

Biofuels' Role in Mexico's Rural Development

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Abstract. Biofuels are expected to promote growth, create jobs, and reduce poverty and inequality in developing areas while contributing to environmental sustainability. Achieving these goals will require accounting for their potential synergies and tradeoffs while addressing causal interactions across scales. An agent-based, general-equilibrium model of rural Mexico is used to analyze the challenges of this country's recent biofuels initiative. Results reveal that modest increases in crop prices could generate substantial feedstock surpluses for biofuels based on either corn or alternative crops, representing US\$236 - \$273 million in annual sales. Significant profits in feedstock production would raise land rents at the forest margin. A corn-based industry would increase forests' opportunity costs up to 2.0%, particularly in Southeast Mexico. One based on alternative crops could raise them substantially more, particularly in Central Mexico, entailing significant land-cover changes. The feedstock sector would promote commercial agriculture but generate scant economic growth in rural areas. A highly mobile migrant labor force could keep wage increases small and temporary. Stagnant wages and rising food prices ultimately could reduce rural purchasing power with mixed implications on food security. Rural food deficits could decrease, but on-farm consumption would also contract markedly whether feedstocks are based on staples or cash crops. While absentee producers and landlords will be the major beneficiaries of the Mexican biofuels industry, no mechanisms have been contemplated to mitigate adverse impacts on rural wellbeing and land use. Assessments of biofuels' potential in other developing countries, particularly Sub-Saharan Africa, should be reconsidered using a similar methodology.

Keywords: corn; cash crops; feedstocks; food security; land use change; agriculture.

1. Introduction

Only a few years ago many observers predicted that bioenergy would help satisfy growing demands for energy while protecting the environment and simultaneously create jobs, promote equity and raise the living standard of the world's poor [1-4]. But other analysts seemed equally confident that a rapidly expanding biofuels industry would entail higher crop prices, price volatility, and food insecurity without clear environmental benefits [5, 6]. Arguments on both sides of the debate remained largely theoretical in late 2006, when crop prices began to surge, ultimately leading to a global food crisis in 2008. The factors driving this surge in prices included the low value of the dollar and world-wide changes in crop production/utilization ratios that decimated inventories [7-10]. In the case of corn, drivers also included the growth of the biofuels industry, particularly ethanol, which drove corn prices in the United States up sharply. Energy and food prices are expected to continue affecting developing economies for the foreseeable future, influencing their balance of payments and prospects of growth [11]. The effects will not be uniform across the developing world. Analysts distinguish countries like Haiti, whose weak finances will likely deteriorate with changes in the terms of trade, and others like Mexico, whose large energy sector should provide wider scope for adjustment [7, 8]. At the micro level, nevertheless, expected price trends are bound to hurt poor consumers everywhere—that is, unless governments intervene [7, 11]. Notwithstanding these expectations, many analysts remain confident that biofuels will provide ample opportunities for growth in developing areas [7, 12-15]. Agricultural growth—an expected outcome of the industry's demand for feedstocks—will drive economic development and reduce poverty, which will help safeguard food security. Potentially adverse effects on food supplies and natural resources will constitute at most a short-term trade-off. Adequate policies and good timing should allow governments to arrive at a desirable outcome in the long run, when technological advances will relieve the pressure on food prices and the environment [12, 13]. Accordingly, governments around the world are promoting the development of a domestic bioenergy industry in the name of national security, as a buffer against oil-market shocks and a way of conserving foreign reserves (that might then be used to finance food imports) [5].

Government initiatives under way, such as the recent Mexican Biofuels Law, have wide and ambitious goals. Achieving all their targets nevertheless will require integrating widely disparate food, energy and environmental policies while accounting for their potential synergies and tradeoffs [5, 7]. The success of these initiatives could depend on anticipating and addressing effectively the multiple effects of policies over social, economic and environmental variables. This will require in turn the development and implementation of an integrated analytical framework capable of addressing the interactions between causal factors and outcomes at different scales—i.e., field, farm, regional, national and international levels—while accounting for the specificity of market and policy conditions within and across individual localtions. Alas, integrating micro and macroeconomic processes within a variable context can be an elusive goal [16, 17]. Here we use an agent-based, general equilibrium model of rural Mexico—a simple analytical framework that integrates across organizational and spatial scales—in order to analyze the challenges of the Mexican Biofuels initiative and its implications on agricultural markets, rural development, food security and land-use change.

1.1. The Mexican context

As an early participant in the recent corn-price saga, Mexico became the poster child of the food crisis [18-20]. Corn is a food staple in Mexico, where per-capita consumption is the world's second highest. Imports represent 30% of domestic consumption, and the country is the second largest importer of American corn. Domestic corn prices are tightly linked to US prices [21, 22], and since the peso also is tightly linked to the dollar, a weak dollar could not buffer price increases as in other countries. Not surprisingly, Mexico was expected to bear the most adverse impacts of crop-price increases after Sub-Saharan Africa [23]. Actual impacts of the corn-price surge might have been more complex [20].

In late 2006, consumer prices of corn, corn-flour and tortillas soared across Mexico, creating a major crisis for the new federal administration, which immediately called the public's attention to the spike in international prices and specifically blamed biofuels. It might seem surprising thus that the government's first response was to raise corn-import quotas, but it ultimately resorted to controlling

tortilla prices directly in order to sort out a persisting crisis. Paradoxically, federal authorities began drafting at the same time a plan to promote a domestic biofuels industry, which eventually was signed into law in early 2008. The Mexican government's response to the crisis was consistent nevertheless with remarks made by the autonomous Bank of Mexico, which attributed the spike in prices to speculation in the domestic grain market. Indeed, for the last fifteen years, consumer prices for corn, corn-flour and tortillas have moved largely independently of corn import prices [20].

The Mexican Biofuels Law's professed objective is to diversify the nation's supply of energy, reduce green-house emissions, promote rural development, create jobs and improve the rural poor's standard of living while safeguarding food security [24]. The Mexican Biofuels Program was launched a year later [25]. Its immediate goal was to guarantee a sufficient supply of feedstocks to generate 1.76×10^8 liters of ethanol in its first year (8.1×10^8 liters in the second). In order to produce the 2.3×10^6 tons of biomass required, the Program anticipated incorporating 3×10^5 hectares of land into the feedstock sector. Officials have been vague regarding the type of incentives that could be used to reach this goal, but the focus seems to be on enhancing producer profitability [25, 26]. Deficiency payments and price supports are thus a prime candidate. The Law explicitly states that price trends should be considered when determining the type and amount of incentives needed by the budding industry [24, 27]. Concerns with food security have been addressed by restricting the use of staples, namely corn, as feedstock. The Program will thus focus initially on five cash crops: sugar cane, oil palm, sweet sorghum, jatropha and castor beans. Although imported corn can be used as feedstock unrestrictedly, use of domestic grain requires the government's express authorization. The Ministry of Agriculture simultaneously has promoted a reform that would deregulate use of yellow corn.¹ White and yellow corn prices nevertheless are tightly linked.

¹ Domestic corn grain can be used as feedstock only when surpluses satisfy the country's consumption demand [24, 27]. The Ministry of Agriculture argues that only white corn should be regulated, since yellow corn is used mostly in industrial uses.

2. Methods

Our analysis of the Mexican Biofuels Law focuses on the feedstock sector's implications on land use and the rural economy. Biofuel production per se would employ skilled and unskilled labor, but this employment could be insignificant compared to the feedstock sector's use of rural unskilled labor [14, 15]. The various fuel crops considered in the Mexican Biofuels Program constitute an alternative for most farmers in Mexico [25, 26]. While some of the impacts of an expanding feedstock sector could depend on which of these crops is used [14, 15], the present analysis focuses on the differences between cash crops and corn, the staple crop. Two scenarios are used to analyze these two cases separately: the first simulates a 5% increase in producer prices for corn; the second an analogous increase in cash-crop prices. Given the vagueness of prevailing policy the scale of the shocks might seem arbitrary, but preliminary results showed that these prices would achieve the Program's target, generating similar feedstock surpluses for the biofuel industry.

Our analytical framework is an agent-based model of the Mexican rural economy, used previously in analyses of various policies [20, 28]. The complete model nests individual models of multiple rural households and other (non-rural) agricultural producers into a single economy (i.e., into a general equilibrium context), which in turn is linked to the world economy through trade and migration (see Appendix). The basic household model is similar to the one described by Singh *et al.* [29] when all goods and variable inputs are tradable; it resembles the model of de Janvry *et al.* [30] when one or more markets are missing. As in those models, households are assumed to maximize their utility through consumption subject to several constraints, including a self-sufficiency constraint for subsistence households that sets on-farm consumption equal to production.

Nesting proceeds in three stages. First, rural households in each of five regions are grouped into four types that describe well the socioeconomic landscape of rural Mexico [31]: (i) landless households; (ii) small-holders (<2 ha); (iii) medium-holders (2-5 ha), and (iv) large-holders (>5 ha). Household models are calibrated at this stage using data from the 2003 Mexico National Rural Household Survey (*Encuesta Nacional a Hogares Rurales de México* or ENHRUM).

In a second stage, the four household groups are integrated with absentee (non-rural) producers in their region (i.e., individual landholders and corporations not based in rural areas but that nonetheless participate in rural markets) into five different regional models based on aggregate statistics for the agricultural sector (SIAP). Rental and wage rates are determined at this stage reflecting observed wage and rents disparities across regions due to transaction costs. Given the importance of factor markets to the present analysis, the model was modified to incorporate an explicit supply of land and migrant labor. In order to reflect the sluggishness of land-use change due to conversion costs and managerial inertia, the allocation of land across uses was restricted through a nested constant elasticity of transformation (CET) supply function [32-34]. The function was calibrated using ENHRUM data and econometric estimates available in the literature [34-36]. In modeling migrant labor, supply elasticities were estimated econometrically using survey data [31]. Elasticities vary across household groups and regions, reflecting actual differences in access to foreign and domestic labor markets.

In a final stage, the five regional models are integrated into a model of rural Mexico where other market balances are determined. This three-stage, agent-based modeling approach provides much greater detail than aggregate general equilibrium (CGE) models [14, 15], incorporating differences in prices, production technologies and market participation across regions and individual agents.² It also provides greater flexibility, as it allows heterogeneous producers and consumers to respond idiosyncratically and interact with each other in local markets. For instance, a household that does not participate in food markets may still employ wage labor in subsistence crop production using a technology that is distinct from that of commercial households. It may also sell its labor to other farmers. Each farmer's valuation of the subsistence crop is represented by a household-specific shadow price, and each household's demand for market and non-market goods is distinct from others'.

Simulation models often have been criticized, described as black boxes supported by poor data. This might apply to some aggregate models used in the past. Our disaggregated, agent-based approach

² Some aggregate models have separate demand equations for household groups, but market access, prices and production accounts (and thus technologies and participation in all production activities) typically are shared and performed by a single representative agent [14, 15].

overcomes the first misgiving by explicitly modeling in minute detail the processes that generate a particular outcome [20]. It addresses the second criticism through use of farm-level survey data. Out-of-sample prediction and sensitivity analysis are the two main tools used to validate simulation models. Accurate ex-ante prediction of land-use changes in 2008, following the corn price surge, establishes our model's validity in land-use analysis [20, 28].

2.1. Data

Data on non-rural production (*i.e.*, the activities of absentee or non-rural producers) were derived from the Mexican government's Agricultural Information System (SIAP) after adjusting for the share of production pertaining to rural producers [28]. Data on non-rural technologies were derived from published input-output matrixes for different regions [36]. The Mexico National Rural Household Survey (ENHRUM) was the source of all data for rural areas. Designed in collaboration with Mexico's Census Bureau, the survey's sampling frame provides a statistically reliable characterization of Mexico's population living in rural areas, *i.e.*, in communities with fewer than 2,500 inhabitants. The survey provides detailed data on assets, endowments, productive activities and market participation for 1765 households. Net incomes for sample households were estimated based on detailed data on agricultural and non-agricultural activities and other income sources, including, on- and off-farm labor, migration and public transfers. The sum of income from these sources equals household total net income.

Summary statistics for each of the four household groups can be found in Ref. 31. Rural incomes are highly diversified, and income sources vary sharply across the four groups. Although most rural households grow crops, the share of net income from this activity in total income ranges from less than one per cent (for landless households) to 15.3% (for the largest landholding group). Livestock accounts for another 0.9% to 6.9% of total rural income. Rental income constitutes between 3.4 and 4.4% of total income for the landed groups but logically was negligible for the landless group. The lack of correlation between landholdings and average per-capita income is due to the weight of off-farm income from wages, migrant remittances, public transfers, and non-agricultural production. By far the largest rural income

share is from wages (43.1 to 64.1%), but only 13% of wages come from farm work, reflecting rural households' integration with non-agricultural labor markets. Predictably, while the share of total income from crop production activities is highest for large-holder households, the small-holder and landless households receive most of their income from wage work, mostly off-farm.

2.1.1. Corn production and output

Of the 21.7 million hectares of cropland in 2002, the year of the survey, 40% were sown to corn. Rural households cultivated 37% of this area but produced only 10.5% of total corn output. Rural households were responsible for 60% of the area and 23% of the output in Southeast Mexico, but only 11% and 2%, respectively, in the Northeast. Average corn yields were 3.2 tons per hectare (ton/ha): 2.3 ton/ha in rainfed areas and 8.5 ton/ha under irrigation. Average yields ranged from 1.5 ton/ha in the Southeast to 7.2 ton/ha in the Northwest. Yields obtained by non-rural producers across Mexico were 5.6 times higher than those of rural producers (0.8 ton/ha). The difference in yields between non-rural and rural producers was 720% in West-central Mexico but only 25% in the Northwest.

2.1.2. Land endowments and markets

The average rural landholding is 4.8 hectares but the standard deviation is large (25.1), reflecting a high degree of landlessness. Except for the landless, every household group in rural Mexico rents land both out and in. In Northeast Mexico, rural households rent more land out than in, which means that 65% of rented land is rented to absentee producers. In other regions, rural households rent up to 8 times more land in than out. At least 25% of land rented by rural households in these regions belongs to absentee landowners. Accordingly, in the model, excess demand is satisfied by absentee producers in every region but the Northeast, where absentee producers absorb the excess supply of rural land.

2.1.3. Labor markets

Rural households are net suppliers of local wage labor and migrant labor. Unsurprisingly, the supply of local wage labor is greatest among landless households, but even large-holders are net suppliers in every region but the Northwest. In the latter region, around 25% of the rural supply of wage labor commutes into urban areas on a daily basis. In other regions, less than 15% of the local wage labor commutes. Up to 20% of the remaining labor is employed by neighbors; the rest is employed locally by outside agents or institutions, including absentee producers and the three levels of government. In North and Central Mexico, labor demand by absentee producers is large enough to absorb the excess supply of local labor and employ migrants from other regions.

3. Results

Corn output grows 1.5% following the increase in this crop's price in the first scenario. Similarly, the output of cash crops grows 1.5% after their own prices increase in the second scenario. Corn sales nevertheless grow considerably more in the first scenario than cash-crop sales in the second: sales receipts are 16% greater for corn than for cash crops. In percentage terms, cash-crop sales grow by 1.5%, while corn sales grow by 10.6% (Tables 1, 2). Clearly, the market supply of corn is surprisingly elastic. The reason is that corn market surpluses increase largely at the expense of on-farm consumption, which falls in response to prices. In contrast, given that on-farm consumption of cash crops is nil, cash-crop sales grow only to the extent that output does. This result might seem surprising in light of the classical farm-household model [29], where consumption of staples grows with prices due to higher incomes, reducing market surpluses. In fact, the same "income" effect is observed here in both scenarios; but price changes have additional, indirect effects on both farmers and households that ultimately result in greater corn sales. Indirect impacts such as these, known as general equilibrium effects, are observed only when the interactions among agents are analyzed in an economy-wide context, as done here. In this case, these effects are felt first within the agricultural sector, but they ripple gradually across the entire economy with unexpected albeit important implications for rural development, land use and food security.

Each sector's contribution to agricultural growth clearly depends not only on the extent of its own expansion, which is similar for cash crops and corn, but on the sector's relative size. The gross value of the cash-crop sector is over four times greater than that of corn, so the former's expansion has a greater weight in agricultural gross product. Its contribution to growth also depends on whether the focus is on gross product or in the generation of value added. A major determinant of changes in these two variables is the way in which scarce productive factors, particularly land, are reallocated across economic activities after the price shock. In this case, land in corn expands 2.5% after an increase in corn prices, but total cropland grows only 0.1%, while demand for labor does not register a significant increase (Table 1). By comparison, the area under cash crops expands only 0.9% after an increase in cash-crop prices, but total cropland and demand for rural labor increase 0.5 and 0.7%, respectively. Overall, the expansion of cash crops is associated with a 2.8% increase in the agricultural gross product and a 3.6% increase in its net product or value added (Table 1); the expansion of corn (after an increase in its own price) results in 0.4 and 0.8% growth in these variables, respectively (Table 2).

Changes in demand for land and labor have distinct effects on wages and rents across Mexico depending on the relative importance of cash crops and corn in each region. After corn prices rise, landowners' rents increase between 0.2% in Northeast (NE) Mexico and 3.0% in the Southeast (SE) (Table 4). Farm wages increase up to 0.8% in the Northwest (NW) region but not significantly in the NE. Increases are considerably higher after cash-crop prices rise: cropland rents increase between 4.0% in the NW region and 5.9% in Central (C) Mexico, while wages increase between 0.2% in the NE and 3.4% in C Mexico (Table 3). Higher demand for land and labor combined with higher rents and wages explains why agricultural value added increases substantially more with cash-crop prices than corn's (Tables 1, 2).

Changes in land rents, wages and profits determine the opportunity cost of uncultivated land, which ultimately drives land-cover change and deforestation. Crop prices considered here generate profits equivalent to at least 5% of cropland rents in every region (Tables 3, 4); but the availability of pastures mitigates the encroachment of forests that otherwise would ensue, since pastures are more easily converted into cropland than forests. Expected changes in the opportunity cost of land at the forest edge

reflect the relative availability of pastures across regions: the opportunity cost of uncultivated land rises between 0.1% in NE Mexico and 2.0% in the SE after an increase in corn prices (Table 4). This opportunity cost increases considerably more after cash-crop prices rise, i.e., between 2.0 and 4.9%; but in this case, increases are largest in C and West-central (WC) Mexico, where cash crops have the greatest weight (Table 3). Since the expansion of the agricultural frontier is not immediate, existing agricultural land is reallocated in the short-term according to relative changes in cropland rents and profits. Thus, corn land and output contract 1.7% and 1.3%, respectively, after an increase in cash-crop prices (Table 1). The land-intensive livestock sector experiences a similar contraction. An increase in corn prices and an expanding corn sector have a smaller toll on other land-based activities: cash crops and livestock contract only 0.2% after corn prices rise (Table 2). Again, these responses vary widely across regions reflecting changes in local rents, wages and profits (Tables 5 – 14 in Supplementary data).

Crop expansions entail the reallocation of production factors not only across activities but also across farms, e.g., between rural farms and farms owned by absentee (i.e., non-rural) producers. This reallocation is greatest after an increase in corn prices: absentee producers employ 0.4% more cropland and labor after the shock, while demand for these factors among rural producers decreases 0.6 and 0.3%, respectively (Table 2). Accordingly, corn output increases 3.7% in non-rural farms but decreases 0.6% in rural farms. The reason is that the expansion pursued by rural and non-rural large-holders (and the ensuing increase in rents and wages) forces small and subsistence farmers to down-scale their own activities. This has implications on the demand and supply of corn. Sales of corn increase sharply as land is reallocated from subsistence to commercial farms, but on-farm consumption necessarily declines. Since corn purchases also diminish after prices increase, the deficit of corn in rural areas contracts nearly 30% even as the output of rural farms drops. In contrast, non-rural farms' surpluses increase 3.7%, contributing an additional 10.6% to corn volumes available for urban and industrial uses, including feedstocks. Significant differences are observed across regions. In SE Mexico, the consumption of corn of all rural-household groups falls more than their output, reducing the region's large deficit by almost 16% (Table 10). In C Mexico the current deficit of corn is transformed into a small surplus despite a

2.5% contraction of rural farms' output (Table 11). In contrast, every group in the NW except the landless expands its output and sales of corn, expanding the region's large surplus by 4.0% (Table 11).

The demand and supply of corn is affected also after an expansion of cash crops. In this case, non-rural corn surpluses contract 1.3% as producers turn to cash crops; and rural deficits grow 16% as households substitute purchased corn for on-farm production. Corn volumes available for non-rural uses decline 4.9% as a result.

Agricultural price shocks have implications beyond agriculture. As crop production expands, the increase in rural wages is felt across the rural economy. Non-agricultural activities contract 0.4 and 1.9% after the expansion of corn and cash crops, respectively (Tables 1, 2). Thus, the entire rural economy grows at considerable lower rates than the agricultural sector. The gross product of rural areas still grows 1.7% after cash-crop prices rise but only 0.2% after corn prices. Net growth is slightly higher: rural value added increases 2.6 and 0.6% after cash crops and corn, respectively (Tables 1, 2). Overall, the expansion of cash crops contributes more to rural economic growth in every region but the SE, where the economy grows as much as with cash crops as with corn. But growth is not distributed homogeneously within these regions. Aggregate-growth statistics reported above conceal important differences between rural and non-rural farms. For instance, after accounting for non-agricultural activities, non-rural producers generate 3.6% more value added than before cash crops expand; rural households only 1.6% (Table 1). Differences between these groups are more pronounced after corn expands. In this case, non-rural producers generate 0.9% more value after the expansion; rural households generate only 0.2% more (Table 2). These differences have important repercussions on the distribution of income, but identifying winners and losers requires accounting for the redistribution of value added among landowners, workers and capital owners.

The contraction of subsistence output and non-agricultural income observed in both scenarios represents a considerable loss for most rural households; but their wage earnings rise as household members hire out their labor. Simultaneous increases in on-farm employment and wage rates result in a 4.9% increase in wage income after cash-crop prices rise; but wage income rises only 0.7% after corn

prices because demand for labor is tempered by the heterogeneity of supply responses within this sector. Incomes do not rise uniformly across the population; changes are loosely associated with landholding sizes. Wages constitute an outlay for rural large-holders that employ labor, e.g., in NE Mexico. Rural large-holders in general earn 1.5% less in wages after corn prices increase, while landless households earn 1.1% more (Table 2). In contrast, every household group experiences an increase in wage income after cash-crop prices rise. Gains remain associated with landholding sizes, ranging from 1.9% for large rural landholders to 5.6% for the landless. At the same time, wage gains entail losses in other income sources. For instance, employment in local farms entices migrants to return to their communities and would-be migrants not to leave. Accordingly, remittances decrease 1.3% after an expansion of cash crops but only 0.1% after an expansion of corn (Tables 1, 2).

As opposed to wages, rents constitute a net outlay for rural households but a net gain for absentee landowners, who experience a 3.2% gain, after all income sources are considered, when biofuels are based on cash crops. Income grows only 1.0% for rural households. The same pattern is observed in every region, but it is slightly more equitable in the NW, where rural and non-rural incomes increase 2.6 and 4.2%, respectively (Tables 5 - 9). It is least equitable in the SE, where rural incomes barely increase. In contrast to wage-income gains, full-income changes are positively associated with landholding sizes. However, differences across groups and regions depend not only on factor endowments, as in aggregate models [14, 15], but also on each group's activities. After an increase in the price of cash crops, income gains range from 0.4% for the landless to 2.3 and 3.2% for rural and non-rural large-holders, respectively. Gains do not differ significantly in nominal and real terms due to the small weight of cash crops in household consumption. The outcome is qualitatively different when corn prices rise. In this case, rural households' income grows 0.2% nominally, but these gains become 0.4% losses in real terms due to corn's weight in rural diets (Table 2). Absentee producers' income still grows 0.9% in real terms. Nominal-income changes remain tied to landholdings sizes: absentee producers and rural large-holders experience 0.9 and 0.7% gains, respectively; households with less than 5 hectares or no land do not experience any nominal gains. All rural household groups experience real-term losses, but differences

across groups depend on consumption patterns more than landholding sizes. Outcomes are similar in every region but the NE, where incomes register few changes because of corn's low weight in the local economy. In SE and C Mexico, where corn is most important, real incomes decrease up to 1% after corn prices rise.

4. Discussion

Simulation results suggest that modest increases in crop prices could generate considerable surpluses for an emerging biofuels industry whether this is based on cash crops or the staple corn. Sales of feedstocks could represent a significant flow of revenue into the agricultural sector. A 5% increase in price could raise sales of corn and cash crops by US\$273 and \$236 million, respectively. However, the implications on agricultural growth and the rural economy depend on factors other than revenue. Some of these implications will be similar whatever fuel crop is used. In both cases examined, for instance, surpluses will not derive from productivity-enhancing innovation but from higher profits associated with sales. Although some growth will be tied to higher productivity, namely in corn, most will be associated with an area expansion. Thus, feedstock supplies will come at the expense of other land-based activities, particularly if the agricultural frontier were tightly constrained. To this extent, the ability of feedstocks to foster agricultural growth could be limited. Other repercussions will depend on the particular fuel crop used. Cash crops, given their higher revenue per unit area, could have a greater aggregate impact on the rural economy than corn. As opposed, production of corn, particularly for on-farm consumption, often constitutes a drain of cash flows into rural Mexico [28]. The specific costs and benefits experienced by various sectors of the population will depend nevertheless on the microeconomics of the supply response of each type of crop.

Aggregate supply responses conceal the reallocation of land and labor among individual farms [20]. As demand for feedstocks grows, prices will determine the optimal allocation of these resources. In the case of corn, only the most efficient farms might be capable of adding value and expand in the face of higher land and labor costs. Thus, the output of large farms might expand significantly, but small farms

could have few reasons to expand. Subsistence corn farmers are relatively inefficient and do not always value corn at market prices [37, 38]. Thus, they might not benefit from price increases but would still experience higher wages and rents. Whether these constitute actual outlays or only the opportunity costs of family land and labor, many of these farmers could forsake subsistence activities in favor of wage work in order to secure an income. A corn-based biofuels industry therefore could entail an expansion of commercial corn output at the expense of subsistence agriculture. A corn sector restructured in such a way could generate substantial feedstock surpluses without radically altering land and labor markets. Supply responses are much more homogeneous in the cash-crop sector, so demand for land and labor could rise considerably more if biofuels are based on alternative crops. Differences between a feedstock sector based on cash crops and one based on staples could have important implications on local livelihoods.

Feedstocks in general could be a large source of added value, but this value would not necessarily be appropriated by farmers. According to our results, rural farms might generate 1.6% more value after a 5% increase in cash-crop prices, but rural incomes would increase only 1.0%. Absentee producers could face an analogous situation since profits tend to dissipate as supply adjusts. But producers have other income sources. Value generated in the feedstock sector ultimately will be distributed between producers and the owners of land, capital and labor. Some payments to factor owners will help distribute biofuels' benefits more equitably. Large-holders relying on hired labor might need to share their increased revenue with farm workers through wage increases. Small farms also would fail to fully appropriate the value of their output, having to pay rents to landholders and the owners of agricultural machinery [28]. Although the size of these transfers is tightly linked to each stakeholder's endowments, factors beyond stakeholders' control will play a significant role. Aggregate demand and supply determine relative rent and wage changes, as do restrictions on the exchange of land, labor and capital through local markets. The cost of commuting or migrating restricts the mobility of labor, creating temporary disparities in regional wages. The immobility of land and restrictions on land use can create even greater disparities in rental rates across regions. Wage increases would benefit the poor, mostly working rural households, but

changes in rents and profits can have regressive effects. Rents and profits also tend to flow out of rural areas. Other market imperfections and limited availability of arable land could allow rural farmers to maintain a profit; but over half of all corn produced in rural areas generates no profits; it is consumed on-farm either as food or feed: 87% of rural households do not sell corn [28]. In sum, few households in rural areas would benefit directly from the feedstock sector, particularly one based on corn.

Alternatively, analysts believe that the biofuels industry could have a multiplier effect on the rural economy that would help spread its benefits more widely across the population. However, most revenue generated by the feedstock sector could elude rural Mexico entirely: 60% of the area in corn and nearly 70% of that in cash crops is managed by absentee producers [28]. Moreover, given their higher productivity, non-rural farms currently account for an overwhelming share of agricultural output: nearly 90% in the case of corn [28]. Since some rural farms could move out of corn production after a price shock, a corn-based feedstock sector might not generate any growth in the rural agricultural sector. This would not be the case for cash crops. Some of the revenue generated by cash crops might leak out of rural areas through capital and land rents or input purchases, but wages would flow in the opposite direction. In some places, this cash flow could increase demand for locally-produced goods and promote rural economic activity, but several factors could preclude such outcome in Mexico.

Paid employment presumably could have a similar effect on the rural economy to that of migration, which helps fund productive investment in rural areas but reduces the availability family labor [39]. In this case, however, employment in the feedstock sector would be mostly a substitute for increasingly unaffordable subsistence activities.³ Moreover, the amount of income available for investment would depend on the scale of wage increases, which would be small and temporary as long as rural households remain a highly mobile labor force via migration. In the long run, rural wages can only rise to the extent that labor productivity increases; but there is no indication that feedstocks would induce such change. Temporary wage increases would still benefit households, but they also constitute a cost for the rural

³ This might not be unique to the feedstock sector. In fact, wage income has increased substantially in rural Mexico since the mid nineties, largely replacing on- and off-farm activities as a source of income [40].

economy. Since wage increases would not be transmitted to urban markets, they would also diminish the relative competitiveness of local goods vis-à-vis industrial substitutes. Commercial integration with urban areas makes such substitutes widely available. As a result, commerce could siphon cash flows out of rural areas as soon as labor markets brought them in.

More generally, analyses that overlook price effects within rural economies overestimate the indirect benefits and underestimate the costs of the feedstock sector and biofuels industry. Crop expansions based on prices impose costs on other sectors, so demand for feedstocks alone will not likely promote widespread growth of the rural economy. Absentee producers who are not part of the rural economy do not experience these costs, so their earnings could rise as much or more than agricultural revenue (Tables 1, 2). Since rural households depend more closely on the local economy, their incomes could grow considerably less or not at all. Absence of real income gains in fact could be the foremost factor precluding a rural multiplier effect, most clearly in the case of corn.

As discussed above, feedstock surpluses would derive mostly from an increase in area. An additional 325×10^3 hectares could be sown to cash crops in Mexico after a 5% increase in prices—slightly more than the Biofuels Program's initial goal. If this had no effect on the agricultural frontier, as government officials expect, some 66×10^3 hectares could move out of corn and into alternative fuel crops. This would exacerbate the rural corn deficit, ultimately reducing domestic corn volumes available for urban and industrial uses. Since US and Mexican corn markets are integrated, there should be no shortfall in supply. That is, alternative fuel crops might not increase the price of food in urban Mexico, but they would exacerbate the country's dependence on food imports, which poses its own risks to national food security [8].

Mexico would not need to import more corn if producer prices for this crop rose within the scope of the Biofuels Program. Some 245×10^3 hectares could be added to this crop after a 5% price increase. Surpluses available as biofuel feedstock would increase significantly, but these would come largely at the expense of subsistence production. Overall, because of feedstocks' inevitable impact on the opportunity cost of land (i.e., rents), on-farm consumption will likely drop markedly whether corn or cash crops are

used for fuel. However, the consequences on food security at the household level remain uncertain, particularly for smallholders and the landless. These groups might devote more time to wage labor (probably in the feedstock sector) but spend their earnings substituting for declines in subsistence production. This would replace one type of risk for another: households would be less vulnerable to weather shocks but more exposed to changes in the terms of trade between food and labor [41]. On the other hand, reducing the biofuel industry's repercussions on food safety would require expanding the agricultural frontier.

5. Conclusions

The Mexican Biofuel Strategy is based on the assumption that cash flows from feedstocks will reactivate agriculture, delivering considerable benefits to the rural population [26, 27]. It also assumes, perhaps because of wide access to corn imports, that food security will be safeguarded by the use of cash crops for fuel [26, 27]. Simultaneously, it expects that the program will have no impact on the agricultural frontier [26]. Our results confirm that the demand for feedstocks foreseen for the Program's first year could be satisfied through domestic supplies of either cash crops or corn given modest price increases. Supply responses would promote growth, particularly if cash crops were used. Nevertheless, the repercussions on rural incomes, food security and land use would not be as expected in the Strategy.

The Mexican Biofuels Commission coordinates efforts to achieve the Biofuels Law's goals: diversifying the nation's supply of energy while promoting rural development, improving the poor's living standard and reducing carbon emissions [24]. However, the Strategy on which this coordination is based does not fully recognize the trade-offs among these goals. For instance, the study that underlies the Strategy considers only risks to aggregate food availability [25, 26, 42]. It cautions against the use of corn given the country's dependence on imports but concludes that incorporating 800×10^3 hectares to alternative fuel crops would not compromise food security. As discussed above, avoiding the use of staples as feedstocks does not guarantee that the rural poor will have the same access to food. Moreover, the Strategy literally confuses agricultural growth for rural development [26]. A significant expansion of

agricultural output nevertheless could entail scant growth of the rural economy or, in the case of corn, a contraction of its gross product. Even if the value added of rural farms grew, this need not imply income gains for rural households. Unless labor productivity rises, a combination of stagnant wages and rising food prices could redistribute the wealth generated by the biofuel industry regressively, increasing inequality.

As for the implications on land use, it is a truism that as long as total cropland remains constant, food and fuel crops will compete for land. The Mexican Biofuels Program aims to sow 300×10^3 hectares to fuel crops in its first year without impinging on the forest margin [25]. However, the Biofuels Strategy does not contemplate raising the productivity of either labor or land [26]. Thus, it is unlikely that feedstock production will not raise the opportunity costs of forest lands. Conversion of land from other uses might reduce forest-cover losses in NE Mexico, where pasture is considerably more abundant than cropland. But the opportunity costs of land in other regions could rise up to 5% with a biofuel industry based on cash crops and 2% with one based on corn (Tables 3, 4). This would not necessarily translate into deforestation in every region, particularly with corn. Water availability could constrain the agricultural frontier in NW Mexico, where corn is grown on irrigated land. But a corn-based industry would raise the opportunity costs of land most sharply in the SE, where forests are commonly cleared for corn and deforestation rates already are Mexico's highest [43]. An industry based on cash crops would have a much greater impact in the SE but most of all in other regions. Since these crops can grow on rainfed land, a biofuels industry could entail significant land-cover changes. These impacts will be greater if the Biofuel Program expands five-fold in its second year as planned. Given the ineffectiveness of current conservation programs, particularly in SE and C Mexico, this could translate into deforestation [28].

Around the world, farmers are responding to demand for feedstocks from an emerging biofuels industry. Initiatives promoting biofuels proclaim ambitious social, development and environmental goals. A realistic assessment of biofuels' potential requires considering all aspects of this complex system simultaneously. An elastic supply of feedstocks, for instance, is essential to maintain biofuels'

competitiveness; yet a rise in crop prices is necessary to draw some of the benefits into the agricultural sector. Likewise, measures that could distribute biofuels' benefits more widely (e.g., through smallholder out-grower schemes) tend to reduce the industry's profitability [14, 15]. Accurate assessments also require detailed data. Current assessments seem to suggest that biofuels could enhance growth and reduce poverty in various Sub-Saharan countries without endangering food security; but the studies on which they are based assume ideal conditions [14, 15]. Stylized, aggregate models cannot be the basis for detailed assessments or accurate forecasts. A common assumption in these models is that the industry's benefits would be distributed widely across the population irrespectively of who undertakes production, i.e., that returns to land and labor would increase homogenously. Our analysis shows why this might not be the case in a real economy.

Our assessment of the Mexico Biofuels initiative reveals significant trade-offs among its goals. Biofuels might help diversify Mexico's energy supplies but could contribute little to rural development or reducing poverty and equality. The implications on food security also are uncertain. Poverty reduction and food security depend crucially on returns to productive assets [41]. An emerging feedstock sector could change the relative value of land vis-à-vis labor, which is the main asset of landless rural households. It could also increase land rents and profits; but this could bring changes in control over the land and the distribution of rents and profits, which usually hurts the most vulnerable [44, 45]. Without additional policies, these changes could compromise food security and emissions reductions. In order for government to play its role, it must acknowledge these trade-offs. A more in-depth analysis of the Mexican Biofuels initiative will require disclosure of hitherto unpublished data on the type and amount of public resources flowing into the feedstock sector. Recent administrative reforms in the Ministry of Agriculture have made this information unavailable.

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Appendix A

Model equations

First stage (household) equations and constraints:

Households are assumed to maximize utility:

$$U^h = U^h(X_i^h) \quad i = 1, \dots, I \text{ goods} \quad (\text{A.1})$$

where X_i^h is household h 's demand for good i , subject to the following four constraints:

Cash Income:

$$\sum P_i X_i^h = Y^h \quad (\text{A.2})$$

where P_i is the price of good i and Y^h is the household's income, the sum of net output, factor payments, remittances and exogenous income.

Production Technologies:

$$Q_i^h = Q_i(FD_i^h, V_i^h) \quad (\text{A.3})$$

where Q_i^h is the household's output of good i , FD_i^h is a vector of f factor inputs (labor, land and capital)

whose elements are $FD_{i,f}^h$; and V_i^h represents other, intermediate inputs. Production is represented by

Cobb-Douglas production functions, where exponents are equal to measured factor shares in value added.

We adopt the usual assumption in agricultural-household models that capital is fixed. Land, however, is not

fixed, within the limits imposed by the imperfect transformability of land from one use to another (see

below). Following the economy-wide modeling tradition, constant input-output ratios are assumed for

other (intermediate) inputs. Unlike aggregate CGE models, however, these input-output ratios vary

widely across household groups and regions, reflecting constraints (e.g., liquidity on small farms) and

other considerations limiting input (e.g., fertilizer) demands. This simple specification permits estimation

of multiple separate models and lend transparency to the results. Results are generally robust to the specification of functional forms inasmuch as scenarios involve marginal changes in exogenous variables and the model is always estimated at the same point given by survey data. Despite the linearity of individual responses, aggregate supply and demand responses are highly nonlinear, shaped by households' production and consumption parameters and the endogenous price of the composite agricultural good.

Endowments:

$$\sum_{i=1}^I FD_{i,f}^h + FS_f^h + MIG_f^h = \bar{T}_f \quad (A.4)$$

$FD_{i,f}^h$ denotes the household's demand for factor f in production activity i ; FS_f^h is the household's net supply of factor f to regional markets; MIG_f^h is its net supply outside the region (for example, labor migration); and $\bar{T}_f$ is the household's total factor endowment.

Remittance functions:

$$R_f^h = \phi_f^h(MIG_f^h) \quad (A.5)$$

In addition to the previous constraints, first-order conditions for utility maximization imply the following:

(a) Marginal value product equals price for all factor factors f :

$$P_i Q_{f,i} = w_{i,f} \quad (A.6)$$

where $w_{f,i}$, a factor's price in activity i , equals either w_f , regional prices for factors that are mobile across production activities and households (in our simulations, these are labor and land), or $\omega_{f,i}$, shadow price of factors fixed by activity and household (capital).

(b) Marginal remittances (the marginal value product of migration for the household) equals regional wage

w_f :

$$\partial R_f^h / \partial MIG_f^h = w_f \quad (A.7)$$

(c) Marginal utility equals the marginal utility cost of consumption:

$$U_i^h = \lambda^h P_i \quad (A.8)$$

where λ^h is the marginal utility of income.

Households' cash income constraints are binding:

$$Y^h - \sum P_i X_i^h = 0 \quad (A.9)$$

For subsistence households, non-traded goods are constrained by:

$$Q_i^h = X_i^h + V_i^h, \quad i \in \text{nontradables} \quad (A.10)$$

These first-order conditions yield consumption-demand functions of the form:

$$X_i^h = X_i^h(P, Y^h), \quad i = 1, \dots, I \text{ goods} . \quad (A.11)$$

Consumption demands are represented by a linear expenditure system (LES) with no minimum required quantities. The parameters in the demand equations are set equal to measured budget shares for each household and good.

Second stage (regional) constraints:

The general-equilibrium conditions imply equilibrium in rural factor markets,

$$\sum_{h=1}^H \left(FS_f^h - \sum_{i=1}^I FD_{i,f}^h \right) = 0 \quad (A.12)$$

and material-balance equations,

$$MS_i^r = Q_i^h - \sum_{h=1}^H X_i^h, \quad (A.13)$$

for every good i and all households h in each region, where MS_i is net regional marketed surplus.

Rural trade balance is implied by the other equations in the model:

639
$$\sum_{i=1}^I p_i MS_i + \sum_{h=1}^H R_f^h = 0 \quad (\text{A.14})$$

640

641 Third stage (economy-wide) constraints:

642 Finally, material-balance equations imply that the sum of surpluses of good i for all regions r be equal to net
 643 exports:

644
$$\sum_{r=1}^5 MS_i^r = NX_i. \quad (\text{A.15})$$

645

Table 1. Percentage responses to a 5% increase in the price of cash crops in Mexico. Aggregate, nationwide responses to the price change (a), can be disaggregated into responses by absentee producers (b) and rural producers (c), which in turn can be disaggregated across households (d to g) based on landholdings (see Methods). Each of these groups' responses can be disaggregated further according to geographical region (SI Tables S5 – S9).

	(a) Mexico (b + c)	(b) Non-rural producers	(c) Rural households (d to g)	Rural households			
				(d) Landless	(e) Small-holders (<2 ha)	(f) Medium-holders (2-5 ha)	(g) Large-holders (>5 ha)
<i>Output</i>							
Corn	-1.3	-1.3	-1.4	-2.6	-1.3	-1.5	-1.0
Cash crops	1.5	1.8	1.1	2.0	0.8	0.6	1.4
Livestock	-1.3	-1.1	-2.2	-2.0	-1.9	-2.6	-2.2
Non-ag			-1.9	-2.6	-2.0	-	-1.3
<i>Surplus [deficit]</i>							
Corn	-4.9	-1.3	[15.9]	[50.0]	[15.9]	-67.4	[8.7]
<i>Revenue & value added</i>							
Total gross product	1.7	2.5	1.1	-0.8	1.7	3.2	2.8
Total value added	2.6	3.6	1.6	-0.3	0.6	2.5	3.6
Ag gross product	2.8	2.5	3.2	1.0	2.8	3.8	3.6
Ag value added	3.6	3.6	3.7	3.3	1.7	3.6	4.1
<i>Factor use</i>							
Labor	0.7	2.0	-0.4	-2.0	-2.6	-1.2	0.2
Corn land	-1.7	-1.7	-1.8	-3.0	-1.5	-1.7	-1.7
Other cropland	0.9	1.0	0.4	1.4	-0.6	-0.7	0.8
All cropland	0.5	0.9	0.0	0.4	-0.9	-0.8	0.4
Pasture	-1.4	-1.2	-2.1	-1.2	-2.4	-2.6	-2.4
<i>Income</i>							
Remittances			-1.3	-1.1	-1.2	-1.6	-1.3
Wages			4.9	5.6	4.7	5.0	1.9
Nominal income		3.2	1.0	0.4	0.7	1.5	2.3
Real income		3.2	1.05	0.4	0.7	1.5	2.3

Table 2. Percentage responses to a 5% increase in the price of corn in Mexico. For regional disaggregation see SI Tables S10 - S14.

	(a) Mexico (b + c)	(b) Non-rural producers	(c) Rural households (d to g)	(d) Landless	Rural households			(g) Large-holders (>5 ha)
					(e) Small-holders (<2 ha)	(f) Medium-holders (2-5 ha)		
<i>Output</i>								
Corn	1.5	3.7	-0.6	-6.4	-3.5	-3.6		4.2
Cash crops	-0.2	-0.3	-0.2	-0.4	-0.1	-0.1		-0.3
Livestock	-0.2	-0.2	-0.4	-0.5	-0.3	-0.3		-0.4
Non-ag			-0.4	-0.6	-0.5	-		-0.3
<i>Surplus [deficit]</i>								
Corn	10.6	3.7	[-29.5]	[20.4]	[-15.0]	23.1		[-32.6]
<i>Revenue & value added</i>								
Total gross product	0.2	0.6	-0.1	-0.3	-0.7	-0.4		1.0
Total value added	0.6	0.9	0.2	-0.3	-0.5	-0.3		1.2
Ag gross product	0.4	0.6	0.1	-1.1	-1.0	-0.5		1.2
Ag value added	0.8	0.9	0.5	-1.0	-1.2	-0.5		1.4
<i>Factor use</i>								
Labor	0.0	0.4	-0.3	-0.5	-0.8	-0.4		0.3
Corn land	2.5	4.7	-1.7	-10.3	-8.6	-8.7		5.6
Other cropland	-0.3	-0.4	-0.3	-0.4	-0.1	0.0		-0.5
All cropland	0.1	0.4	-0.6	-2.7	-3.2	-1.2		0.5
Pasture	-0.3	-0.2	-0.4	-0.3	-0.7	-0.5		-0.4
<i>Income</i>								
Remittances			-0.1	-0.1	-0.1	-0.1		-0.1
Wages			0.7	1.1	0.6	0.8		-1.5
Nominal income		0.9	0.2	0.0	0.0	0.0		0.7
Real income		0.9	-0.36	-0.1	-0.8	-0.7		-0.5

Table 3. Percentage changes in wages, rents and profits in response to a simulated 5% increase in the price of cash crops. Cash crop prices have a direct positive impact on cropland rents (c) and wages (f), which indirectly reduces the effect on cropland rents. Cash crop prices also create profits for cash-crop producers (b) but can reduce those of corn producers (a). Pasture rents change marginally (d). Changes in the opportunity costs of land at the forest margin (e) reveal the balance of all these forces within each region.

	(a) Corn profits	(b) Cash-crop profits	(c) Cropland rents ^a	(d) Pasture rents	(e) Opportunity costs of land ^a	(f) Wages
Southeast	0.4	8.7	5.3	0.3	3.6	0.7
Center	-0.3	6.3	5.9	-0.1	4.9	3.4
West-center	0.3	5.7	4.7	0.7	4.3	2.0
Northwest	0.6	4.9	4.0	0.0	3.3	2.4
Northeast	0.9	5.5	5.4	0.1	2.0	0.2

a. Cropland rents are composite rents for all crops; the opportunity costs of land at the forest margin are composite rents for all agricultural land, *i.e.*, cropland and pasture.

Table 4. Percentage changes in wages, rents and profits in response to a simulated 5% increase in the price of corn. Corn prices have a direct positive impact on cropland rents (c) and wages (f), which indirectly reduces the effect on cropland rents. Corn-price changes also create profits for corn producers (b) but only marginally for cash-crop producers (a). Pasture rents change marginally (d). Changes in the opportunity costs of land at the forest margin (e) reveal the balance of all these forces within each region.

	(a) Corn profits	(b) Cash-crop profits	(c) Cropland rents ^a	(d) Pasture rents	(e) Opportunity costs of land ^a	(f) Wages
Southeast	6.5	0.0	3.0	0.2	2.0	0.2
Center	5.7	0.0	0.4	0.1	0.3	0.1
West-center	4.9	0.0	1.0	0.2	0.9	0.4
Northwest	6.1	0.3	1.7	0.0	1.4	0.8
Northeast	6.7	0.0	0.2	0.0	0.1	0.0

a. Cropland rents are composite rents for all crops; the opportunity costs of land at the forest margin are composite rents for all agricultural land, *i.e.*, cropland and pasture.