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Gender Implications of Biofuels Expansion in Africa: The Case of Mozambique

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Summary. — We use a gendered dynamic CGE model to assess the implications of biofuels expansion in a low-income, land-abundant setting. Mozambique is chosen as a representative case. We compare scenarios with different gender employment intensities in producing jatropha feedstock for biodiesel. Under all scenarios, biofuels investments accelerate GDP growth and reduce poverty. However, a stronger trade-off between biofuels and food availability emerges when female labor is used intensively, as women are drawn away from food production. A skills-shortage among female workers also limits poverty reduction. Policy simulations indicate that only modest improvements in women's education and food crop yields are needed to address food security concerns and ensure broader-based benefits from biofuels investments.

Key words — biofuels, gender, growth, poverty, land abundance, Africa

1. INTRODUCTION

A combination of high oil prices and mandates for biofuels use in developed countries, particularly in Europe, has spurred significant investor interest in biofuels production. This interest extends to low-income, land-abundant economies in Africa (Arndt, Msangi, & Thurlow, 2010). For example, Mozambique has recently received numerous requests for land to produce biofuel feedstock, such as sugarcane for ethanol and jatropha for biodiesel. By 2009, requests exceeded 20 million hectares, which is equivalent to two thirds of total arable land in the country and four times the land currently cultivated. Not all requests are considered credible, however, with many of them merely attempting to obtain land use rights in a country where the state formally owns all land. Nevertheless, a recent rapid appraisal of biofuels investors identified 15 ongoing projects seeking to plant a total 500,000 hectares.

Hence, a significant expansion into biofuels is underway, even if only approved projects are considered. Moreover, the number of projects and the amount of dedicated land could easily grow in many low income and land abundant countries. Production and market assessments for Mozambique and Tanzania indicate that biofuels are internationally competitive at world oil prices above US$60 and US$66 per barrel respectively (Econergy, 2008; Felix, Cardona, & Quintero, 2010). These break even points are approximately the same as the level identified by Tyner (2010) for profitability of corn ethanol produced in the United States without government subsidies. 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 (IEA, 2009). In short, there are substantial incentives to produce biofuels both in developed economies and in land abundant low income economies. These incentives may become even more pronounced over time if oil prices rise as futures markets suggest. Sophisticated investors can also lock in now prices favorable to biofuels production out to 2018.

This article uses a gendered dynamic computable general equilibrium (CGE) model to examine the macro- and micro-level implications of expanding biofuels production in a low income and land abundant economy. For purposes of concreteness, we focus on the case of Mozambique. The gender lens is important because biofuels expansion implies rapid growth in cash/export crop production, where men tend to predominate. Food crop production, where women provide the majority of labor, will be indirectly affected *via* resource competition and exchange rate effects, which are likely to make imported foods relatively more attractive.

Previous studies examined the growth and poverty implications of alternative feedstocks and institutional structures (see Arndt, Benfica, Tarp, Thurlow, & Uaiene, 2010). In this paper, we focus on smallholder outgrower schemes and select jatropha as the example feedstock to produce biodiesel. We

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Table 1. *Labor use by gender and skill groups*

	Share of activity's total labor use (%)			
	Food crops	Cash crops	Live stock	Non farm
All labor	100.0	100.0	100.0	100.0
Male	47.4	68.8	51.9	89.2
Female	52.6	31.2	48.1	10.8
Skilled	11.4	15.2	14.8	27.0
Male	8.1	12.8	10.3	23.2
Female	3.3	2.5	4.5	3.8
Semi-skilled	12.6	14.1	14.8	24.9
Male	7.7	11.2	8.8	22.1
Female	4.9	2.9	6.0	2.8
Unskilled	76.1	70.7	70.3	48.1
Male	31.6	44.8	32.7	43.9
Female	44.5	25.8	37.7	4.2

Source: 2004/05 Mozambique Smallholder Survey (Benfica, 2006).
Notes: "Skilled" are workers who completed secondary school; "semi-skilled" workers completed primary school.

then investigate alternative gender employment intensities in feedstock production and downstream processing. To our knowledge, this is the first attempt to formally analyze the gender implications of biofuels expansion in developing countries. We start by describing the gender dimensions of agriculture in Africa with emphasis to Mozambique, before providing a rationale for a gendered analysis of biofuels expansion. The structure of the gendered CGE model is then outlined. The full model specification is included in Appendix A. Simulation results for the biofuels expansion scenarios are then presented, followed by two policy scenarios that address the constraints to increasing women's participation and benefits in biofuels production. The final section concludes.

2. GENDER AND AFRICAN AGRICULTURE

Women play a crucial role in African agriculture, which is typically a low technology, land- and labor-intensive activity. In many African countries, women make up 60–80% of the workforce in agriculture, play a significant role in food production, but have little control over resources (Mehra & Rojas, 2008). In Mozambique, previous studies indicate that, while women and men allocate similar amounts of time to crop production, women spend more time on household chores, such as childcare (Adam & Coimbra, 1996; Sousa, 1997; Arndt and Tarp, 2000). Within agriculture, women are also more responsible for food crop production, such as maize and cassava, while production responsibilities in cash crops tend to be more evenly distributed across genders (Pitcher, 1996; Waterhouse, 1997). However, men typically control cash crops and their monetary proceeds (Lastarria-Cornhiel, 1997). There are also clear gender roles in field activities, with men doing predominantly land preparation and planting, and women doing weeding and harvesting (Benfica, 2006).

Table 1 describes patterns of labor use by gender and education-based skill levels obtained from a smallholder farm survey in Mozambique (Benfica, 2006). Three key patterns emerge. First, production in all activities relies on unskilled labor, which reflects the country's skills shortage. Secondly, higher-skilled labor is used intensively in nonfarm activities and is dominated by male workers. This reflects especially low educational attainment among women. Finally, male and female labor use is fairly balanced within farm activities as a whole, but women engage more in food crop and livestock production, whereas men dominate cash/export crops.

Table 2 reports labor income and consumption shares for household groups. A third of Mozambique's population lives in urban areas. Urban households derive almost equal shares of labor income from different skill groups, but they rely heavily on male workers. Urban households have similar income patterns to households with *per capita* expenditures in the top earning quintile. Conversely, rural households earn most of their labor income from unskilled work, such as smallholder farming, and a larger-than-average share from female labor. Rural and bottom quintile households have similar income patterns, and spend a much larger share of their incomes on foods compared to higher-income and urban households. Poverty is also higher in rural rather than urban areas, even after accounting for differences in living costs.

A fifth of Mozambique's population live in households headed by women, as self-reported in the household survey. Female-headed households earn most of their income from female labor. This is expected since female-headship is often associated with absent males, possibly due to death or migration. Female-headed households are also more reliant on unskilled workers' earnings, reflecting the general scarcity of higher-skilled female labor. Food consumption shares and

Table 2. *Household labor income and expenditure patterns*

	All	Rural	Urban	Male-headed	Female-headed	Bottom quintile	Top quintile
Population (1,000)	18,302	12,431	5,871	14,549	3,753	3,661	3,660
Labor income (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Male	70.9	65.8	75.2	79.9	36.7	66.9	74.3
Female	29.1	34.2	24.8	20.1	63.3	33.1	25.7
Skilled	16.8	1.4	30.0	17.7	13.6	0.2	31.5
Semi-skilled	21.7	9.4	32.1	21.9	20.7	5.3	30.5
Unskilled	61.5	89.2	37.9	60.4	65.7	94.5	38.0
Consumption (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Foods	55.0	68.9	44.9	54.0	59.2	71.8	43.7
Nonfoods	45.0	31.1	55.1	46.0	40.8	28.2	56.3
Poverty rate (%)	54.1	55.3	51.5	51.9	62.5	n/a	n/a

Source: Engendered 2003 Social Accounting Matrix (McCool *et al.*, 2009).
Notes: "Skilled" are workers who completed secondary school; "semi-skilled" workers completed primary school. National quintiles based on *per capita* consumption. Poverty headcount rate is based on the official provincial poverty lines.

poverty rates are both significantly higher for female-headed households, which reflects their reliance on lower-paying farm employment and confirms their vulnerable status. Finally, the gender poverty gap is widest in urban areas, where male-headed households are, as a group, better endowed with skilled labor than female-headed households.

Prevailing barriers-to-entry for women in cash crops include skills deficit, technology, and limited access to, and control of, resources (i.e., land, labor and finance). This is confirmed by Mozambique's agricultural census, which finds that female-headed households typically have smaller land holdings and fewer livestock assets than male-headed households (FAO, 2005). They are more likely to own low agro-potential land and are far less likely to use chemical fertilizers or farm tools. Women also have weaker decision making power and access to nonfarm opportunities. These farm-level constraints and low education levels explain much of the heightened poverty and vulnerability that women experience in Mozambique. In our analysis we evaluate how expanding biofuels production affects poverty incidence rates by gender of the household-head.

3. BIOFUELS EXPANSION AND GENDER

The expansion of biofuels in low income countries raises many questions for policy makers. Some of the more fundamental questions relevant for the African context include: (i) will lower-income people benefit, including vulnerable groups such as women? (ii) how do these benefits differ under plantation and smallholder outgrower approaches? (iii) will biofuels threaten food security if they displace food production? (iv) should the government be concerned about the stability of world biofuel prices? and (v) what are the opportunity costs of subsidies and public investments to support the biofuels sector, such as roads and ports?

Arndt, Benfica, *et al.* (2010) assess the implications of large-scale biofuels investments for a low income African economy. They find that while biofuels production will employ unused resources (e.g., land), it will also compete over land and labor with existing food and traditional cash crops, causing some food crop displacement. Overall, however, expanding biofuels enhances economic growth and reduces poverty. The mechanisms for these favorable outcomes are a result of new foreign direct investment in biofuels production, the increased quantity of land under cultivation, and improved access to reasonably efficient feedstock production and processing technologies.[1] The degree of poverty reduction is found to depend principally on the third element—production technologies and associated institutional arrangements. Compared to capital-intensive plantations, an outgrower approach is more pro-poor since it involves greater use of unskilled labor and accrues more land rents to smallholders. Outgrower schemes are also seen to enhance local development if they generate technological spillovers to food crops.

This article is the first effort to rigorously examine the gender implications of large-scale biofuels expansion. It is typical in the African context that emerging opportunities in high value crops are taken by men, but evidence have indicated that with the same access to resources and inputs women stand to achieve similar or higher returns than men (Mehra & Rojas, 2008). This suggests that there are potential gains to be realized by substantially increasing, with the appropriate policy incentives, women's access to resources and opportunities in sectors such as biofuels. In this study, focused in the case of Mozambique, we expect outcomes to vary by gender for three reasons. First, when cash generating opportunities arise, women are often confined to traditional roles, while men assume greater control, extract most of the direct benefits, and may not maximize potential spillover effects. Secondly, as mentioned earlier, women are responsible for both income-earning activities and household chores. Therefore, if women engage in biofuels production this may incur time-use trade-offs that affect welfare in a variety of ways. Thirdly, the distribution of skills is unfavorable to women. In so far as new biofuels activities demand better skilled labor than other crops, women's participation will be constrained, especially if they must sustain their roles in other low productivity activities.

It is clear then that biofuels expansion will have particular implications for women's welfare. These will be determined by the extent of women's involvement in biofuels production and how this affects outcomes in other sectors (i.e., food/cash crops and nonfarm activities) *via* resource competition and changes in relative prices in urban and rural areas, including exchange rate effects. In our analysis, we select jatropha production under contract farming and processing under standard technologies as a case study.[2] To assess gender implications, we simulate biofuels expansion under a range of female employment-intensities. In the low participation scenario we assume that women only account for 20% of employment in the new biofuels sector, while in the high participation scenario we assume 80% female employment. We develop a gendered economywide model to estimate economic and welfare outcomes for these alternative employment scenarios.

4. GENDERED CGE MODEL OF MOZAMBIQUE

The gendered CGE model of Mozambique is built in the tradition of Arndt and Tarp (2000). These models focus on productive sectors using the definitions of productive sectors as applied by the System of National Accounts (United Nations Statistics Division, 1993). Gender differences are characterized by differing degrees of intensity of use of male and female labor across activities as presented in Table 1. More detailed descriptions of sex roles, including social reproduction and leisure activities, have been developed (see Fontana & Wood, 2000). In this application, we elect for a more parsimonious model though consideration of social reproduction and leisure is an important topic for future research.

The Mozambique CGE model employed for this analysis captures differences in employment patterns for men and women across activities (see Table 1) by identifying 56 sectors, 26 of which are farm and food processing activities.[3] Representative producers in each sector combine intermediate inputs with factors of production so as to maximize profits. The model separates factors into land, labor, and capital. Using data from recent surveys, labor is further disaggregated by gender and three education-based skill groups. Nested production functions allow producers to imperfectly substitute between factors based on their relative prices.[4] Labor is assumed to be fully-employed earning flexible wages. This captures labor constraints, which, as mentioned earlier, are most binding for higher-skilled women. This specification of factor markets means that if biofuels production uses male workers more intensively, then men's economywide wages will rise faster than women's, and producers will try to use more female labor. Land and labor is able to migrate between sectors in response to changing factor demands. By contrast, new capital is allocated across sectors according to profit-rate differentials and then, once invested, becomes immobile earning sector-specific returns.

International trade is captured in the model 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 indirect taxes). This reflects differences in domestic and foreign products and allows for two-way trade. Mozambique is a small economy and so its trade flows do not influence world prices. The real exchange rate (i.e., price index of tradable-to-non-tradable goods) adjusts to maintain a constant current account balance. This treatment of external trade and balances is an important feature of the model since large-scale biofuels expansion will have macroeconomic implications.

Section 2 shows how households' labor income patterns vary by gender (see Table 2). The model captures these differences by distributing factor incomes to households' based on their factor endowments drawn from recent survey data. Representative households are disaggregated by rural and urban areas, *per capita* expenditure quintiles, and the gender of the self-reported household head. Households save part of their income (based on fixed savings rates) and consume commodities under a linear expenditure system, which permits non-unitary income elasticities. [5] This specification allows us to measure shifts in the distribution of incomes, and to track how changes in household demand affect production and prices for non-biofuels commodities. Households also 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, a separate consumption-based micro-simulation module links each respondent in the 2002/03 household survey (INE, 2004) to their corresponding representative household group in the model. Changes in commodity prices and households' consumption spending are passed down from the CGE model to the micro-simulation module, where *per capita* consumption and standard poverty measures are recalculated.

The model's variables and parameters are calibrated to data from a social accounting matrix that captures the initial structure of Mozambique's economy in 2003 (see McCool, Thurlow, & Arndt, 2009). Parameters are then adjusted over time to reflect demographic and economic trends and the model is re-solved annually for the period 2003–15. Between periods the model is updated to reflect exogenous rates of land and labor expansion and technical change. The rate of capital accumulation is determined endogenously, with previous period investment converted into new capital stocks, which are then added to previous capital stocks after applying depreciation. In our analysis we will simulate various biofuels expansion scenarios and then compare them to a "without biofuels" baseline scenario.

5. BASELINE AND BIOFUELS EXPANSION SCENARIOS

(a) *Baseline scenario*

We first produce a baseline growth path that assumes that Mozambique's economy continues to grow during 2003–15 in line with its recent performance (i.e., 2000–07). For each year, we update the model to reflect changes in population, labor and land supply, and factor productivity. The model then endogenously determines individual sectors' growth rates and changes in employment and household incomes. The key aspect to consider here is that the baseline scenario does not include the biofuels sector and thus serves as a basis for comparison.

Since Mozambique is a land-abundant country, we assume that land supply and population grow at 2% per year, which is slower than the rate of cropped area expansion over the past decade, and is consistent with expected future trends (Thurlow, 2008). We capture rising skill intensities in the labor force by allowing the supply and productivity of skilled and semi-skilled labor to grow faster than unskilled labor. There is also unbiased technological change in the baseline scenario, with the shift parameter on the production function increasing at 3.0% per year in non-agriculture and 0.8% per year in agriculture. These parameter choices are consistent with growth accounting exercises for Mozambique (Arndt, Jones, & Tarp, 2007). Together, these assumptions produce a baseline scenario in which *per capita* GDP grows at an average of 4% per year during 2003–15.

(b) *Gendered biofuels expansion scenarios*

In the biofuels expansion scenarios, we create a dedicated sector for jatropha for biodiesel production. The farm output from the jatropha sector is used as raw material for a dedicated downstream processing sector. Beginning from an effectively zero base, we increase the amount of land allocated to jatropha feedstock production in gradual increments over the 12-year simulation horizon, eventually totaling 550,000 hectares in 2015. This is similar to the jatropha-based biodiesel scenario in Arndt, Benfica *et al.* (2010). The capital necessary for biofuel production is assumed to be entirely foreign-financed and is incremental to existing foreign investment levels assumed without biofuels. As foreign investment represents the primary fixed factor, variations in world prices for biofuels would be fully reflected in variations in returns to capital, which are entirely repatriated by assumption. Hence, the benefits to the Mozambican economy are fairly constant across a wide range of biofuel prices.

All of the biodiesel that is produced in the model is assumed to be exported. World prices for biofuels, fossil fuels, and foods are the same across scenarios. The pricing level for biofuels is assumed to be sufficient to stimulate the assumed level of biofuels investment and to cover marginal cost for all installed capital. Note that the assumption that all biofuel investment is foreign-financed is complementary to the pricing assumption.

We assume that all jatropha production is undertaken *via* smallholder outgrower schemes, which entail a significant use of smallholder farmers in a coordinated, but not fully integrated value chain. Jatropha is thus relatively labor-intensive, requiring approximately 50 farm workers for every 100 hectares planted (see Table 3). The technologies for processing

Table 3. *Biofuel production characteristics*

Jatropha production characteristics (per 100 ha)	
Land employed (ha)	100.0
Crop production (tons)	300.0
Farm workers employed (people)	48.7
Land yield (tons/ha)	3.0
Biofuel produced (l)	36,000
Processing workers employed (people)	11.8
Feedstock yield (l/ton)	120.0
Biodiesel production characteristics (per 10,000 l)	
Biofuel production (l)	10,000
Feedstock inputs (tons)	83.3
Land employed (ha)	27.8
Farm workers employed (people)	10.9
Processing workers employed (people)	3.3

Source: Authors' calculation based on Econergy (2008).

jatropha into biofuel require an additional three workers for every 10,000 l produced. These technical coefficients for jatropha-based biodiesel production are based on a detailed engineering study for Mozambique (Econergy, 2008).[6]

In order to assess the gendered effects of expanding biofuel production, we make two assumptions. First, we assume that of the total 550,000 hectares of land area expansion for jatropha production, half will come from new areas brought under cultivation, and the rest will be from displacing other crops in areas where they are currently being produced. In our view, this is the most reasonable possible assumption that can be made a priori.[7] Based on the assumed production technology in Table 3, this new land reallocation will allow Mozambique to produce 198 million liters of biodiesel per year. Expanding feedstock production will employ an additional 268,000 smallholder farmers, while downstream biofuel processing will generate a further 61,000 manufacturing jobs.[8] The model assumes that all workers are already employed and must therefore be drawn away from other sectors. Under the alternative scenarios, the model results indicate that somewhat more than half of the labor pulled into biofuel production would have been in the agricultural sector in 2015 even without biofuels investment.

Second, due to an absence of information on likely gender intensities of production of jatropha, we assume different female employment intensities in the production of the jatropha feedstock and downstream biodiesel processing activities. More specifically, we run three simulations in which the share of women in total biofuels employment is 20%, 50%, and 80%, respectively. Given the gendered structure of the economy at the baseline, this will imply that women are increasingly pulled away from other productive occupations to engage in feedstock and biodiesel production, which will have implications for economic growth, household welfare, and food security.

Before continuing, it is important to highlight that the scenarios are chosen in order to cleanly and clearly isolate the implications of biofuels investments under the assumption of relatively labor intensive production technologies. The scenarios are not policy recommendations. Pure export orientation and complete foreign-financing are chosen merely as useful extreme points. As has been emphasized, capital intensive production technologies for feedstock would have different implications. Similarly, the choice of jatropha does not suggest that this is the ideal feedstock. We choose jatropha because it has a high labor-intensity and commands substantial investor interest. However, relatively little is actually known about the agronomic properties of jatropha in the Mozambican context. As such, it is possible that other crops, such as sweet sorghum or outgrower sugarcane will eventually dominate the local industry. Nevertheless, the intuition obtained from considering the gender intensity of biofuels production using basic production coefficients based on jatropha would very likely apply to these other crops.

Finally, biofuel production requires general investment in roads, ports and other infrastructure. As Hausmann (2007) points out, this is almost surely a considerable improvement over the dedicated infrastructure investments normally associated with resource extraction. For example, a natural gas pipe serves only one function. Roads and ports, on the other hand, are non-exclusive. As a result, biofuel investments may "crowd in" other investments due to improvements in productive infrastructure, particularly for transport. On the other hand, a failure to develop sufficient complementary infrastructure would constrain biofuels production and dedication of sufficient infrastructure investment to biofuels producing areas likely implies less investment in other zones. In the modeling conducted here, we assume that existing infrastructure investment budgets accommodate the needs of the biofuels sector. The implications of this assumption for regional growth patterns (which cannot be tracked in a national model such as the one employed here) are discussed in Arndt *et al.* (2010).

(c) *Impacts on agriculture, economic growth and employment*

Table 4 presents the model's macroeconomic assumptions and simulation results. In all biofuels scenarios the amount of land allocated to feedstock production increases from 0 to 550,000 hectares during 2003–15. By assumption, half of the lands needed to produce the feedstock are those already used by other crops. Accordingly, total land supply increases by only 275,000 hectares beyond the 1.2 million hectare expansion in the baseline. The model then determines the optimal allocation of the remaining land based on crop production technologies and the relative profitability of different activities. Results indicate that, while some of the displaced lands come from food crops, it is actually the non-biofuel export crops that are most severely affected by expanding biofuels production. For example, in the baseline, land under export crops grows by 193,000 hectares, or by a cumulative 80% over the 12 year simulation period. This rate is much faster than the 24% cumulative growth rate of food crops indicating continued rapid commercialization of Mozambican agriculture in the baseline. However, in the three biofuels scenarios (i.e., Scenarios 1–3), cumulative growth in the area allocated to export crops is approximately halved to 84,000–102,000 hectares. The disproportionate decline in traditional export crops is caused by biofuels exports, which trigger a large appreciation of the real exchange rate as the value of foreign receipts rises faster than payments. The appreciated exchange rate lowers the competitiveness of non-biofuel exporters, thus compounding the effects of resource competition (i.e., land and labor displacement).

The intensity at which women are employed in biofuels production influences the composition of displaced crops. As discussed in Section 2, women are more intensively employed in food crop production. Therefore, as more women are pulled into producing biofuel feedstock, there is a larger reduction in the amount of land used for food production. Conversely, men are more heavily engaged in traditional export crops, and so as more male workers are used in biofuels production, the more negative the impact on export crops. This is also evident in Table 5, which shows impacts of biofuels expansion on sectoral GDP. Food crop's annual growth rate declines more rapidly when more women are employed in the biofuels sector. Declining food production also causes cereals prices to increase relative to other commodities, especially in more female-intensive employment scenarios.[9]

National GDP grows faster as a result of biofuels production, as new land is employed and foreign capital is injected into the Mozambican economy. This growth is primarily driven by agriculture, despite falling production in agriculture's non-biofuels subsectors. Downstream biofuels processing stimulates industrial growth, even though food processing is adversely affected by declining domestic food crop supplies. Construction spending drives the expansion of other industries, as savings and investment levels rise alongside national income. There is, however, a decline in services GDP as workers employed in the new biofuels sectors are pulled out of more labor-intensive subsectors, such as retail trade.

Table 6 reports changes in factor returns. As expected, expanding biofuels production increases demand for agricultural land and unskilled farm workers, causing their wages

Table 4. *Macroeconomic assumptions and results, 2003–15*

	Initial, 2003	Baseline scenario	Female employment scenarios			Policy scenarios	
			20% (1)	50% (2)	80% (3)	Education (4)	Extension (5)
			Average annual growth rate (%)				
Population ('000)	18,302	2.00	2.00	2.00	2.00	2.00	2.00
Labor supply ('000)	3,422	2.09	2.09	2.09	2.09	2.09	2.09
Skilled	88	3.00	3.00	3.00	3.00	3.10	3.00
Semi-skilled	416	2.50	2.50	2.50	2.50	2.71	2.50
Unskilled	2,919	2.00	2.00	2.00	2.00	1.90	2.00
			Final year values (2015) less base year values				
Land supply ('000 ha)	4,482	1,202	1,477	1,477	1,477	1,477	1,477
Food crops	4,241	1,009	843	834	825	821	818
Export crops	241	193	84	93	102	106	109
Biofuel feedstock	0	0	550	550	550	550	550
			Final year values (2015)				
Real exchange rate	100	101.5	84.6	83.9	83.0	83.0	85.3
Consumer prices	100	100.0	100.0	100.0	100.0	100.0	100.0
Cereals price index	100	128.5	134.6	136.6	138.4	139.4	132.7

Source: Mozambique CGE model results.
Notes: "Employment scenarios" are differentiated by the share of female workers in the biofuels feedstock and processing sectors; "policy scenarios" assume 80% female employment in biofuels.

Table 5. *Sectoral GDP growth results, 2003–15*

	Initial share, 2003 (%)	Baseline growth rate (%)	Deviation from baseline (%-point)				
			Female employment scenarios			Policy scenarios	
			20% (1)	50% (2)	80% (3)	Education (4)	Extension (5)
Per capita real GDP	100.00	3.95	0.24	0.27	0.28	0.38	0.39
Agriculture	25.92	1.90	1.47	1.37	1.25	1.29	1.50
Food crops	17.72	1.38	−0.08	−0.22	−0.39	−0.36	0.04
Export crops	1.50	1.48	−2.32	−2.27	−2.23	−2.15	−2.04
Biofuel feedstock	0.00	0.00	n/a	n/a	n/a	n/a	n/a
Other agriculture	6.71	3.24	−0.55	−0.65	−0.80	−0.69	−0.74
Industry	23.15	4.34	0.50	0.58	0.66	0.74	0.70
Food processing	5.46	3.78	−0.40	−0.42	−0.47	−0.40	−0.27
Biofuel processing	0.00	0.00	n/a	n/a	n/a	n/a	n/a
Other industry	17.69	4.51	0.23	0.35	0.46	0.55	0.46
Services	50.93	4.68	−0.39	−0.33	−0.29	−0.15	−0.21

Source: Mozambique CGE model results.
Notes: "Employment scenarios" are differentiated by the share of female workers in the biofuels feedstock and processing sectors; "policy scenarios" assume 80% female employment in biofuels.

and rental rates to rise. However, supplying the labor needed for downstream biofuels processing reduces average real wages for higher-skilled workers. This is because biofuels processing sectors demand less skilled labor and pay, on average, lower wages than the sectors displaced by biofuels production (i.e., *via* resource competition and reduced demand for non-biofuels exports).[10] However, when female workers are employed intensively in biofuels processing, their wages increase substantially while male workers' wages decline further. In fact, female workers' wages rise significantly even when employment in the biofuels sectors is divided evenly between men and women (i.e., Simulation 2). This reflects the shortage of female workers with at least primary school education.

Our results indicate that changing the female intensity of employment in the biofuels sectors has little effect on the magnitude of the gain in total GDP for Mozambique. However, we find that it does affect the sectoral composition of these gains, with agriculture and industry benefiting more under male- and female-intensive scenarios, respectively. This is due to different gender employment patterns across sectors (see Table 1). In our analysis we assume that these patterns are principally bound by traditional gender roles and other non-economic factors, implying that there is only limited substitutability between male and female workers. If, on the other hand, gender roles were more mutable, then sectoral differences in our model results are less pronounced.[11] In this case,

Table 6. *Factor income results, 2003–15*

	Annual wage, 2003 (US$)	Baseline growth rate (%)	Deviation from baseline (%-point)				
			Female employment scenarios			Policy scenarios	
			20% (1)	50% (2)	80% (3)	Education (4)	Extension (5)
Labor wages (US$)	737	2.40	0.06	0.03	−0.01	0.08	0.29
Skilled labor	4,835	1.48	−0.27	−0.47	−0.67	−0.82	−0.26
Male	5,175	1.44	−0.24	−0.63	−1.05	−1.00	−0.64
Female	3,637	1.68	−0.38	0.28	0.97	0.08	1.39
Semi-skilled labor	1,316	1.35	−0.06	−0.27	−0.49	−0.70	−0.09
Male	1,423	1.15	0.00	−0.59	−1.29	−1.05	−0.88
Female	986	2.22	−0.30	0.92	2.13	0.60	2.50
Unskilled labor	532	2.71	0.19	0.25	0.31	0.47	0.55
Male	621	1.15	0.36	−0.15	−0.71	−0.78	−0.31
Female	425	4.95	−0.02	0.71	1.38	1.78	1.48
Land rental rates	–	5.99	1.37	1.21	0.94	1.15	0.78
Domestic capital returns	–	−2.23	−0.47	−0.74	−1.02	−1.05	−0.69

Source: Mozambique CGE model results.
Notes: "Employment scenarios" are differentiated by the share of female workers in the biofuels feedstock and processing sectors; "policy scenarios" assume 80% female employment in biofuels; "domestic capital" excludes the returns to foreign investment in the biofuels sectors.

men more readily replace women in producing foods, and women more easily engage in traditional export crop production. However, while such substitutability may emerge over time, it does not reflect prevailing conditions in Mozambique, as evidenced by current employment patterns and gender wage differentials. Our results are thus consistent with Mozambique's current situation, and they suggest that raising the female-intensity of employment in the new biofuels sectors would increase returns to female labor and thus narrow the gender wage gap.

(d) *Household incomes and poverty effects*

One of the strengths of CGE models is their ability to translate changes in factor incomes into shifts in the level and distribution of household incomes. In our model this is based on households' factor endowments and income sources (see Table 2). Table 7 presents changes in equivalent variation for household groupings, which is a measure of welfare that accounts for changes in prices. Results indicate that all household groups benefit from expanding biofuels production. Rural households benefit from increased returns to land and unskilled labor, and since rural areas are typically poorer in Mozambique, welfare improves in the lower expenditure quintiles. Urban households also benefit from new employment opportunities and higher wages for higher-skilled labor, and despite higher cereals and food prices.

The CGE model is linked to a microsimulation module that calculates changing poverty rates based on detailed consumption data from the household survey (see Section 4). Under the baseline scenario, the national poverty headcount rate falls from 54.1% in 2003 to 30.9% by 2015. As mentioned above, expanding biofuels production increases consumption and spending and welfare for households in the lower expenditure quintiles and this translates into an even lower national incidence of poverty. For example, when employment in the new biofuels sectors is evenly divided between men and women (i.e., Simulation 2), the national poverty rate falls by an additional 4.7 percentage points to 26.3% in 2015. Large-scale biofuels investments thus have the potential to substantially reduce poverty in Mozambique (see Table 8).

National poverty declines regardless of how intensively women are employed in the new biofuels sectors. However, the distribution of incomes varies. Female-headed household benefit most when more women are employed in biofuels production, since this leads to higher returns to both their labor and land. Conversely, increasing the female employment share reduces the benefits for male-headed households. However, increasing women's participation in biofuels production does not lead to larger reductions in national poverty, despite the higher incidence of poverty for female-headed households. Two factors explain the outcome. First, cereals and food prices increase by more in the more female-intensive scenarios, thus reducing real incomes for poorer households for whom food is an important part of the consumption basket (see Table 2). Secondly, poorer household are more likely to be endowed with semi-skilled male workers than similarly skilled female workers. Thus increased wages for semi-skilled female labor benefits households in the middle of the income distribution, rather than those below the poverty line. Similarly, urban areas are more endowed than rural areas with scarce semi-skilled female labor, and so it is urban households, particularly those headed by women, that benefit from the large increase wages for female workers.

In summary, expanding biofuels production in Mozambique accelerates economic growth and reduces poverty. These national-level outcomes are not greatly influenced by how intensively women are employed in the new biofuels sectors. However, if current gender roles persist, then increasing the number of women employed in biofuels production causes food crop production to contract by more, while involving more men will have more adverse effects on export crops. Concerns over potential trade-offs between biofuels and food crops are thus more justified when women are engaged in biofuels production, even though this would enhance the benefits for generally poorer female-headed households. Indeed, it is the displacement of food crops and the shortage of higher-skilled female labor that constrains the poverty reducing effects of

Table 7. *Per capita welfare (equivalent variation) results, 2003–15*

	Consumption, 2003 (US$)	Baseline growth rate (%)	Deviation from baseline (%-point)				
			Female employment scenarios			Policy scenarios	
			20% (1)	50% (2)	80% (3)	Education (4)	Extension (5)
All households	135.8	3.39	0.48	0.47	0.44	0.51	0.59
Male-headed	137.5	3.23	0.52	0.41	0.29	0.36	0.44
Female-headed	129.2	4.04	0.35	0.68	0.99	1.04	1.10
Rural areas	84.5	3.40	0.62	0.62	0.60	0.69	0.73
Male-headed	84.4	3.21	0.66	0.59	0.47	0.56	0.62
Female-headed	85.0	4.12	0.45	0.74	1.01	1.13	1.12
Urban areas	244.6	3.35	0.35	0.32	0.28	0.32	0.45
Male-headed	255.0	3.21	0.38	0.25	0.09	0.15	0.28
Female-headed	209.1	3.92	0.25	0.59	0.93	0.91	1.06
Quintile 1 (low)	49.3	3.20	0.68	0.60	0.48	0.58	0.65
Quintile 2	61.6	3.10	0.59	0.56	0.50	0.56	0.67
Quintile 3	81.7	3.08	0.53	0.51	0.46	0.54	0.63
Quintile 4	115.7	3.30	0.48	0.51	0.52	0.59	0.67
Quintile 5 (high)	370.9	3.55	0.41	0.39	0.36	0.42	0.51

Source: Mozambique CGE model results.
Notes: Initial consumption is in 2003 dollars unadjusted for purchasing power parity; "employment scenarios" are differentiated by the share of female workers in the biofuels feedstock and processing sectors; "policy scenarios" assume 80% female employment in biofuels.

involving more women in biofuels production. In Section 6 we consider two policies to address these constraints.

6. POLICY SCENARIOS

(a) *Improving female workers' education levels*

Although Mozambique has made significant strides toward achieving universal primary school enrolment, there is still a lack of skilled labor in the economy. Moreover, the shortage of skilled female workers is particularly pronounced. For example, only a quarter of workers with at least primary school education are women, even though women comprise almost half of the total workforce. Thus, while school enrollment for girls is improving in Mozambique, there still exists a substantial skills gap between men and women in the workplace. This was apparent in our results by the large increase in wages needed to attract skilled women into the biofuels sector. Moreover, since women's educational attainment is lowest in poor households, the benefits of higher wages did not translate into higher poverty reduction when more women were employed in producing biofuels. Therefore, in our first policy scenario we start from Simulation 3 (i.e., an 80% female employment share in biofuels) and then simulate an increase in the educational attainment of female workers. More specifically, we assume that a quarter of semiskilled and skilled workers needed to produce biofuels come from an upgrading of unskilled workers' education to at least primary school levels. Similarly, productivity for the remaining unskilled workers is assumed to increase by 3% over 2003–15, reflecting a small improvement in these workers' education levels.

Table 8. *Poverty results, 2003–15*

	Baseline scenario poverty rates (%)		Deviation from baseline, 2015 (%-point)				
	2003	2015	Female employment share			Policy scenarios	
			20% (1)	50% (2)	80% (3)	Education (4)	Extension (5)
National	54.07	30.94	−4.62	−4.66	−4.53	−5.13	−5.12
Male-headed	51.90	30.46	−4.56	−4.05	−3.21	−3.83	−3.92
Female-headed	62.46	32.82	−4.88	−7.03	−9.67	−10.15	−9.76
Rural areas	55.29	30.22	−5.27	−5.22	−4.84	−5.68	−5.06
Male-headed	53.47	30.10	−4.96	−4.67	−3.91	−4.70	−4.24
Female-headed	62.85	30.74	−6.58	−7.52	−8.70	−9.75	−8.45
Urban areas	51.47	32.46	−3.25	−3.48	−3.87	−3.96	−5.25
Male-headed	48.44	31.25	−3.68	−2.69	−1.64	−1.93	−3.23
Female-headed	61.76	36.56	−1.82	−6.14	−11.41	−10.88	−12.12

Source: Mozambique CGE model results.
Notes: Poverty rates based on gender of the self-reported household-head; "employment scenarios" are differentiated by the share of female workers in the biofuels feedstock and processing sectors; "policy scenarios" assume 80% female employment in biofuels.

Table 4 shows the assumptions of the Education scenario (i.e., Simulation 4), which should be compared to the results of Simulation 3. The growth rate of skilled and semiskilled labor is higher than in the other scenarios, while the supply of unskilled labor is smaller. This scenario is equivalent to having 10,400 and 1,100 more workers with primary and secondary schooling by 2015, respectively. This reduces the upward pressure on female workers' wages (see Table 6). For example, semi-skilled female workers' wages increased by 2.1% per year in Simulation 3 but by only 0.6% in the Education scenario. The net effect is still a rise in average wages, as more women benefit from the skills premium earned by higher educated workers.

Increasing education levels for women improves the welfare of both male- and female-headed households, since both benefit from higher average wages and national income. Poorer rural households benefit the most, since this is where skills are currently most lacking. Improved welfare for household in lower expenditure quintiles translates in larger decline in national poverty in the Education scenario (i.e., by 0.6 percentage points relative to Simulation 3). The previously strong bias in welfare improvements toward urban female-headed households is now lessened, with the benefits of higher skilled wages more evenly distributed across quintiles and rural and urban areas.

However, improving education levels encourages more women to migrate into nonfarm activities. This further reduces the amount of land allocated to food crop production, and increases cereals prices and wages for unskilled labor (see Tables 4 and 6). This is only partly offset by having more productive unskilled workers, such that the decline in food crop production remains virtually unchanged (see Table 5). Thus, while raising female workers' education levels ensures that poorer households are able to benefit from female participation in biofuels production, it does not address concerns about displaced food production.

(b) *Enhancing the productivity of food production*

As mentioned in Section 3, Mozambican agriculture depends heavily on small-scale farmers producing mainly for subsistence. These farmers employ rudimentary technologies and achieve low crop yields, despite Mozambique's considerable agro-ecological potential. There is therefore considerable scope for enhancing farm productivity in Mozambique through, for example, investments in agricultural research and extension (see Thurlow, 2008). Moreover, there is also evidence that farmers' engagement in export outgrower schemes generates positive spillovers for food crops (see Arndt, Benfica, *et al., 2010*). Raising food crop yields may prove important for the successful establishment of a biofuels industry in Mozambique given the perceived trade-off between food security and biofuels objectives. This is evident in our results, which showed declining food production as a result of biofuels investments. Therefore, in our second policy scenario we again assume that 80% of biofuels jobs are held by women (i.e., Simulation 3), and then simulate an increase in the productivity of food crop production by 6% over 2003–15. This is a modest improvement in yields compared to the large yield gaps identified by national agricultural research institutes in Mozambique (Thurlow, 2008).

Table 5 shows production results for the Extension scenario (i.e., Simulation 5), which should be compared to those of Simulation 3. Raising food crop yields by 6% negates the decline in food crop GDP, although it does not return production to baseline growth rates. Cereals prices increase by less in the Extension scenario and food processing is less adversely affected by declining domestic food crop supplies. Together this generates faster overall GDP growth. Household welfare in both rural and urban areas improves due to higher agricultural incomes and/or lower food prices (see Table 7). Poverty declines for all household groups and the benefits of enhanced agricultural productivity and lower food prices are more evenly distributed across male- and female-headed households. Therefore, only slightly enhanced food crop yields are sufficient to offset declining food production, even if women are more intensively engaged in producing biofuels.

7. CONCLUSIONS

An expansion of biofuels production is already underway in land abundant African countries and is likely to accelerate over the next decade. Previous studies examined the growth and poverty implications of different feedstocks and institutional arrangements in producing biofuels. In this paper we investigated whether there are any trade-offs from increasing the participation of women in biofuels production under the assumption of labor intensive feedstock production technologies. For purposes of concreteness, we focus on the case of Mozambique. Engaging female labor may help address the pronounced poverty among female-headed households in Mozambique, especially in rural areas.

We developed a gendered dynamic CGE model of Mozambique linked to a survey-based micro-simulation module. We used the model to evaluate different female employment intensities in biofuels production. Results indicate that changing the share of women working in biofuels does not greatly influence the overall gain in GDP. It does, however, alter the distribution of these gains. Increasing women's participation heightens the trade-off between biofuels and food availability, since women are typically responsible for food production. This leads to higher food prices. Moreover, a shortage of skilled female labor implies that wages for these workers increase substantially. Since poorer households are often net buyers of food and are almost always less endowed with skilled female labor, the impact of biofuels expansion on poverty is somewhat less pronounced when female labor is used intensively in biofuels production. Thus, while biofuels expansion generates economic growth and poverty reduction, there are constraints that limit the benefits from increasing women's participations in these new sectors.

We also simulated two policies to address the constraints to female participation in biofuels. Increasing the number of years of schooling for unskilled female workers was found to enhance the gains in economic growth from biofuels, while also allowing greater participation of the poor in skill-intensive biofuels production. Improving education levels did not, however, address the displacement of food production. In the second policy scenario we introduced a modest 6% increase in food crop productivity over 12 years. This was sufficient to offset the decline food production experienced in the biofuels expansion scenarios. Moreover, higher agricultural revenues and lower food prices extended the benefits of biofuels investments to poorer households. We therefore conclude that biofuels investments provide an opportunity to significantly reduce poverty in Mozambique, especially when combined with policies to raise agricultural productivity and the education levels of female workers.

NOTES

1. Similar investments in other sectors, such as textiles, would also lead to favorable growth and poverty outcomes assuming the products can be sold competitively on world markets. However, foreign investor interest in textiles or other labor-intensive manufacturing sectors in Africa has been tepid at best. In more land-abundant countries, investor interest is strongly oriented toward agriculture (and biofuels) compared to nearly any other labor-intensive sector.

2. Jatropha can be produced under plantation arrangements. The relative merits of institutional arrangements for biofuels production are discussed in Arndt, Benfica, et al. (2010), Arndt, Msangi, et al. (2010). Here, we focus on outgrower arrangements as it has more salient poverty and gender implications.

3. Tables A1–A3 in Appendix A present the model's variables, equations and disaggregation, respectively.

4. In our nested factor demand system, we assume that producers can more easily switch between genders than they can between skill categories. Substitution elasticities between skill categories are assumed to be 0.30, while they are 0.75 between male and female workers within each skill category.

5. Production and trade elasticities are from Dimaranan (2006). Income elasticities are econometrically-estimated using the 2002/03 household survey (INE, 2004).

6. Technical coefficients for jatropha are inherently uncertain due to a lack of experience with the crop in Africa in general and Mozambique in particular. Uaiene and Arndt (2009) consider jatropha production potential. In addition, the coefficients employed are similar to those developed by Felix et al. (2010) for other feedstocks that require significant labor input.

7. Due to the low density of complementary infrastructure in Mozambique such as roads, railways, water, and electricity, there is pressure for land near areas where that infrastructure exists. The more desirable plots of land that are relatively near complementary infrastructure are, in many cases, currently occupied by smallholder farming communities applying extensive farming techniques. It is, in our view, highly improbable that large-scale expansion of biofuels could take place without a considerable degree of land displacement.

8. Our employment estimates differ slightly from those in Arndt *et al.* (2010) due to updated technical coefficients.

9. The consumer price index is chosen as the numeraire in the model and therefore remains fixed in all scenarios. Changes in the cereals price index therefore reflect real price changes.

10. Wages in existing sectors and the new biofuels sectors are based on INE (2004) and Econergy (2008), respectively.

11. Setting the substitution elasticity between male and female workers of each skill category at 2.0 instead of 0.5 produces similar outcomes for each gender and for food and export crop production.

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APPENDIX A. MODEL SPECIFICATION

See Tables A1–A3.

Table A1. *Model indices, variables and parameters*

Indices			
c	Commodities and activities	h	Representative households
f	Factors (land, labor and capital)	t	Time periods
Exogenous parameters (Greek characters)			
α^p	Production function shift parameter	θ^v	Value-added share of gross output
α^q	Import function shift parameter	π	Foreign savings growth rate
α^t	Export function shift parameter	ρ^p	Production function substitution elasticity
β	Household marginal budget share	ρ^q	Import function substitution elasticity
γ	Non-monetary consumption quantity	ρ^t	Export function substitution elasticity
δ^p	Production function share parameter	σ	Rate of technical change
δ^q	Import function share parameter	τ	Foreign consumption growth rate
δ^t	Export function share parameter	v	Capital depreciation rate
ε	Land and labor supply growth rate	φ	Population growth rate
θ^i	Intermediate share of gross output	ω	Factor income distribution shares
Exogenous parameters (Latin characters)			
ca	Intermediate input coefficients	*pwm*	World import price
cab	Current account balance	*qfs*	Total factor supply
cd	Domestic transaction cost coefficients	*qgov*	Base government consumption quantity
ce	Export transaction cost coefficients	*qinv*	Base investment demand quantity
ci	Capital price index weights	*rf*	Factor foreign remittance rate
cm	Import transaction cost coefficients	*sh*	Marginal propensity to save
cpi	Consumer price index	*tf*	Factor direct tax rate
cw	Consumer price index weights	*th*	Personal direct tax rate
ga	Government consumption adjustment factor	*tm*	Import tariff rate
gh	*Per capita* transfer from government	*tq*	Sales tax rate
pop	Household population	*wh*	Net transfer from rest of world
pwe	World export price		
Endogenous variables			
AR	Average capital rental rate	*QG*	Government consumption quantity
FS	Fiscal surplus (deficit)	*QH*	Household consumption quantity
IA	Investment demand adjustment factor	*QI*	Investment demand quantity
PA	Activity output price	*QK*	New capital stock quantity
PD	Domestic supply price with margin	*QM*	Import quantity
PE	Export price	*QN*	Aggregate intermediate input quantity
PM	Import price	*QQ*	Composite supply quantity
PN	Aggregate intermediate input price	*QT*	Transaction cost demand quantity
PQ	Composite supply price	*QV*	Composite value-added quantity
PS	Domestic supply price without margin	*WD*	Sector distortion in factor return
PV	Composite value-added price	*WF*	Economywide factor return
QA	Activity output quantity	*YF*	Total factor income
QD	Domestic supply quantity	*YG*	Total government revenues
QE	Export quantity	*YH*	Total household income
QF	Factor demand quantity	*X*	Exchange rate

Table A2. *Model equations*

Prices

$$PM_{ct} = pwm_c \cdot (1 + tm_c) \cdot X + \sum_{c'} PQ_{c't} \cdot cm_{c'c} \tag{1}$$

$$PE_{ct} = pwe_c \cdot X_t - \sum_{c'} PQ_{c't} \cdot ce_{c'c} \tag{2}$$

$$PD_{ct} = PS_{ct} + \sum_{c'} PQ_{c't} \cdot cd_{c'c} \tag{3}$$

$$PQ_{ct} \cdot (1 - tq_c) \cdot QQ_{ct} = PD_{ct} \cdot QD_{ct} + PM_{ct} \cdot QM_{ct} \tag{4}$$

$$PX_{ct} \cdot QX_{ct} = PS_{ct} \cdot QD_{ct} + PE_{ct} \cdot QE_{ct} \tag{5}$$

$$PN_{ct} = \sum_{c'} PQ_{c't} \cdot c\alpha_{c'c} \tag{6}$$

$$PA_{ct} \cdot QA_{ct} = PV_{ct} \cdot QV_{ct} + PN_{ct} \cdot QN_{ct} \tag{7}$$

$$cpi = \sum cw_c \cdot PQ_{ct} \tag{8}$$

Production and trade

$$QV_{ct} = \alpha^p_{ct} \cdot \sum_f (\delta^p_{fc} \cdot QF_{fct}^{-\rho^p_f})^{-1/\rho^p_f} \tag{9}$$

$$WF_{ft} \cdot WD_{fct} = PV_{ct} \cdot QV_{ct} \cdot \sum_{f'} (\delta^p_{f'c} \cdot QF_{f'ct}^{-\rho^p_c})^{-1} \cdot \delta^p_c \dot{Q} F_{fct}^{-\rho^p_c - 1} \tag{10}$$

$$QN_{ct} = \theta^i_c \cdot QA_{ct} \tag{11}$$

$$QV_{ct} = \theta^v_c \cdot QA_{ct} \tag{12}$$

$$QA_{ct} = \alpha^t_c \cdot (\delta^t_c \cdot QE_{ct}^{\rho^t_c} + (1 - \rho^t_c) \cdot QD_{ct}^{-\rho^t_c})^{1/\rho^t_c} \tag{13}$$

$$\frac{QE_{ct}}{QD_{ct}} = \left(\frac{PE_{ct}}{PS_{ct}} \cdot \frac{(1 - \delta^t_c)}{\delta^t_c}\right)^{1/(\rho^t_c - 1)} \tag{14}$$

$$QQ_{ct} = \alpha^q_c \cdot (\delta^q_c \cdot QM_{ct}^{-\rho^q_c} + (1 - \delta^q_c) \cdot QD_{ct}^{-\rho^q_c})^{-1/\rho^t_c} \tag{16}$$

$$\frac{QM_{ct}}{QD_{ct}} = \left(\frac{PD_{ct}}{PM_{ct}} \cdot \frac{(1 - \delta^q_c)}{\delta^q_c}\right)^{1/(1 + \rho^t_c)} \tag{17}$$

Table A2—(*continued*)

$$QT_{ct} = \sum_{c'} (cd_{cc'\cdot QD_{c't}} + cm_{cc'} \cdot QM_{c't} + ce_{cc'} \cdot QE_{c't}) \tag{18}$$

Income snd expenditures

$$YF_{ft} = \sum_{c} WF_{ft} \cdot WD_{fct} \cdot QF_{fct} \tag{19}$$

$$YH_{ht} = \sum_{f} \omega_{hf} \cdot (1 - tf_f)(1 - rf_f) \cdot YF_{ft} + gh_h \cdot pop_{ht} \cdot cpi + wh_h \cdot X \tag{20}$$

$$PQ_{ct} \cdot QH_{cht} = PQ_{ct} \cdot \gamma_{ch} + \beta_{ch} \cdot \left((1 - sh_h) \cdot (1 - th_h) \cdot YH_{ht} - \sum_{c'} PQ_{ct'} \cdot \gamma_{c'h} \right) \tag{21}$$

$$QI_{ct} = IA_t \cdot qinv_c \tag{22}$$

$$QG_{ct} = g\alpha_t \cdot qgov_c \tag{23}$$

$$YG_t = \sum_{h} th_h \cdot YH_{ht} + \sum_{f} tf_f \cdot YF_{ft} + \sum_{c} (tm_c \cdot pwm_c \cdot QM_{ct} \cdot X + tq_c \cdot PQ_{ct} \cdot QQ_{ct}) \tag{24}$$

Equilibrium conditions

$$qfs_{ft} = \sum_{c} QF_{fct} \tag{25}$$

$$QQ_{ct} = \sum_{c'} c\alpha_{cc'} \cdot QN_{c't} + \sum_{h} QH_{cht} + QG_{ct} + QI_{ct} + QT_{ct} \tag{26}$$

$$\sum_{c} pwm_c \cdot QM_{ct} + \sum_{f} (1 - tf_f) \cdot rf_f \cdot YF_{ft} \cdot X_t^{-1} = \sum_{c} pwe_c \cdot QE_{ct} + \sum_{h} wh_h + cab_t \tag{27}$$

$$YG_t = \sum_{c} PQ_{ct} \cdot_{ct} + \sum_{h} gh_h \cdot pop_{ht} \cdot cpi + FS_t \tag{28}$$

$$\sum_{h} sh_h \cdot (1 - th_h) \cdot YH_{ht} + FS_t + c\alpha b_t \cdot X_t = \sum_{c} PQ_{ct} \cdot QI_{ct} \tag{29}$$

Capital accumulation and allocation

$$AR_{ft} = \frac{YF_{ft}}{qfs_{ft}} \tag{30}$$

$$QK_{fct} \cdot \left(\sum_{c'} PQ_{c't} \cdot ci_{c'} \right) = \left(\frac{QF_{fct}}{qfs_{ft}} \cdot \frac{WF_{ft} \cdot WD_{fct}}{AR_{ft}} \right) \cdot \left(\sum_{c'} PQ_{c't} \cdot QI_{c't} \right) \tag{31}$$

(*continued on next page*)

Table A2—(*continued*)

$$QF_{fct+1} = QF_{fct} \cdot (1 - v) + QK_{fct} \tag{32}$$

Land and labor supply, technical change , population growth,and other dynamic updates

$$qfs_{ft+1} = qfs_{ft} \cdot (1 + \varepsilon_f) \tag{33}$$

$$\alpha^p_{ct+1} = \alpha^p_{ct} \cdot (1 + \sigma_c) \tag{34}$$

$$pop_{ht+1} = pop_{ht} \cdot (1 + \phi_h) \tag{35}$$

$$g\alpha_{t+1} = g\alpha_t \cdot (1 + \tau) \tag{36}$$

$$c\alpha b_{t+1} = c\alpha b_t(1 + \pi) \tag{37}$$

Table A3. *Model activities, factors and households*

Activities	Maize; sorghum; rice; wheat; cassava; other roots; beans; vegetables; fruits; groundnuts; cashews; tea; tobacco; sugarcane; cotton; jatropha; other crops; cattle; poultry; other livestock; forestry; fisheries; mining; meat & dairy; other foods; milling; sugar refining; beverages; tobacco processing; textiles; wood products; petroleum; diesel; biodiesel; other fuels; chemicals; non-metals; metals ; machinery; transport equipment; furniture & other manufacturing; electricity; water; construction; trade; hotels & catering; transport; communications; finance; business; public services; other services
Factors	Skilled male/female labor; semi-skilled male/female labor; unskilled male/female labor; land; capital
Households	Rural/urban *per capita* expenditure quintiles by male/female household-head