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Biofuels, poverty, and growth: a computable general equilibrium analysis of Mozambique

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ABSTRACT. This paper assesses the implications of large-scale investments in biofuels for growth and income distribution. We find that biofuels investment enhances growth and poverty reduction despite some displacement of food crops by biofuels. Overall, the biofuel investment trajectory analyzed increases Mozambique's annual economic growth by 0.6 percentage points and reduces the incidence of poverty by about 6 percentage points over a 12-year phase-in period. Benefits depend on production technology. An outgrower approach to producing biofuels is more pro-poor, due to the greater use of unskilled labor and accrual of land rents to smallholders, compared with the more capital-intensive plantation approach. Moreover, the benefits of outgrower schemes are enhanced if they result in technology spillovers to other crops. These results should not be taken as a green light for unrestrained biofuels development. Rather, they indicate that a carefully designed and managed biofuels policy holds the potential for substantial gains.

1. Introduction

Mozambique is a land-abundant country, with only one-sixth of its 30 million hectares of arable land currently under cultivation. The land remains state owned, and use rights must be requested from the state. As a country with significant untapped agricultural potential, Mozambique has captured the interest of biofuel investors. As of mid-2008, the government had pending use-rights requests for more than 12 million hectares, with nearly all of the requests relating to biofuels. The specific crops considered were sugarcane and sweet sorghum for the production of ethanol, and jatropha for the production of biodiesel.

Biofuel production in Mozambique is considered profitable without subsidies at world oil prices above US$70 per barrel (Econergy, 2008). Interest in biofuel production thus reflects in part the surge in world oil prices culminating in the first half of 2008. Policies to raise biofuel use in European countries, derived from desires to reduce greenhouse gas (GHG) emissions, also drive investor interest largely independent of the price of oil. Mozambique's government views biofuels as a way of raising economic growth and exports, and encouraging rural development and poverty reduction. However, this raises a series of policy questions, including (i) will lower-income people benefit from large-scale biofuel investments; (ii) what are the implications of producing on a plantation basis compared to contracting smallholder farmers; (iii) what is the demand for complementary investments, such as roads and ports; (iv) are there potential threats to food security if biofuels displace food production; (v) should the government be concerned about the stability of world biofuel prices; and (vi) what are the environmental and particularly GHG emissions implications of large-scale biofuels production?

The decline in oil prices in the second half of 2008 from $150 per barrel to less than $40 per barrel highlights the issue of price stability. Nevertheless, as noted earlier, oil prices are not the only driver of biofuels demand. In fact, larger and more serious biofuels investors in Mozambique are targeting European markets where demand is driven by mandates for biofuels use. This highlights the final question listed above relating to the CO_2 emissions reductions associated with biofuels. Large-scale biofuels investments are possible independent of oil prices if Mozambican biofuels result in net reductions in CO_2 emissions relative to fossil fuels.

This paper considers an analysis of biofuels investments in Mozambique as worthwhile despite the dramatic oil price declines. This is true for two reasons. First, in the medium term and without substantial efforts to reduce global GHG emissions, oil prices are likely to rise. For example, futures prices for crude oil on the New York Mercantile Exchange rise continuously until 2017, which is the last year for which quotes are available (NYMEX, 2009). Futures prices pass the $70 mark in 2011. Others project even higher prices. The *World Energy Outlook 2008*, published by the International Energy Agency, projects that real oil prices will average $100 per barrel during 2008–2015 with increases thereafter (IEA, 2008). Given the delays in producing biofuels, the relevant prices for investors are expected prices about 2–3 years from now and then looking forward from there. These prices are favorable to biofuels production.

Second, without a prolonged global economic contraction on the order of the Great Depression, the main reason for relatively low oil prices persisting well into the future would be a concerted global effort to reduce GHG emissions. As highlighted later in the conclusion, the GHG balance with respect to Mozambican biofuels is a crucial topic for further research, especially regarding land use. Nevertheless, if properly managed, Mozambican biofuels have the potential to reduce net GHG emissions relative to fossil fuels. It is likely then that Mozambican biofuels could find profitable markets in an environment where CO_2 emissions are priced.

In summary, while a global economic contraction may be associated with a lull in investment interest in Mozambican biofuels, the likelihood is that substantial interest in biofuels production in Mozambique will revive in the near term and persist well into the future. Any temporary lull in investor interest potentially provides an opportunity to properly design biofuels policy in order to maximize potential gains and avoid potential pitfalls.

Our analysis estimates the impact of large-scale biofuel investments on economic growth and income distribution using a dynamic computable general equilibrium (CGE) model. We also compare plantation and outgrower approaches to producing biofuels. Finally, we consider the relationship between food crops and biofuels. Four sections follow this introduction. First, information on the Mozambican country context is presented, followed by a brief review of the biofuel-related literature. The modeling framework and results are then presented. A final section concludes and discusses policy implications and directions for future research. We find that biofuels are potentially strong contributors to economic growth and poverty reduction. These findings highlight the need for a future research agenda to realize the gains and avoid pitfalls.

2. Growth, agriculture, and poverty in Mozambique

Mozambique has made large strides over the past 15 years, following the conclusion of the civil war in 1994. For example, recent *Africa Development Indicators* 2007 (World Bank, 2007) listed Mozambique as the fastest growing diversified African economy. The ADI reports an average GDP growth rate during 1996–2005 of 8.3 per cent per year, only exceeded by three oil-exporting countries: Equatorial Guinea, Chad, and Angola. Agriculture has been a contributor to this growth with the share of the sector in GDP declining only slightly over the period to about 25 per cent. Household survey data indicate that the national poverty headcount fell from 69 to 54 per cent during 1997–2003. Detailed analysis of the distribution of income growth indicates that growth during 1997–2003 was pro-poor on a broad definition (poverty declined) but not pro-poor on a more restricted criterion because the distribution of income deteriorated mildly (Arndt *et al.*, 2006).

While Mozambique's situation has improved over the past 15 years, it remains sobering, especially in rural areas where 70 per cent of the total population resides. About half of the rural inhabitants are 'absolutely poor', meaning that they have difficulty acquiring basic necessities, such as sufficient food for meeting caloric requirements (Arndt and Simler, 2007). Rural dwellers, especially the poor, depend heavily on crop agriculture for their incomes. However, crop technologies are rudimentary and agricultural value-added remains concentrated in cassava, maize, and beans. Only a small minority of rural households use improved seeds, fertilizers, and pesticides (Uaiene, 2008). While urban centers are more diverse, agriculture remains the largest employment sector for urban dwellers. Thus, despite being a key economic sector, agriculture remains underdeveloped, with adverse consequences for both rural and urban populations.

Widespread rural poverty does not stem from a lack of agricultural potential. In contrast, agricultural conditions in Mozambique are generally favorable (Diao *et al.*, 2007). Vast tracts of high-quality land remain unexploited. Water resources, in the form of multiple rivers, are also abundant and underexploited. Furthermore, the country's long coastline and multiple harbors open towards the dynamic markets of Asia and into expanding regional markets. Given such potential, a number of explanations exist for the underdevelopment of agriculture, including protracted civil war, limited labor availability within a land-abundant country, and inadequate investments in agricultural technologies and rural infrastructure. Private (foreign) investments in biofuels may thus provide an opportunity to exploit available resources and increase the contribution of agriculture to exports and economic growth.

Mozambican agriculture can be divided into two parts. On the one hand, there exists a large and mainly subsistence-oriented sector focused on food crop production. This sector, which represents about 90 per cent of agricultural value added, uses low input technology and is subject to high volatility. Technology is land-extensive with up to 20 ha in fallow for every hectare cultivated. Purchased input use is practically nil, except when smallholders are involved in outgrower schemes for the production of cash crops. On the other hand, there is a small emergent commercial sector driven by external investments. Despite growth, the commercial sector's small size has implied only a small contribution to overall growth and poverty reduction.

Investments in commercial agriculture have occurred through two kinds of institutional arrangements. First, commercial tobacco and cotton farmers have successfully established vertically coordinated arrangements with smallholders. Beyond its immediate benefits to smallholders (i.e., access to inputs and income from sale of cash crops), evidence suggests the existence of technology spillovers, where farmers in outgrower schemes (and their neighbors) adopt improved technologies for other crops (Strasberg, 1997; Benfica, 2006; Uaiene, 2008). For example, using a stochastic frontier approach, Uaiene (2008) finds that growing tobacco or cotton raises overall farm efficiency. Strasberg (1997) and Benfica (2006) document expanded input use on food crops by cash crop farmers involved in outgrower schemes.

The second production arrangement is on a plantation basis, as is seen with sugarcane. Plantation workers have typically fared better than subsistence-oriented farmers. However, the plantation approach has not been associated with technology spillovers and has failed to generate many jobs for farm laborers. Thus, while biofuels represent investments on a larger scale than existing traditional exports, the institutional arrangement of these new investments, including the associated production technology vectors and spillovers, will have strong implications for the character of growth. As such, we examine biofuel investments under both of the institutional structures.

3. Literature review

As discussed above, medium-term prospects for biofuel production remain strong despite the current oil price decline. However, the implications of continued growth in biofuels are less clear. Optimists, such as Ricardo Hausmann, Director of the Center for International Development at Harvard University, foresee a world in which biofuels blunt the monopoly power of OPEC, thus leading to a stabilization of world fuel prices at approximately the marginal cost of biofuel production (Hausmann, 2007). Hausmann also views biofuels as being net positive for growth and development, particularly in Africa and Latin America, due to the large land endowments of these continents. Compared with the natural resource-extractive industries that often dominate investment, especially in Africa, biofuel production technologies tend to be more labor intensive and hence more pro-poor. In addition, biofuel production requires general investment in roads and port infrastructure, as opposed to the dedicated investments normally associated with resource extraction. As a result, biofuel investments may 'crowd in' other investments due to improvements in productive infrastructure, particularly for transport.

Others, such as Oxfam International (2007), are less sanguine. They stress rising food prices, and concomitant aggravation of poverty, particularly urban poverty, associated with biofuel production. In addition, while recognizing the potential of biofuels to provide new markets for poor farmers and generate rural employment, they are concerned that biofuel plantations will reduce smallholder lands, employ capital-intensive technologies, and pay substandard wages.

The environmental implications of biofuel production are heavily debated. Biofuels have often been identified as a means for reducing GHG emissions. This is because plant biomass captures carbon from the air. Conversion of this biomass to biofuel and subsequent combustion returns the carbon to the air, thus creating a cycle (Hazell and Pachauri, 2006). However, this cycle is not completely closed, as biofuels require energy for their growth, processing, and transportation, thus implying positive net emissions. Pimentel (2003) calculates that the energy balance of ethanol from corn is actually negative. However, these calculations are disputed by Graboski and McClelland (2002), and the bulk of the evidence indicates that biofuels, particularly those derived from the more efficient crops, are a substantial net energy contributor.

More serious concerns regarding environmental impacts, including GHG emissions, focus on land use. Fargione *et al.* (2008) find that GHG reductions from using biofuel compared to fossil fuels depend on land use and the source of land used for biofuels. In particular, clearing new land for biofuels may generate large GHG emissions due to burning and decomposition of organic matter. Fargione *et al.* refer to these land-conversion emissions as the 'carbon debt'. This debt varies by the biome, in which the land conversion occurs, and the crop planted for biofuel production. In the case of production of sugarcane for ethanol on land cleared from Brazilian Cerrado, they estimate that it would take 17 years to repay this debt (in other words, 17 times the carbon savings per year from using the produced ethanol versus gasoline equals the carbon debt). The payback periods for some other biomes and crops are even longer.

These observations are pertinent because biofuel optimists, such as Hausmann, assume that global cultivated land area can be expanded by up to 50 per cent (from 1.4 to 2.1 billion hectares). If dedicated to biofuels, this land expansion would generate annual energy roughly equivalent to the energy content of current oil production.

While the biofuel boom has generated considerable discussion on its implications for poor countries, these debates are supported by few quantitative economic analyses. A review of the literature yields no published articles estimating growth and poverty impacts of large-scale biofuel investment in a low-income country. In this context, an analysis of Mozambique is useful since the concerns of this country reflect many of the main aspects of the current debate. Highly relevant issues include the choice of production technology, institutional arrangements in production, technology spillovers, land area expansion, diversion of resources away from food production, and complementary investments. In the next section, we develop an economic modeling framework capturing the transmission mechanisms linking biofuels to the above issues.

4. The modeling framework and results

4.1. Background on CGE models

The impact of biofuel investment is simulated using a dynamic CGE model. These models are often applied to issues of trade strategy, income distribution, and structural change in developing countries. The models have features making them suitable for such analysis. First, they simulate the functioning of a market economy, including markets for labor, capital and commodities, and provide a useful perspective on how changes in economic conditions are mediated through prices and markets. Secondly, the structural nature of these models permits consideration of new phenomena, such as biofuels. Thirdly, these models assure that all economywide constraints are respected. For instance, biofuels may generate substantial foreign exchange earnings, use a large quantity of land, and demand a substantial amount of labor. It is therefore important to consider the balance of payments and the supply of useable land and labor. Fourthly, CGE models contain detailed sector breakdowns and provide a 'simulation laboratory' for quantitatively examining how various impact channels influence the performance and structure of the economy. Finally, CGE models provide a theoretically consistent framework for welfare and distributional analysis.

In CGE models, economic decision-making is the outcome of decentralized optimization by producers and consumers within a coherent economywide framework. A variety of substitution mechanisms occur in response to variations in relative prices, including substitution between labor types; capital and labor; imports and domestic goods; and between exports and domestic sales. Institutional rigidities and imperfect markets are captured by exogenously imposing immobile sector capital stocks, labor market segmentation, and home consumption. These permit a more realistic application to developing countries.

4.2. Mozambique CGE model

The Mozambique CGE model contains 56 activities/commodities, including 24 agricultural and 7 food-processing sectors (see Thurlow, 2008). Five factors of production are identified: three types of labor (unskilled, semi-skilled, and skilled), agricultural land, and capital. This detail captures Mozambique's economic structure and influences model results. Since biofuels will either be exported or used to replace fuel imports, substantial increases in biofuel production will have implications for foreign exchange availability and trade. With more foreign exchange, Mozambique will be able to import more and reduce exports of other products (besides biofuels). As a result, we expect sectors with high trade shares (either a large share of production exported or a high degree of import competition) to be more affected compared to non-traded sectors. The basic structural features of the Mozambican economy are presented in table 1.

Within the existing structure and subject to macroeconomic constraints, producers in the model maximize profits under constant returns to scale, with the choice between factors governed by a constant elasticity of substitution (CES) function. Factors are then combined with fixed-share intermediates using a Leontief specification. Under profit maximization, factors are employed such that marginal revenue equals marginal cost based on endogenous relative prices.

Substitution possibilities exist between production for domestic and foreign markets. This decision of producers is governed by a constant elasticity of transformation (CET) function that distinguishes between exported and domestic goods, and by doing so, captures any time- or quality-related differences between the two products. Profit maximization drives producers to sell in markets where they can achieve the highest returns. These returns are based on domestic and export prices; the latter is determined by the world price times the exchange rate adjusted for any taxes. Under the small-country assumption, Mozambique faces a perfectly elastic world demand curve at a fixed world price. The final ratio of exports to domestic goods is determined by the endogenous interaction of the relative prices for these two commodity types.

Substitution possibilities also exist between imported and domestic goods under a CES Armington specification. This takes place both in intermediate and final usages. These elasticities vary across sectors, with lower elasticities reflecting greater differences between domestic and imported goods. Again, under the small-country assumption, Mozambique faces infinitely elastic world supply at fixed world prices. The final ratio of imports to domestic goods is determined by the cost-minimizing decision-making of domestic demanders based on the relative prices of imports and domestic goods (both of which include the relevant taxes).[1]

[1] For both the CES and the CET functions, a relatively flexible value of 3.0 was applied for the substitution parameter across all sectors. Qualitative results are robust to the choice of CES and CET parameters values.

Table 1. *Structure of Mozambique's economy in 2003*

	Share of total (%)				*Export intensity (%)*	*Import penetration (%)*
	GDP	*Employment*	*Exports*	*Imports*		
Total GDP	100.0	100.0	100.0	100.0	9.7	21.9
Agriculture	25.9	50.9	20.3	2.6	9.6	3.3
Food crops	18.2	32.6	3.8	2.0	2.2	3.7
Traditional exports	1.1	1.7	1.2	0.4	19.5	15.4
Other agriculture	6.7	16.6	15.4	0.2	24.4	0.8
Manufacturing	13.7	5.0	59.4	70.6	29.9	52.5
Food processing	5.0	3.0	2.0	14.3	1.7	23.1
Traditional crop processing	0.9	0.5	3.4	3.6	38.1	51.5
Other manufacturing	7.8	1.5	54.1	52.7	62.3	75.8
Other industries	9.5	15.0	12.5	5.7	9.1	9.0
Private services	42.2	26.7	7.7	21.2	2.0	10.9
Government services	8.7	2.4	0.0	0.0	0.0	0.0

Note: 'Export intensity' is the share of exports in domestic output, and 'import penetration' is the share of import in total domestic demand. Sums of shares in this table and subsequent tables may not equal 100 due to rounding.
Source: Mozambique 2003 social accounting matrix (SAM).

The model distinguishes among various institutions, including enterprises, the government, and 10 representative household groups. Households are disaggregated across rural/urban areas and income quintiles. Households and enterprises receive income in payment for the producers' use of their factors of production. Both institutions pay direct taxes (based on fixed tax rates) and save (based on marginal propensities to save). Enterprises pay their remaining incomes to households in the form of dividends. Households, unlike enterprises, use their incomes to consume commodities under a linear expenditure system (LES) of demand.

The government receives revenues from activity taxes, sales taxes, direct taxes, and import tariffs, and then makes transfers to households, enterprises, and the rest of the world. The government also purchases commodities in the form of government consumption expenditures, and the remaining income of the government is saved (with budgets deficits representing negative savings). All savings from households, enterprises, government, and the rest of the world (foreign savings) are collected in a savings pool from which investment is financed.

The model includes three macroeconomic accounts: government balance, current account, and savings-investment account. In order to bring about balance in the macro accounts, it is necessary to specify a set of 'macroclosure' rules, which provide a mechanism through which balance is achieved. A savings-driven closure is assumed for the savings-investment account, such that households' marginal propensities to save are fixed, and investment adjusts to income changes to ensure that investment and savings levels are equal. For the current account, a flexible exchange rate adjusts in order to maintain a fixed level of foreign savings (i.e., the external balance is held fixed in foreign currency terms). Finally, in the government account, the fiscal deficit is assumed to remain unchanged, with government revenues and expenditures balanced through changes in direct tax rates to households and enterprises.

Labor is assumed to be mobile across sectors and fully employed. This is a conservative assumption. If, for example, biofuels production results in higher employment, then the tradeoffs between biofuels and food production would be less pronounced and the GDP gains from biofuels would be larger. Under the full employment closure, expanding biofuels production implies reduced use of labor elsewhere in the economy. This is also consistent with widespread evidence that, while relatively few people have formal sector jobs, the large majority of working-age people engage in activities that contribute to GDP. Hence, engaging these people in biofuels production has an opportunity cost. The model numeraire is the consumer price index (CPI).

The CGE model is calibrated to a 2003 social accounting matrix (SAM) (McCool *et al.*, 2009), which was constructed using national accounts, trade and tax data, and household income and expenditure data from the 2002 national household survey (INE, 2004). Trade elasticities are from the Global Trade Analysis Project (Dimaranan, 2006). The model is calibrated so that the initial equilibrium reproduces the base-year values from the SAM.

The features described above apply to a single-period 'static' CGE model. However, because biofuel investments will unfold over a dozen years or more, the model must be capable of forward-looking growth trajectories. Therefore, the model must be ‘dynamized’ by building in a set of accumulation and updating rules (e.g., investment adding to capital stock; labor force growth by skill category; productivity growth). In addition, expectation formations must be specified. Expectations are a distinguishing feature of macroeconomic models. In our CGE model, a simple set of adaptive expectation rules is chosen so that investment is allocated according to current relative prices. Implicitly, investors expect current price ratios to persist indefinitely. We also do not explicitly model crowding-in of private investment in nonbiofuel sectors, as suggested by Hausmann, opting instead to focus on the direct impact of biofuels. We do, however, consider potential technology spillovers.

A series of dynamic equations ‘update’ various parameters and variables from one year to the next. For the most part, the relationships are straightforward. Growth in the total supply of each labor category and land is specified exogenously, sector capital stocks are adjusted each year based on investment, net of depreciation. Factor returns adjust so that factor supply equals demand. The model adopts a ‘putty-clay’ formulation, whereby new investment can be directed to any sector in response to differential rates of return, but installed equipment remains immobile (e.g., a factory cannot be converted into a railroad). Sector- and factor-specific productivity growth is specified exogenously. Using these simple relationships to update key variables, we can generate a series of growth trajectories, based on different biofuel investment scenarios.

The CGE model also estimates the impact of investments on household incomes. Each household questioned in the 2002 national household survey is linked to its corresponding representative household in the CGE model. This is the expenditure-side microsimulation component of the Mozambican model. In this formulation, changes in representative households’ consumptions and the prices for each commodity in the CGE model are passed down to their corresponding households in the survey, where total consumption expenditures are recalculated. This new level of real per capita expenditure for each survey household is compared to the official poverty line and standard poverty measures are recalculated.

It is important to highlight that our focus is on the *differential* impact across scenarios. From this vantage point, what matters most is whether our baseline scenario (which excludes biofuel investment) and the various biofuel scenarios are reasonable. Examining the differences among scenarios allows us to isolate the impacts of biofuel investments. The modeling is not an attempt to forecast particular economic outcomes nor is it an attempt to completely set forth optimal biofuels policy. The focus is on generating clear and analytically tractable comparisons.

4.3. Baseline scenario

We first produce a baseline growth path that assumes that Mozambique’s economy continues to grow during 2003–2015 in line with its recent performance. For each year, we update the model to reflect changes in population, labor and land supply, and factor productivity (see table 2). Since Mozambique is a land-abundant country, we assume that land supply

Table 2. *Core macroeconomic assumptions and results*

	Initial (2003)	*Baseline scenario (1)*	*Sugarcane scenario (2)*	*Jatropha scenario (3)*	*Jatropha + spillovers (4)*	*Combined scenario (2+4)*
	Average annual growth rate (2003–2015) (%)					
Population (thousands)	18,301	2.00	2.00	2.00	2.00	2.00
GDP	100.0	6.09	6.41	6.32	6.46	6.74
Labor supply	63.9	2.09	2.09	2.09	2.09	2.09
Skilled	10.7	3.00	3.00	3.00	3.00	3.00
Semi-skilled	13.9	2.50	2.50	2.50	2.50	2.50
Unskilled	39.3	2.00	2.00	2.00	2.00	2.00
Capital stock	30.0	6.35	6.75	6.73	6.74	7.14
Land supply	6.1	2.00	2.21	2.40	2.40	2.60
	Final year value (2015)					
Real exchange rate	1.00	0.95	0.89	0.86	0.88	0.81
Consumer prices	1.00	1.00	1.00	1.00	1.00	1.00
Cereals price index	1.00	1.20	1.22	1.24	1.19	1.22

Source: Results from the Mozambican CGE microsimulation model. Exchange rate index is given in foreign currency units per local currency unit (i.e., a decline is an appreciation).

and population grow at 2 per cent per year, which is slower than the rate of cropped area expansion over the past decade.[2] We capture rising skill intensities in the labor force by allowing the supply and productivity of skilled and semi-skilled labors to grow faster than unskilled labor.[3] There is also unbiased technological change in the baseline scenario, with the shift parameter on the production function increasing at 3 per cent per year in non-agriculture and 0.8 per cent per year in agriculture. These parameter choices are consistent with growth accounting exercises for Mozambique (Arndt *et al.*, 2007). Together, these assumptions produce a baseline scenario in which the Mozambican economy grows at an average of 6.1 per cent per year.

4.4. Biofuel scenarios

In the biofuel scenarios, we create dedicated sectors for sugarcane for ethanol production and jatropha for biodiesel production. The outputs of these sectors are employed as the raw materials for dedicated processing sectors. Beginning from an effectively zero base, we increase the amount of land allocated to the biofuel raw material sectors in gradual increments over the 12-year simulation horizon. For all four biofuel sectors, the capital necessary for biofuel production is assumed to be 100 per cent foreign-financed and is incremental to the foreign investment levels assumed without biofuels. Returns to biofuel capital are assumed to be repatriated.[4] The resulting biofuel production is assumed to be 100 per cent exported.[5]

World prices for biofuels, fossil fuels, and foods are the same across scenarios. The pricing level for biofuels is assumed to be sufficient to

[2] An anonymous reviewer correctly points out that bush conversion to cropland is investment. In reality, this investment may constitute a large majority of rural savings. To our knowledge there has not been a rigorous accounting of the value of cleared land in Mozambique. Since clearing land is labor intensive, it suffices to know the quantity of labor required to clear a parcel of land and the shadow value of that labor. The latter is problematic since land clearing occurs almost entirely post-harvest and pre-planting. During this period, there are few alternative nonfarm activities, implying low shadow values on time. For this and other reasons, clearing land rarely appears as investment in national accounts. This analysis, like all that preceded it, ignores land conversion, which is likely to be a benign oversight if the land clearing occurs during slack labor demand periods. If biofuels investors hire labor to clear land then the model may understate the poverty gains from biofuels investment.

[3] Skilled (semi-skilled) labor productivity grows at 2 (1) per cent. Total labor force growth is faster than population growth because forecasted population growth is below historical rates and the population pyramid is skewed towards the young (nearly 50 per cent of the population is below 15 years old).

[4] This conservative assumption prevents an overstatement of the benefits of biofuels investment. To the extent that biofuels investment is domestically financed, benefits would be greater assuming that world prices remain favorable.

[5] For the purposes of this deterministic exercise, the difference between export of biofuels and import displacement of petroleum (which is a purely imported commodity) by biofuels is small. The appropriate mix between export and domestic production in the context of uncertain world prices is left for future research.

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. 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 constant across a wide range of biofuel prices. The critical assumption is that price expectations amongst biofuels investors are high enough to stimulate the assumed level of investment.

The production structures of jatropha/biodiesel and sugarcane/ethanol are different (see table 3). The proposed sugarcane investments in Mozambique are assumed to be plantation-based, whereas jatropha production is assumed to be undertaken primarily through smallholder outgrower schemes. Jatropha is thus more labor-intensive, requiring almost 50 workers for every 100 ha planted. Sugarcane requires only 34 farm laborers for every 100 ha planted, but it is more capital-intensive, employing three times more capital per hectare than jatropha. Relative to the quantity of biofuel produced, jatropha is more land-intensive, requiring more than twice as many hectares to produce the same number of liters of fuel (biodiesel or ethanol). The technologies for processing both crops into biofuel require an additional two to three workers for every 10,000 L produced. Overall, jatropha processing is more labor-intensive, while sugarcane processing is more capital-intensive.[6]

The results from the baseline scenario are compared with four biofuel scenarios. In scenarios 2 and 3, we expand sugarcane and jatropha production separately. Since a similar amount of biofuels is produced in each scenario, this analysis provides a comparison between plantation and smallholder biofuel production. As mentioned earlier, Mozambique's experience with traditional export crops strongly suggests that smallholders' food crop yields may increase following participation in outgrower schemes, due to technology spillovers (Strasberg, 1997; Benfica, 2006; Uaiene, 2008). This arises from the transfer of better farming practices and/or improved access to fertilizers and other inputs. Scenario 4 captures this possibility by repeating the jatropha scenario, but with faster productivity growth for food crops. Finally, in scenario 5, we combine the expansion of both sugarcane and jatropha, including technology spillovers, to assess the overall impact of biofuels on growth and poverty in Mozambique.

In the sugarcane and jatropha scenarios (i.e., scenarios 2 and 3, respectively) we increase the land allocated to these crops by 280,000 and

[6] While based on the best available information, some uncertainty surrounds the figures in table 3. The agronomics of jatropha are particularly uncertain due to the paucity of experience with the crop in Southern Africa. It may be that a different crop, such as sweet sorghum, will prove itself more amenable to outgrower schemes. Nevertheless, investors' interest in sugarcane and jatropha leads us to focus our technology estimations on these two crops.

Table 3. *Biofuel production characteristics*

Production characteristics for biofuels	*Sugarcane & ethanol*	*Jatropha & biodiesel*
Inputs and outputs per 100 ha		
Land employed (ha)	100	100
Crop production (t)	1,500	300
Farm workers employed (people)	33.6	49.2
Land yield (t/ha)	15.0	3.0
Farm labor yield (t/person)	44.7	6.1
Land per farm worker (ha/person)	3.0	2.0
Capital per hectare (capital units/ha)	6.6	2.2
Labor-capital ratio (persons/100 units of capital)	5.0	23.0
Biofuel produced (L)	75,000	36,000
Processing workers employed (people)	15.6	11.9
Feedstock yield (L/t)	50.0	120.0
Processing labor yield (L/person)	4,816	3,018
Inputs and outputs per 10,000 L		
Biofuel production (L)	10,000	10,000
Feedstock inputs (t)	200	83
Land employed (ha)	13.3	27.8
Farm workers employed (people)	4.5	13.7
Processing workers employed (people)	2.1	3.3
Capital employed (capital units)	80.6	42.9

Note: The same fundamental production coefficients are depicted per 100 ha of land and per 10,000 L of biofuel produced.

55,000 ha, respectively (see table 4).[7] As mentioned earlier, Mozambique is a land-abundant country and current production techniques are highly extensive employing long periods of fallow. Nevertheless, access to large, contiguous pieces of unused land is limited by insufficient road infrastructure, meaning that it is unlikely that biofuel investments will be undertaken entirely on new lands. In the biofuel scenarios, we rely on the judgment of experts in Mozambique in assuming that half of the production of biofuel crops takes place on unused land, while the remainder occurs on

[7] This is below the 13 million hectares of biofuel crop production currently being proposed in Mozambique. However, many proposals may only be speculative and so the sugarcane and jatropha scenarios provide a more plausible assessment of near-term investments.

Table 4. *Agricultural production results*

	Initial value (2003)	Baseline value (2015) (1)	Deviation from baseline final value (2015)			
			Sugarcane scenario (2)	Jatropha scenario (3)	Jatropha + spillovers (4)	Combined scenario (2+4)
Total land (1000 ha)	4,482	5,684	140	275	275	415
Biofuel crops	0	0	280	550	550	830
Sugarcane	0	0	280	0	0	280
Jatropha	0	0	0	550	550	550
Food crops	4,291	5,371	−73	−183	−193	−292
Maize	1,300	1,597	−62	−122	−96	−180
Sorghum & millet	621	666	−2	−6	−20	−19
Paddy rice	179	225	−13	−24	−20	−37
Traditional exports	191	313	−67	−92	−82	−123
Tobacco	17	8	−1	−2	−2	−3
Sugarcane	27	55	−6	−9	−7	−12
Cotton	115	216	−59	−78	−72	−105
Production (1000 tons)						
Biofuel crops						
Sugarcane	0	0	4,200	0	0	4,200
Jatropha	0	0	0	1,650	1,650	1,650
Food crops						
Maize	1,248	1,949	−52	−107	−5	−103
Sorghum & millet	363	497	4	6	14	16
Paddy rice	200	326	−14	−26	−9	−32
Traditional exports						
Tobacco	12	8	−1	−2	−2	−3
Sugarcane	397	996	−82	−125	−109	−188
Cotton	116	284	−70	−91	−87	−128
Production (1000 L)						
Ethanol	0	0	210,000	0	0	210,000
Biodiesel	0	0	0	198,000	198,000	198,000

Source: Results from the Mozambican CGE microsimulation model.

land already under cultivation. We thus reduce the amount of land available for existing crops by half the amount of land needed for biofuel crops, and then let the model determine the optimal allocation of the remaining land based on the production technologies and relative profitability of different crops.

The reduction in land available to nonbiofuel crops causes food crop production to decline, especially cereals, which have relatively high import penetration. Accordingly, both scenarios show higher cereal prices relative to the baseline (see table 2). This is most pronounced under the jatropha scenario, since this crop requires more land and more labor than sugarcane. Food imports rise in response to falling production and rising prices. This is further encouraged by an appreciation of the real exchange rate caused by increased biofuel exports. However, while food imports replace declining domestic production, it is the traditional export crops that suffer the most. These crops not only have to compete for scarcer land and labor resources, but they also lose competitiveness in international markets due to currency appreciation. Food crops, on the other hand, are less affected by appreciation because they rely more on domestic markets. Accordingly, land allocated to traditional exports declines more than for food crops.

Given its lower input requirements, a larger share of the value-added generated from producing jatropha and biodiesel remains on the farm, leading to faster agricultural GDP growth compared to plantation-based production of sugarcane (see table 5). However, land-intensive jatropha production has a more detrimental impact on traditional export crops, thereby reducing the supply of inputs for traditional export crop processing. While sugarcane and ethanol production has a smaller effect on agricultural growth, it has a larger impact on manufacturing and overall GDP growth. This occurs because sugarcane and ethanol production uses relatively less labor and land, thereby competing less with other domestic activities, and while it requires relatively more capital, this capital is assumed to come from abroad.

Resource competition also explains some of the decline in nonbiofuel GDP growth under the biofuel scenarios. Since roughly one worker is required for every 3 ha of land planted with sugarcane, the expansion of sugarcane by 280,000 ha generates jobs for 94,000 farm laborers (see table 6). Similarly, jatropha production employs 271,000 smallholder farmers. Biofuel processing employs 36,000 and 55,000 manufacturing jobs for ethanol and biodiesel production, respectively. The model assumes that all workers are already engaged in productive activity and must therefore be drawn away from other sectors. Under the sugarcane and jatropha 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. This captures the labor reallocated to jatropha production by smallholder farmers, as well as the migration of farmers off their own land to work as laborers on sugarcane plantations.

Table 5. *Sectoral growth results*

	GDP share (2003)	*Average annual growth rate (2003–2015) (%)* Baseline scenario (1)	Sugarcane scenario (2)	Jatropha scenario (3)	Jatropha + spillovers (4)	Combined scenario (2+4)
Total GDP	100.0	6.09	6.41	6.32	6.46	6.74
Agriculture	25.9	4.29	5.13	5.82	6.03	6.69
Food crops	18.2	4.29	4.31	4.24	4.54	4.45
Traditional exports	1.1	3.53	2.15	1.49	1.68	0.47
Biofuel crops	0.0	0.00	na	na	na	na
Other agriculture	6.7	4.39	4.29	4.10	4.24	4.16
Manufacturing	13.7	5.46	6.66	5.71	5.82	6.98
Food processing	5.0	5.54	5.52	5.29	5.51	5.35
Traditional processing	0.9	8.53	6.07	5.21	5.40	3.58
Biofuel processing	0.0	0.00	na	na	na	na
Other manufacturing	7.8	4.99	4.82	4.63	4.67	4.42
Other industries	9.5	10.25	9.68	9.44	9.46	8.98
Water	0.3	8.71	13.11	11.90	11.99	15.39
Private services	42.2	6.17	6.28	6.07	6.20	6.26
Government services	8.7	5.88	5.96	5.93	6.07	6.04

Source: Results from the Mozambican CGE microsimulation model.

Table 6. *Labor employment results*

	Initial employment (2003)	Baseline employment (2015) (1)	Deviation from baseline final employment (2015)			
			Sugarcane scenario (2)	*Jatropha scenario (3)*	*Jatropha + spillovers (4)*	*Combined scenario (2+4)*
Total (thousands)	3,577	4,586	0	0	0	0
Agriculture	1,820	2,484	59	165	127	165
Food crops	1,166	1,666	−2	−34	−88	−117
Traditional exports	60	68	−10	−16	−15	−22
Biofuel crops	0	0	94	271	271	365
Other agriculture	594	750	−23	−56	−41	−60
Manufacturing	178	179	20	22	28	50
Food processing	107	91	−3	−10	−6	−10
Traditional processing	20	27	−9	−12	−11	−16
Biofuel processing	0	0	36	55	55	90
Other manufacturing	52	61	−5	−11	−10	−15
Other industries	537	743	−76	−125	−117	−167
Water	9	10	6	3	3	8
Private services	955	1,080	−3	−62	−39	−49
Government services	86	100	1	−1	1	1

Source: Results from the Mozambican CGE microsimulation model.

The remaining jobs created by biofuel crop production are filled by workers that would have migrated to jobs within the nonagricultural sector in the absence of biofuels investment. In the absence of biofuels investment, these workers would have gained employment in the construction and trade services sectors. Because a relatively long period of time (12 years) is under consideration, the model does not specify separate rural and urban labor markets. The relative growth of the agricultural and non-agricultural sectors can be explained by changes in the rate of migration by new entrants into the labor market. Enhanced employment opportunities due to biofuels cause a higher percentage of new entrants to engage in rural activities. Finally, because jatropha is more labor intensive, the share of total labor engaged in agriculture is larger in the jatropha scenario than in the sugarcane scenario.

Compared to sugarcane, a larger share of additional land returns accrue to smallholder farmers in the jatropha scenario. These farmers in turn spend a larger share of their incomes on goods produced domestically and in rural areas. As such, while both sugarcane and jatropha production benefits rural households, jatropha production increases incomes the most, especially for lower-income households. This is shown by changes in the equivalent variation (EV), which measures welfare improvements after controlling for price changes (see table 7). The results indicate that, in the jatropha scenario, welfare improves more for lower-income rural households than for higher-income and urban households. This is because jatropha production is more land- and unskilled labor-intensive and the resulting increases in factor returns benefit lower-income and rural households relatively more. In contrast, sugarcane production is more capital- and skill-intensive, thereby shifting the relative factor prices in favor of higher-income urban households.

Uneven distributional impacts are also reflected in poverty outcomes once the income effects from the CGE model are passed down to the microsimulation module. Both biofuel scenarios lead to significant declines in national poverty (see table 8). However, rural poverty declines faster under the jatropha scenario. Smallholder jatropha production is also twice as effective at reducing poverty amongst the poorest rural households, as evidenced by its larger impact on the depth and severity of poverty.

The impact of jatropha on poverty is more pronounced once we include technology spillovers. In the spillovers scenario, we again allocate 550,000 ha to jatropha production, with half of production taking place on unused land. However, we now raise total factor productivity (TFP) growth for food crops by an additional 0.5 percentage points per year during 2003–2015. In partial factor productivity terms, the average maize yield increases from 0.96 to 1.22 ton/ha over the 12-year baseline scenario, but rises to 1.30 ton/ha under the spillover scenario. Similar productivity gains are imposed on other cereals, root crops, and vegetables. The result is a reversal in the decline of food crop production (see table 5) and a drop in food prices relative to the baseline scenario (see table 2). Improving yields also reduces the amount of land needed to produce food crops thereby alleviating some of the resource competition between traditional export and biofuel crops (see table 4). This accelerates agricultural growth and poverty reduction for both rural and urban households, with the latter benefiting from lower

Table 7. *Equivalent variation results*

	Initial per capita spending (2003)	*Baseline growth (2003–2015) (1)*	*Deviation from baseline growth rate (2003–2015)*			
			Sugarcane scenario (2)	*Jatropha scenario (3)*	*Jatropha + spillovers (4)*	*Combined scenario (2 + 4)*
Rural households						
Quintile 1	1,147	4.84	0.33	0.73	0.93	1.12
Quintile 2	1,401	4.91	0.33	0.62	0.80	1.04
Quintile 3	1,856	4.98	0.33	0.56	0.74	0.99
Quintile 4	2,410	5.12	0.33	0.53	0.69	0.96
Quintile 5	4,860	5.50	0.35	0.40	0.54	0.85
Urban households						
Quintile 1	1,297	4.81	0.27	0.33	0.56	0.78
Quintile 2	1,731	5.18	0.29	0.22	0.42	0.69
Quintile 3	2,180	5.05	0.29	0.21	0.41	0.69
Quintile 4	3,384	5.57	0.29	0.11	0.28	0.57
Quintile 5	11,172	6.16	0.29	0.00	0.13	0.43

Source: Results from the Mozambican CGE microsimulation model.

Table 8. *Poverty results*

	Initial poverty rates (2003)	*Final year poverty rates (2015) (%)*				
		Baseline scenario (1)	*Sugarcane scenario (2)*	*Jatropha scenario (3)*	*Jatropha + spillovers (4)*	*Combined scenario (2 + 4)*
Headcount poverty, P0						
National	54.07	32.04	29.70	28.45	27.54	26.11
Rural	55.29	32.98	30.68	28.54	27.58	26.54
Urban	51.47	30.06	27.63	28.26	27.44	25.21
Depth of poverty, P1						
National	20.52	10.19	9.29	8.65	8.27	7.61
Rural	20.91	10.92	9.98	9.02	8.66	8.07
Urban	19.69	8.67	7.83	7.88	7.43	6.64
Severity of poverty, P2						
National	10.33	4.59	4.12	3.77	3.58	3.27
Rural	10.67	5.09	4.59	4.08	3.90	3.61
Urban	9.62	3.53	3.13	3.11	2.90	2.55

Source: Results from the Mozambican CGE microsimulation model.

food prices. This scenario highlights the benefits of technology spillovers from biofuel outgrower schemes, as well as the continued importance of improving non-export crop productivity.

In the final scenario, we combine the effects of jatropha and sugarcane production. The results indicate that biofuel production has a substantial impact on the Mozambican economy. GDP growth accelerates by 0.65 percentage points per year. This growth acceleration is concentrated in the agricultural and manufacturing sectors, which grow by an additional 2.4 and 1.5 percentage points per year, respectively (see table 5). Biofuel crop production and processing requires 455,000 jobs, most of which are filled by workers who would have migrated to construction and trade services in the absence of biofuels (see table 6). The national poverty headcount declines by an additional 5.9 percentage points by 2015, which is equivalent to lifting an additional 1.4 million people above the poverty line. At the same time, the macroeconomic impact of rapid export-led growth is a sharper appreciation of the real exchange rate. This again increases import competition in domestic markets and reduces the competitiveness of existing exports, especially traditional export crops. This may lead to short-term adjustment costs as farmers reallocate their land and workers migrate between sectors and regions.

4.5. Displaced investment by region and relative poverty impacts

A national CGE model cannot consider regional development issues. Inevitably, biofuel production will concentrate in particular regions, with implications for public investment patterns. For instance, biofuel production will require accompanying investment in transportation infrastructure, such as roads and ports. The total magnitude of biofuels investment is not large relative to total public investment funds, which amount to about $500 million per year. In addition, as Hausmann points out, most biofuel investments are nonexclusive. A road constructed in a productive region can transport both biofuels and food crops. As a result, in the results presented above, the model implicitly assumes that existing budgets accommodate these needs. Nevertheless, public budgets are limited, and if biofuel-producing regions experience increased public investment, then other regions may experience declining investments under a constant public investment budget. Since most investment is aid financed, a constant public investment budget across biofuel and nonbiofuel scenarios is a reasonable analytical starting point.

We suggest three possible outcomes for this redirection of investment. First, regions not producing biofuels grow less rapidly, and these reductions in growth are not offset by increases elsewhere. In this case, the biofuel scenarios overstate the economywide gains from biofuel production. Secondly, regions not producing biofuels grow less rapidly but these reductions are entirely offset by incremental growth beyond the biofuel sectors in the biofuel regions. This relates to the nonexclusivity of transport infrastructure (up to a capacity point). Extra investment in transport infrastructure for biofuel regions may well crowd-in additional economic activity, which could offset the activity foregone in the nonbiofuel regions. In this case, the scenarios correctly project the economywide gains, but the national framework masks some regional disparities. Finally, regions not producing biofuels grow less rapidly but these reductions are more than offset by incremental growth beyond the biofuel sectors in the biofuel regions. This could occur if agglomeration economies or other spillover effects induce a crowding-in of a greater level of economic activity than was foregone in the nonbiofuel regions. In this case, the benefits of biofuels are understated and the actual regional disparities are more pronounced. In the absence of a solid foundation for any particular outcome, we reran the above scenarios under the assumption that the additional required public investment is raised via a proportional increase in commodity taxes and direct income taxes. These investment scenarios produced qualitatively similar results to the biofuel scenarios presented above.[8]

We did not consider a counterfactual scenario in which Mozambique's government invests in alternative agricultural sectors, such as smallholder food crops. Thurlow (2008) compares the growth and distributional effects of alternative sources of agricultural growth in Mozambique and finds that biofuel crops are not the most pro-poor source of agricultural growth relative to other crops. For instance, the poverty–growth elasticity of biofuel crops is −0.43, which is significantly smaller than the elasticities for maize (−0.73), sorghum and millet (−0.65), and horticulture (−0.48). However, biofuel crops have far higher growth potential, allowing them to generate larger *absolute* poverty reductions than existing food and traditional export crops.

5. Conclusions, policy implications, and recommendations for future research

Our model results suggest that biofuels can provide Mozambique with an opportunity to substantially enhance economic growth and poverty reduction. Both modes of production considered here, ethanol produced from sugarcane grown using a plantation approach and biodiesel produced from jatropha using an outgrower approach, are projected to increase production and welfare and reduce poverty. However, the outgrower approach, as represented by jatropha, is much more strongly pro-poor due to greater use of unskilled labor and the accrual of land rents to smallholders rather than plantation owners. The growth and poverty reduction benefits of outgrower schemes are further enhanced if the schemes result in technology spillovers to other crops.

Large-scale biofuel production unavoidably imposes adjustments on other sectors due to competition for land and labor and the implications of increased foreign exchange availability on the real exchange rate. In relative terms, traditional export crops shrink the most relative to the baseline scenario in order to make space for biofuels. However, the allocated areas and production levels of food crops also decline, while food prices and imports increase relative to the baseline. Overall, while welfare and food security broadly increase due to enhanced purchasing power, certain households may be adversely affected due to the price and quantity adjustments associated with rapid growth in biofuel production.

[8] These results are available from the authors upon request.

These results suggest that careful attention should be paid to the labor intensities of the production methods employed for biofuel crops. The model indicates that the degree of labor intensity influences the distribution of income. In addition, certain institutional structures that increase the probability of technology spillovers to other crops (such as outgrower schemes) are shown to be highly desirable.

At the same time, any insistence on a solely outgrower model may not be the best approach, as investors may strongly prefer vertically coordinated arrangements that supply a more certain flow of raw material. A hybrid approach wherein the initial investment occurs in plantation mode up to a certain threshold, beyond which further expansion of biofuel crops follows an outgrower arrangement, merits careful consideration.

Finally, it should be emphasized that the concerns raised by Oxfam are not idle worries. A policy whereby biofuels displace smallholders on the highest quality land, employ highly capital intensive technologies, and repatriate profits to foreign investors and/or accrue profits to elite Mozambicans is not a recipe for national income growth and poverty reduction. The results point to strong potential for gains. Actual gains will depend upon policies, execution, and monitoring.

There are numerous topics for further research, four of which are described in the following. First, water usage is not considered explicitly in the model. While irrigation is not strictly necessary for jatropha or sweet sorghum, sugarcane typically requires irrigation and therefore has implications for water resources. The large increase in water demand caused by biofuel crops is reflected in the water sector's high growth following new biofuel investments (see table 5). Second, the model does not consider the potential spillovers to other exporting sectors due to increases in transport and other infrastructures required by biofuel production (i.e., the crowding-in highlighted by Hausmann, 2007). Such spillovers from foreign direct investment would enhance the benefits from biofuel production, thereby justifying concomitant public investment vis-à-vis other investment opportunities.

Third, the implications of converting unused land to biofuel production should be considered in the context of GHG emissions. It is likely that the mode of conversion and the crops planted for biofuels could substantially influence the GHG emission balance. As a perennial crop, it is possible that jatropha possesses significant advantages over other sources of biofuel crops in terms of overall GHG balance, due to relatively mild emissions as a result of conversion of new land. Conversion of bush land to irrigated land also likely has strong implications for the carbon balance.

As emphasized in section 1, this is important. If Mozambican biofuel production is demonstrably 'green' in terms of CO_2 balance, it is more likely to receive a significant premium in international markets providing a buffer to downside price risk. As recent oil market movements indicate, downside price risk cannot be ignored. In this spirit, other methods for mitigating downside price risk for biofuels, such as generation of electricity and identification of potential substitute crops for biofuels, should also be considered in greater detail.

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