-	(FAO 8)	(FAO 9)	(FAO 10)
Biofuels (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
Crop land (1 000 ha)	8 207	8 887	168	95	86	0	168	0	273	0	50	357
Biofuels 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
Production (1000 mt)												
Biofuels 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 micro-simulation model.*

Notes: *Sugar 1/2/3: Small-scale / mixed / large-scale sugar-cane production (land expansion) with large-scale ethanol processing*
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane 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

on national GDP since there are no growth linkages to the agricultural sector and only small gains in manufacturing. Moreover, the growth-effects under the mixed cassava production approach (i.e. *Cassava 3*) are not as large as those of the mixed sugar-cane 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 sugar cane. Similarly, obtaining cassava feedstock solely by increasing smallholders' yield (i.e. *Cassava 2*) generates larger growth-effects, as no land displacement of other crop lands 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 7.9 reports impacts on labour employment. The number of new jobs created in the biofuels sector varies greatly across scenarios. The low labour-intensity of large-scale sugar-cane production means that only 72 000 farm jobs are created in the *Sugar 3* scenario. Conversely, outgrower schemes employ far more farmers (see Table 7.4), with 758 000 additional workers producing sugar cane in the *Sugar 1* scenario.[1] Sugar cane is less labour-intensive than cassava production and it is the *Cassava 1* and jatropha scenarios that engage the largest number of workers in feedstock production. Moreover, while improving crop yields amongst 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) while ignoring the labour "displacement" effects. Thus, even if all feedstock production were to take place on new lands (i.e. no land displacement) non-feedstock crops would still decline due to increased competition over non-land resources (such as labour).

The downstream processing of biofuels creates very few jobs, with almost all employment effects from biofuel investments coming from feedstock production.[2] Moreover, unlike feedstock production, jobs in processing plants are for higher-skilled workers, most of which are sourced from other manufacturing subsectors. Lower-skilled feedstock farmers or labourers mainly come from within the agriculture itself. However, both sugar-cane and cassava have lower-than-average labour-land ratios. This means that reallocating land to these crops effectively reduces demand for agricultural labour. Excess farm workers therefore migrate to the non-farm 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.

1 Note that employment numbers do not adjust for under-employment and include unpaid family members.

2 About 620 biofuels processing jobs are created in Sugar 1-3; 860 in Sugar 4; 1600 in Sugar 5; 333 in Molasses; and 248 in Cassava 1-3.

TABLE 7.8

Sector growth results, 2007-2015

	GDP share, 2007 (%)	Baseline growth (%)	Deviation from Baseline scenario growth rate (%-point)									
			Sugar 1	Sugar 2	Sugar 3	Sugar 4	Sugar 5	Molasses	Cassava 1	Cassava 2	Cassava 3	Jatropha
				(FAO 2)	-	(FAO 3)	(FAO 4)	(FAO 5)	-	(FAO 8)	(FAO 9)	(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
Biofuels 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
Biofuels process.	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 manu.	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
Govt. 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 micro-simulation model.*

Note: *Equivalent variation is a measure of household welfare that controls for changes in commodity prices.*
Sugar 1: Small-scale sugar-cane production (land expansion) with large-scale ethanol processing
Sugar 2: Mixed small- and large-scale sugar-cane production (land expansion) with large-scale ethanol processing
Sugar 3: Large-scale sugar-cane production (land expansion) with large-scale ethanol processing
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane production (land expansion) with large-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: Small-scale cassava production (yield improvements) with large-scale ethanol processing
Cassava 3: Mixed small- and large-scale cassava production (land expansion) with large-scale ethanol processing

TABLE 7.9

Employment results, 2007-2015

	Employ-ment, 2007	Baseline employ., 2015	Deviation from Baseline scenario final employment, 2015									
			Sugar 1	Sugar 2	Sugar 3	Sugar 4	Sugar 5	Molasses	Cassava 1	Cassava 2	Cassava 3	Jatropha
				(FAO 2)	-	(FAO 3)	(FAO 4)	(FAO 5)	-	(FAO 8)	(FAO 9)	(FAO 10)
Total (1000s 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
Biofuels 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
Biofuels process.	0	0	1	1	1	1	3	0	0	0	0	1
Other manu.	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
Govt. services	280	327	2	2	1	2	2	1	1	1	1	1

Source: *Results from the Tanzania DCGE and micro-simulation model.*

Notes: *Sugar 1/2/3: Small-scale / mixed / large-scale sugar-cane production (land expansion) with large-scale ethanol processing*
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane 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

7.3.4 CHANGES IN HOUSEHOLD INCOMES AND POVERTY

Biofuel investments increase national GDP and factor returns, causing households' incomes to rise. While this is true in all of the biofuel scenarios, there are significant differences in the distributional impacts across household groups. Table 7.10 reports changes in households' equivalent variation, which is a welfare measure that controls changes in prices. All rural quintiles benefit from the introduction of a biofuel industry in Tanzania. However, higher-income rural households benefit more under larger-scale production scenarios, such as Sugar 3 and Cassava 3, as most large-scale farmers fall into the higher expenditure quintiles. Lower-income households, on the other hand, benefit more under smallholder outgrower schemes, especially when they are combined with improvements in crop yields.

Urban households also benefit from an increase in the economy-wide returns to labour 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 labour wages for their incomes. Moreover, these households are typically endowed with semi-skilled labour, which is used more intensively in the biofuel processing sectors (i.e. as operators and technicians).

The national distributional effects of biofuel investments on households' equivalent variation are shown in Figure 7.2. Molasses generates very little additional value-added in the economy and so its effects on household welfare are small. While larger-scale sugar cane-based biofuel production is far more beneficial for households, it is higher-income households that benefit far more than lower-income households (i.e. the curve for *Sugar 3* is upward sloping). By contrast, the welfare gains are more evenly distributed across expenditure quintiles when smallholder outgrower schemes are used to produce sugar cane (i.e. *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 (i.e. *Cassava 3*) is least effective amongst the cassava scenarios in raising household welfare, with higher-income households benefiting the most in this scenario. This is because the displacement of existing farm land 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.

TABLE 7.10

Household per capita equivalent variation results, 2007-2015

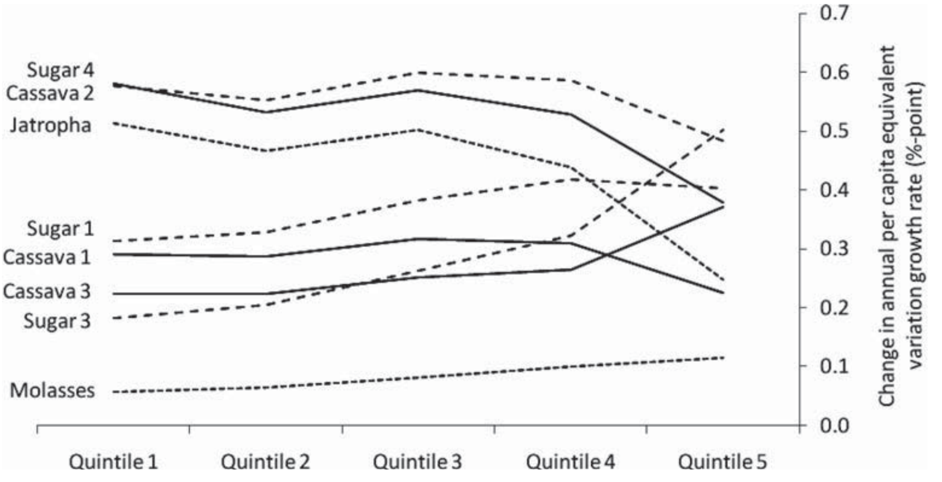
	Per cap. cons., 2007 (US$)	Baseline growth, 2015 (%)	Deviation from Baseline scenario growth rate (%-point)									
			Sugar 1	Sugar 2	Sugar 3	Sugar 4	Sugar 5	Molasses	Cassava 1	Cassava 2	Cassava 3	Jatropha
				(FAO 2)	-	(FAO 3)	(FAO 4)	(FAO 5)	-	(FAO 8)	(FAO 9)	(FAO 10)
Rural	372.4	1.32	0.41	0.57	0.59	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	1614.2	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 micro-simulation model.*

Notes: *Sugar 1/2/3: Small-scale / mixed / large-scale sugar-cane production (land expansion) with large-scale ethanol processing*
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane 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

Figure 7.2

Change in per capita equivalent variation from Baseline scenario by quintile, 2007-2015



Source: Results from the Tanzania DCGE and micro-simulation 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.

Finally, Table 7.11 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 sugar-cane scenario (i.e. *Sugar 3*) and the scenario that produces 20 percent of feedstock using smallholders (i.e. *Sugar 2*). Similarly, the poverty-effects of the mixed cassava production approach (i.e. *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 are made to enhance crop smallholder productivity.

7.4 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 like Tanzania understand how different biofuel technologies can contribute to achieving national development objectives. Drawing on detailed production cost estimates, this study developed a dynamic economy-wide model of Tanzania to estimate the growth and distributional implications of alternative biofuel production scenarios. These scenarios differed in the feedstock used to produce biofuels (sugar cane, molasses and cassava), the scale of feedstock production (small-scale outgrower versus larger-scale plantations), and the way in which feedstock production is increased (yield improvements versus land expansion).

Model results indicate that while some individual farmers may shift resources away from producing food crops, there is no national-level trade-off between biofuels 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, farm workers and non-biofuel experts adapt to new market conditions.

Findings suggest that, while all biofuel production scenarios improve household welfare, it is the small-scale outgrower schemes, especially for typical smallholder crops such as cassava and jatropha, which 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 these findings confirm the welfare gains from producing feedstock through yield improvements rather than land expansion. Given its strong pro-poor outcomes and greater profitability, these findings favour a cassava-based biofuel industry for Tanzania.

There are, however, a number of limitations to this analysis. Most importantly, while the scenarios based on yield improvements generated the highest levels of pro-poor growth, the analysis only accounted for the private costs involved in establishing the biofuel industry. It did not include public sector costs, such as the provision of irrigation and farm inputs to improve farmers' productivity. Given the difficulties that the Government of Tanzania has faced in the past in raising smallholders' crop yields, some of the yield-oriented biofuel scenarios may prove overly optimistic. Moreover, in all of the biofuel scenarios the cost of the providing infrastructure or tax incentives that may be demanded by foreign investors to produce biofuels in Tanzania were not taken into account. If these public investments are not in accordance with the government's national development plan then they will incur opportunity costs. In our analysis the benefits of investing in biofuels were not compared vis-à-vis other social and economic sectors. However, excluding public sector costs, our results indicate that establishing a biofuel industry in Tanzania can contribute to achieving the country's development objectives of enhancing economic growth and reducing poverty.

TABLE 7.11

Poverty results, 2007-2015

	Poverty rate, 2007 (%)	Baseline poverty, 2015 (%)	Deviation from final Baseline scenario poverty rate, 2015 (%-point)									
			Sugar 1	Sugar 2	Sugar 3	Sugar 4	Sugar 5	Molasses	Cassava 1	Cassava 2	Cassava 3	Jatropha
				(FAO 2)	-	(FAO 3)	(FAO 4)	(FAO 5)	-	(FAO 8)	(FAO 9)	(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 micro-simulation model.*

Notes: *Sugar 1/2/3: Small-scale / mixed / large-scale sugar-cane production (land expansion) with large-scale ethanol processing*
Sugar 4: Small-scale sugar-cane production (yield improvements) with large-scale ethanol processing
Sugar 5: Small-scale sugar-cane 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

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APPENDIX 7A

CORE MODEL EQUATIONS.

We first present a simplified or core DCGE model to illustrate how biofuels investments affect economic outcomes in our analysis. The equations are presented in the table 7A.1 below.

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]). Labour, 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 economy-wide factor returns and production in other sectors by increasing resource competition.

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 non-biofuel 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 υ) 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 (i.e. a savings-driven investment closure) (eq. [7]). Finally, prices P equilibrate product markets so that demand for each commodity equals supply (eq. [8]). 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 re-solved for a series of new equilibriums for the 8-year period 2007-2015. Between periods the model is updated to reflect exogenous rates of land and labour 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.

The core model illustrates the basic functioning of a CGE model. However, the full model of Tanzania drops certain restrictive assumptions (see Thurlow, 2005). Constant elasticity of substitution production functions allow factor substitution based on relative factor prices (i.e. ◘ is no longer fixed). The model identifies 58 sectors (i.e. 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 (i.e. Leontief demand). Based on the 2000/01 Household Budget Survey (HBS) (NBS, 2001), labour 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 (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 (i.e. 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 (i.e. price index of tradable-to-non-tradable 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 non-unitary income elasticities (estimated using HBS). Households are disaggregated across rural/urban and farm/non-farm 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 micro-simulation module with each respondent in HBS linked to their corresponding representative household in the DCGE model. Changes in commodity prices and households' consumption spending are passed down from the DCGE model to the survey, where total per capita consumption and poverty measures are recalculated.

TABLE 7A.1

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	$P_{st} \cdot D_{hst} = \beta_{hf} \cdot (1 - \upsilon_h) \cdot Y_{ht}$		(6)
Investment demand	$P_{st} \cdot I_{hst} = \rho_s \cdot \left(\sum_h \upsilon_h \cdot Y_{ht} + E_t \cdot b \right)$		(7)
Current account balance	$w_s^m \cdot M_{st} = w_s^e \cdot X_{st} + b$		(8)
Product market equilibrium	$Q_{st} = \sum_h D_{hst} + I_{hst}$		(9)
Factor market equilibrium	$\sum_h F_{fst} = s_{ft}$		(10)
Land and labour expansion	$s_{ft} = s_{t-1} \cdot (1 + \varphi_f)$	*f* is land and labour	(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)

Subscripts

f	Factor groups (land, labour and capital)
h	Household groups
s	Economic sectors
t	Time periods

Endogenous variables

D	Household consumption demand quantity
E	Exchange (local/foreign currency units)
F	Factor demand quantity
I	Investment demand quantity
M	Import supply quantity
P	Commodity price
Q	Output quantity
W	Average factor return
X	Export demand quantity
Y	Total household income
b	Foreign savings balance (foreign currency units)
s	Total factor supply
w	World import and export prices

Exogenous parameters

α	Production shift parameter (factor productivity)
β	Household average budget share
γ	Hicks neutral rate of technical change
δ	Factor input share parameter
η	Capital depreciation rate
θ	Household share of factor income
κ	Base price per unit of capital stock
ρ	Investment commodity expenditure share
υ	Household marginal propensity to save
ϕ	Land and labour supply growth rate