Impacts of the US Ethanol Boom in Rural Mexico

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Abstract. Assessing the human and environmental impacts of biofuels requires unraveling the connection between international trade, on one hand, and local land-use and social change, on the other, while accounting for cross-scalar linkages between and within social and environmental systems. We propose a disaggregated approach to model how macro shocks shape rural households' decisions, and how these decisions integrate onto aggregate supply and land-use patterns. The approach, built on an agent-based model of rural Mexico, is used to explore the impacts of ethanol-driven US corn price increases. Our estimate of a 5.7% expansion in corn area by 2008 and wide variation across regions corresponds fairly well with ex post reports. Estimates from alternative models exceed ours by up to 200%. Corn land expanded between 1.6% in the southeast and 16% in the northwest. A 3% increase in agricultural value added nevertheless did not promote rural development, whether measured in terms of total rural value added or income. Direct and indirect (multiplier) effects on rural incomes were limited. Rural households experienced a 0.02% increase in real income, while absentee (non-rural) landholders' income increased 3.9%. Our approach highlights the crucial role of local market conditions and interactions among microeconomic actors in shaping biofuels' impacts via local feedback mechanisms. It suggests that subsistence activities might keep deforestation pressures in check in some developing areas while precluding the rural population from benefiting. A disaggregated approach should help integrate future research on land-use change and economics.

A few years ago when high oil prices renewed public interest in alternative energy sources, analysts argued that bioenergy could help meet global energy needs sustainably while creating jobs and stimulating rural development, thus raising the poor's standard of living (1-5). Others countered that a rapidly growing biofuels industry might link the energy and crop sectors too tightly, increase crop prices and price volatility, threaten the food security of the urban poor, and promote deforestation (1, 5-7). Achieving food security and environmental conservation will require some kind of balance, since agricultural and economic growth are closely associated with energy consumption (5, 7-9). It is argued that the right balance could be attained through a combination of good policies and timing (1, 4, 7, 9); but the debate remains highly speculative, for neither the information nor the appropriate methods to strike such a balance have been available.

State-of-the-art macroeconomic models describe how social systems worldwide connect via international markets, linking energy demand, land use and food security (10-13, 42). In contrast to this macro focus in modeling, solutions to global problems often are believed to lie at the most micro level, in technological innovation. It is widely hoped that cellulosic technologies will raise the biofuel industry's efficiency, decreasing greenhouse gas emissions while helping conserve wildlife habitat and cropland (3-5, 14, 15). Similarly, biotechnology is expected to raise agricultural productivity and mitigate crop-price increases, favoring the poor (3, 4). An obstacle in the road to finding effective solutions is the lack of a clear understanding of how the macro and micro scales connect within social systems and of the cross linkages with environmental systems (16). In a coupled socio-environmental system, few direct linkages exist at the global scale. Most linkages operate at the national, sub-national or local level; they cross levels of organization and geographical scales, posing significant methodological challenges involving aggregation and inference (16-18). It is clear that, within social systems, national institutions and policies mediate between the international and local levels. But little is known of how macro forces seep into micro scales or micro processes integrate onto the macro level. Cross-scalar linkages, feedbacks and interactions are not well appreciated in economics (19, 20).

A key concept in land-use analysis is rents. Land rents are influenced by macroeconomic factors but also closely associated with households' decisions (20). In turn, household behavior is the proximate factor of land-use change connecting the social and environmental systems at their most basic level. Accordingly, land-use studies increasingly focus on household microeconomics (20, 21). Nevertheless, few studies have established an empirical connection between international trade and land-use changes at the household level (16). This paper proposes an approach to model the ways in which economic shocks at an international scale get transmitted to households, shaping their decisions, and how these decisions in turn integrate onto larger scales to generate aggregate supply responses and land-use patterns. The approach is built upon an agent-based model of rural Mexico, used here to explore the social and land-use impacts of ethanol-driven US corn price increases. Our findings highlight the crucial role of local market conditions and interactions among microeconomic actors in shaping these impacts.

Mexico and the World Food Crisis. It is clear that the recent boom of the ethanol industry in the US was a major force behind the 2006 price shocks that later developed into a world food crisis (22, 23). But few analyses of the industry's potential impacts outside the US were available in 2006. Analysts anticipated considerable increases in crop prices in some regions by 2020, but commensurate increases became widespread much sooner (3, 10, 12). Although prices were expected to remain high for the foreseeable future, the recent financial crisis has brought fuel and food prices down sharply and changed most expectations. This prevented the consequences of the price shock from reaching their fullest expression except in countries where the crisis began early, e.g., Mexico.

Corn is a staple in Mexico. Per capita consumption is one of the highest worldwide, and the country is the second largest importer of US corn. Imports represent a considerable share of domestic consumption. Moreover, a weak dollar cannot buffer producers and consumers in Mexico from price increases, as in other countries, for the peso is closely tied to the dollar. Not surprisingly, Mexico was expected to bear some of the most adverse impacts of prices increases and soon became the poster child of the food crisis (10, 23, 24). However, no in-depth analyses of the social and land-use implications are available yet.

Results

In Mexico, average producer corn prices at the end of the 2006/2007 cycle were up 23% from a record low a year before, while consumer prices increased 5% during the same period.[1] Using

[1] Sistema de Información Agroalimentaria y Pesquera (SIAP) <www.siap.gob.mx> and Banco de México < www.banxico.org.mx>.

our model to simulate these shocks, we estimate that corn land expanded 5.7% across Mexico by the 2007/2008 cycle, but regional responses varied widely as a result of local conditions. According to our model, corn land expanded almost 16% in northwest Mexico but only 1.6% in the southeast (Table 1). Our simulation draws light on the mechanisms that generated these aggregate supply responses and their association with rents in each region (Table 2).

The price shock created surplus rents (*i.e.*, profits) for corn farmers, generating a disparity across sectors that drew production factors into corn. As farmers converted land into corn and the sector expanded, rents diminished in corn while increasing in other crops (*i.e.*, factor reallocation allowed surplus rents to dissipate); but some disparities persisted due to short-run restrictions on land conversion and differences in land quality. Rent disparities surfaced also within the corn sector across regions: rents in corn increased 5 times more in the northeast and northwest than in central Mexico. All regional disparities were tied to differences in crop-price and wage changes.

Increases in prices affect land rents both directly and indirectly, through wages (20). In our short-run simulation, wages were driven up by the rising demand for labor in corn but not influenced by changes in productivity, which are visible only in the long run (25). Wage increases ranging from 2.0% in west-central Mexico to negligible in the northeast reflect multiple factors, including the size of the corn sector relative to the local economy and workers' access to distant labor markets via migration. As wages increased, land rents decreased and agricultural profits fell, partly offsetting the shock's positive direct effect on rents (Table 2). As a result, labor-intensive crops other than corn experienced only minute changes in rents after the price shock. Significant corn rents drove the rental rate for cropland up nevertheless. This increase drew pasture into cultivation in every region, pushed up rents in the livestock sector, and eventually led to an increase in the composite rent for agricultural land, which ultimately reflects the opportunity cost of land at the forest margin (Table 2).

Thus far we have referred only to aggregate responses to the shock, but these were actually derived by aggregating individual responses in the model. Individual responses varied widely across and within regions, reflecting not only differences among producers but also market interactions between different producer groups as they adjusted to the price shock. We aggregated individual producers into five groups in each region—four rural household groups and absentee landowners/producers, whom we call non-rural landholders (see Methods section).

The latter include Mexico's largest commercial producers. Each group's response to the price shock reflects its participation in markets or, in the case of subsistence producers, its lack of participation (Table 3). Commercial (*i.e.*, surplus) producers in every region responded directly to the shock, reallocating land and labor within their own farms. In contrast, subsistence growers did not experience a direct change in their crop's value since they are guided by household-specific shadow prices (26, 27). However, as commercial producers demanded more land and labor, local rents and wages increased. No one was entirely isolated from these changes, but not everyone was equally affected (28). Wages and rents raised production costs for large-holders, dampening their supply response. They also raised the opportunity costs of family land and labor for small-holders, lowering the value of corn production for home consumption. Individual supply responses differed because each producer responded to a particular combination of price, rent and wage changes based on farm-specific production technologies. Taken together, these disparate micro responses resulted in a muted aggregate supply response (Table 3).

We can unravel the relationship between individual and aggregate behavior further by focusing on factor use and rents in each region. Take for instance west-central Mexico (supporting information (*SI*) Table 4). Corn producer groups in this region adjusted their output by up to 26%; yet, aggregate regional output grew only 6.4%. Since producers observed different sets of price signals, rent disparities arose not only across sectors within the region but also across producers, with important ramifications for the land rental market. In order to capture surplus rents, absentee (non-rural) landholders, who account for most corn production, raised cropland rental rates considerably. But they also moved land out of the rental market to grow corn, at which they are more efficient than their rural tenants. While use of corn land on non-rural farms expanded 21.4%, it declined 14% on rural farms. Agricultural labor followed land from rural to non-rural farms (SI Table 4). Some of these workers were responding to an increase in wages; others were released from subsistence households, where the demand for family labor in subsistence production fell. Taking advantage of relatively stable consumer prices, rural households increasingly opted for purchasing corn in local markets and working for a wage, rather than growing corn for home consumption. As a result of the shock, subsistence corn production in west-central Mexico fell 23%, while commercial corn agriculture grew 17% employing additional cropland and labor.

West-central Mexico occupies an intermediate position in more than a geographical sense. It combines characteristics of agricultural sectors in the rest of the country, where either commercial or subsistence farms tend to dominate the landscape, and therefore supply responses are either more elastic or inelastic (SI Tables S5-S8). Widespread mechanization, high yields and access to markets allowed most farms in the northwest to boost corn surpluses in response to a 27.8% increase in corn rents (SI Table 5). Corn production spread as much on rural as on non-rural farms; corn land expanded 15.8%, and cropland rental rates increased 8.4%. In contrast, corn area expanded ten times less in southeast and central Mexico, where subsistence households ceded use of rented corn land to non-rural producers in response to a 3% increase in rental rates (SI Table 6). Subsistence households often face cash constrains and are very sensitive to cost increases.

In sum, supply responses across Mexico were shaped by local feedback mechanisms (*i.e.*, general equilibrium effects) that also determined the distribution of production factors and value added across farms, with implications on land use and income. The net value (*i.e.*, value added) of Mexican agriculture grew by 3% after increases in corn prices and output (Table 3); but most value was created on non-rural farms, given the reallocation of production factors. If non-rural producers owned all factors of production, they might have appropriated this value fully; but few farmers are self sufficient in both land and labor. As a result, corn rents were distributed across groups as economy-wide adjustments transformed them into profits for producers, higher wages for workers and land rents for landowners (Tables 2, 3). Preexisting factor endowments determined how much of this value reached each segment of the population. Some value spilled from non-rural farms into rural areas as wage income, but a similar amount flowed back out in the form of rental payments. Since rental rates increased up to 8.4% but wages rose no more than 2%, the greatest benefits accrued to landowners, particularly in northeast Mexico where wages increased only marginally (Tables 2-3, SI Tables 4-8).

In their role as surplus corn growers and landowners, non-rural landholders were able to appropriate most of the shock’s benefits. Their income increased 3.9% nationwide and up to 9.2% in the northwest. In contrast, nominal incomes in rural areas increased only 0.5% in spite of a 2.9% increase in wage income. Impacts spread beyond producer groups, affecting non-agricultural employers who faced higher wages and consumers who paid higher food prices. As consumers of corn, most rural households experienced price increases that made rural income gains vanish in real terms (Table 3). But income changes varied considerably across rural areas and household groups (SI Tables 4-8). Corn profits contributed disproportionately to large-holders' income, which rose 1% in real terms. Significant increases in wage income for other groups barely offset losses due to the contraction of subsistence activities. As a result, real income changes for subsistence households were negligible or slightly negative (Table 3).

Discussion

Interactions between economic actors shape supply responses and land-use changes at every scale (20). At the international level, domestic policies are said to interact through global markets, influencing trade outcomes (14). A strong interaction of European Union and US biofuel mandates is expected to amplify their individual impacts on agricultural rents, resulting in a marked expansion of cropland within these two blocks as well as in third countries such as Mexico and other energy-exporting nations of Latin America (11-13). Some of these analyses come from general equilibrium models, which account for feedbacks and interactions that often drive land-use outcomes in unpredictable directions (20); others are based on partial equilibrium models. In spite their differences, most models can be considered aggregate or macro in that they neglect the behavior of individual agents and the interactions among them (29).

In aggregate models, all agricultural producers within a country are subsumed by a single representative agent reallocating production factors across crops and land uses (10-13, 42). Aggregation is largely innocuous under the standard neoclassical representation of the economy with perfect markets, which most models assume (11). Aggregate models were developed in industrialized economies, where relatively homogeneous agents respond to similar sets of signals in well-developed markets using standard technologies. Interactions among similar agents (*e.g.*, farms) are considered inconsequential, so they are sidelined in favor of simple assumptions concerning price determination and market responses (19, 30). It is difficult to conceive of market exchanges in rural Mexico and other developing areas in such abstract terms because heterogeneity across producers is striking and market imperfections abound (27). These are precisely the circumstances in which interactions among individual economic actors can shape social and land-use outcomes (29). Our results highlight the cost of ignoring those interactions when addressing the ethanol boom's impacts in a developing country.

Aggregate models of the Mexican economy predicted substantial increases in corn land in response to the recent shock to international prices, including a 17% expansion by 2008 (12, 31). Our estimate of a 5.7% expansion with marked differences across regions compares more favorably with *ex post* government estimates (Table 1).

In state-of-the-art macro models, the supply of land is modeled in increasing detail, but decision-making remains highly aggregated: a country's agricultural sector still responds as a block to market and policy shocks (10-13). As a result, even land-use forecasts and rent estimates that account for local agronomic conditions remain impervious to the institutional structures that habitually influence individual agents' decision-making (18, 19). In most of rural Mexico, individual supply responses hinge on which price signals register at the farm level, as these signals depend on highly individualized transaction costs (27). So do land rents, which explains why commercial and subsistence farms coexist but respond distinctly to shocks (28).

It is well known that subsistence activities allow peasants to weather shocks to the market economy (32, 33). Our results suggest that these activities also endow the entire agricultural sector with an ability to absorb shocks. Historically, corn area in Mexico has been significantly less volatile wherever agriculture is prominent (Fig. 1; Ref. 26). We should expect aggregate supply responses to become relatively inelastic when individual responses are idiosyncratic rather than uniform. A capacity to absorb exogenous shocks, nevertheless, must be attributed to subsistence and commercial farmers coordinating their actions through local market exchanges, resulting in extensive factor reallocation within the agricultural sector (28). Although differences between these groups are acknowledged, their interaction has played no role in formal land-use models (18, 34, 35). Some macro models account for subsistence production in Mexico by netting out the share of land dedicated to this activity; but they consistently overestimate supply responses by failing to account for those interactions. Estimates from macro models for west-central Mexico exceed ours by as much as 200% (19).

Aggregate models highlight factor reallocation across crops and land uses, which helps dissipate price shocks and rent disparities (11-13); but supply responses also involve the reallocation of land and labor across farms (28, 36). Such reallocation is common in places where large commercial farms coexist with subsistence households and landless laborers, as in much of Mexico. As factors flow in and out of subsistence production regulated by local (*i.e.*, endogenous) rents and wages, the agricultural sector adjusts and shocks dissipate with minor changes in total factor demand. A vigorous commercial supply response in central and southeast Mexico, for instance, led to an unremarkable expansion of corn land, as subsistence production contracted (SI Tables 6, 7). In contrast, factor markets could not absorb commodity price shocks wherever relatively homogeneous producers had few incentives to exchange land and labor, as in the northeast and northwest regions (SI Tables 5, 8).

Significant economic interactions are not limited to strikingly different actors, such as commercial and subsistence farmers. Indirect interactions might arise between any two groups responding to different sets of signals, even between commercial farmers. In Mexico, corn growers selling directly to consumers in local markets respond differently from producers linked to the international market, because consumer and producer prices are not co-integrated (37). Nevertheless, responses by one group affect others through local factor markets. Interactions also occur among agents selling in the same markets; *e.g.*, rising land and labor costs might force a producer with no access to credit to reduce output while others expand it after a price increase. Interactions among agents also need not be local; they can occur across regions, as between participants and non-participants in Mexico's deficiency payment program. Despite claims that the program is not distortionary, owing to its limited coverage and dissociation from market prices, supply responses from program participants in northern Mexico have depressed prices faced by non-participants in the south and central regions (*ca*. 5%), dampening the agricultural sector's aggregate supply response (38).

In contrast to the macro-level interaction between the US and EU biofuel mandates (13), every interaction described above can buffer rather than amplify market and policy shocks. Apart from their impact on the level of aggregate variables, these interactions influence the distribution of costs and benefits in ways that depend on local market structure and participation (39). Similar macroeconomic factors can lead to dissimilar land-use and social outcomes across localities, as intervening processes chain-link or nest across levels of organization (16, 18). Every outcome also is associated with a particular redistribution of productive factors across actors. Costs and benefits also are redistributed. As shown above, an actor's income gains or losses depend on variables shared with others, such as rent and wage changes, as much as on his/her own endowment of land, labor and capital (SI Tables 4-8). Although transaction costs can maintain regional wage disparities, the mobility of labor (relative to land) helps dissipate shocks into other economic sectors and across borders, so wages tend to react to local shocks less than rental rates.

In west-central Mexico, wages increased by only 0.6% despite a large increase in labor use. In contrast, restrictions on land mobility limit price transmission across regions and crops, creating significant rents for local landowners and surplus corn growers.

The price shock associated with the recent ethanol boom offers an opportunity to test, in the context of Mexico, current hypotheses on biofuels' impacts in developing rural areas. Analysts expect biofuels to increase farmers' income and to have more widespread benefits for the rural population via a multiplier effect on development (5, 9). An influential analysis by the Mexican Ministry of Energy takes both types of benefits for granted (40). However, corn-price increases in Mexico brought about a transfer of land and labor into non-rural commercial agriculture, while rural households' output contracted (Table 3). As labor was drawn into non-rural agriculture, to be sure, there was an influx of wage income into the rural economy, but commercial integration drew this income back out into the urban economy, reducing the local multiplier. At the same time, higher wages hindered rural off-farm activities, which contracted slightly. Hence, higher corn prices actually had a negative income multiplier effect on rural areas, particularly in west-central Mexico (26).

Biofuels' potential impact on rural employment is similarly complex. Employment increased only marginally in rural Mexico (Table 3). In regions where the total amount of cropland is fixed in the short run, *e.g.*, in the water-constrained northwest, agricultural employment could grow only through conversion to labor-intensive crops. In west-central Mexico, conversion of pastures to corn did raise total agricultural labor demand, and most value added after the price shock consisted of wages. However, the 8.2% increase in wage income translated into a <1% increase in total income, for it came largely at the expense of losses in the value of on- and off-farm family labor and in migrant remittances (SI Table 4). Where there was already full employment and wages did not increase significantly, the shock resulted largely in the transfer of labor use from one sector into another with no effect on income. As rural migrants recognize, the well-being of working families depends on higher wage rates. Employment growth did not raise wage rates where local employment opportunities drew migrants back (or simply deterred migration by new labor-force entrants).

Value added was distributed via price, rent and wages according to preexisting factor endowments. Although some rural corn growers expanded their output, most rents accrued not to them but to non-rural landowners, except in the northeast (SI Tables 4-8). Since the vast majority

(87%) of Mexican rural households are subsistence producers or produce no corn, few real benefits from price increases reached rural areas either directly or indirectly, except in the northwest where commercial agriculture predominates. In the southeast and central regions, where poverty is greatest, subsistence farmers were relatively unaffected by price increases, as they were unaffected by persistent decreases in previous years (28, 36). However, rural incomes decreased slightly in real terms because most rural areas are net buyers of corn.

Our results cast a new light on the impact of corn trade on land use and deforestation in Mexico. Fifteen years ago it was feared that the removal of price supports for grains after NAFTA, and the ensuing decline of the Mexican corn sector would force unemployed peasants into a subsistence economy impinging on the forest margin (34). It was suggested more recently that ongoing price decreases would force subsistence producers out of rural areas, promoting reforestation (35). It is noteworthy that rural households own most forest lands in Mexico, and few of them produce a corn surplus. Our model reveals that subsistence farmers have had few incentives to expand production in recent years, particularly into marginal lands in the tropical southeast region, where deforestation has been highest in the past (26). Increased labor costs have kept deforestation pressures in check by reducing the already low rents on these lands. Opportunity costs of land rose much higher in the northwest; but it is the scarcity of water, not forests, that defines the agricultural frontier in this region and keeps land-use change in check. In sum, changes in world corn prices have had widely varied effects across rural Mexico, shaped by local conditions and interactions; but it is unlikely that they had a significant impact at the forest margin.

Advances in land-use science will depend on which modeling approach is taken (16, 21, 41). At one end of the spectrum, geographers have incorporated agronomic data into spatially explicit land-use models, creating pixel level maps of potential rents that nevertheless ignore economic processes (41). At the opposite end, macroeconomists seek to map land-use and rent changes by incorporating GIS data into models of the global economy, already widely used in policy analysis (10-13). These models assume that rents are uniform within large agro-ecological zones (13). Eventually, in principle, these two approaches could be integrated, linking macro policies to land-use outcomes at the pixel level but still avoiding the complexity of microeconomics. Unfortunately, in order to estimate changes in land use and social well-being consistently, we must account for this complexity (21). Our approach describes a practical way to integrate heterogeneous microeconomic behavior with a macroeconomic perspective. Analysis of the recent price changes in Mexico suggests that their effect was overestimated: land-use change, particularly in regions prone to deforestation, was small; but at the same time, the benefits for the rural population were negligible.

Methods

Model. Our model is a revised version of a disaggregated general equilibrium (CGE) model of the Mexican rural economy. The model, described in greater detail in Ref. 19, 26, 36, has been used extensively in policy analysis. An economy is defined by the determination of prices and output based on supply and demand equilibrium. CGE models describe the functioning of an entire economy, whether it is the world economy or a household. A household is a very small economy where output and shadow prices of subsistence activities are determined jointly. Our model nests individual models of rural households and other agricultural producers into a single country-wide model, which in turn is linked to the world economy through trade and migration. Nesting proceeded in three stages. First, rural households in each of five regions were grouped into four types: (1) landless households, (2) small-holders (<2 ha), (3) medium-holders (2-5 ha) and (4) large-holders (>5 ha). Subsequently, household types were integrated with absentee (i.e., non-rural) landholders in their region into a single model where regional wages and land rents are determined. Non-rural landholders are individual and corporate producers or landowners that are not based in rural areas but nonetheless participate in rural markets.

Given the importance of factor markets in our analysis, we modified the model to incorporate an explicit supply of land and migrant labor (26, 39). In order to reflect the sluggishness of land-use change due to conversion costs and managerial inertia, we restricted the allocation of land across uses through a nested constant elasticity of transformation (CET) supply function (14, 42, 43). The function was calibrated using data from the 2003 Mexico National Rural Household Survey (*Encuesta Nacional a Hogares Rurales de México* or ENHRUM) and econometric estimates available in the literature (39, 43-45). In modeling migrant labor, we estimated supply elasticities econometrically using ENHRUM data (39). Elasticities vary across household groups and regions, reflecting differences in access to foreign and domestic labor markets. In a final stage, the five regional models were integrated into a model of rural Mexico.

A three-stage modeling approach provides much greater detail and flexibility than aggregate CGE models, allowing us to incorporate differences in prices, production technologies and market participation across regions and households. This entails vast heterogeneity in microeconomic behavior. For instance, a household that does not participate in produce markets may sell its labor to other households or even employ wage labor in subsistence crop production using a technology that is distinct from that of other households. It also has distinct demands for market goods, and its valuation of the subsistence crop is represented by a household-specific shadow price (26, 28, 36).

Data. Our data on non-rural production were derived from the Mexican government's Agricultural Information System (SIAP) after adjusting for the share of production pertaining to rural producers (26). Data on non-rural technologies were derived from input-output matrixes for different regions (45). Data for rural areas are from the 2003 Mexico National Rural Household Survey (ENHRUM). The survey's sampling frame provides a statistically reliable characterization of Mexico's population living in rural areas, that is, in communities with fewer than 2,500 inhabitants.

ENHRUM provides detailed data on assets, endowments, productive activities and market participation for 1765 households. Net incomes for households in the sample were estimated based on detailed data on household activities and other income sources, including agricultural and non-agricultural activities, on- and off-farm wage labor, and migration, as well as from public transfers. The sum of income from these sources equals household total net income. Rural incomes are highly diversified, and income sources vary sharply across groups. Predictably, the share of total income from crop production is highest for large-holders, but small-holders and landless households receive most of their income from off-farm wage work. Summary statistics for all household groups are found in Ref. 26, 36, 39.

Simulation. We simulated the effect of price increases on the 2007/2008 cycle based on price changes experienced by different sets of corn producers between 2005 and 2007. According to ENHRUM data, around 75% of surplus corn growers in rural areas in west-central and north Mexico sold corn at or below producer prices (26). These producers are mostly linked to international commodity markets. In contrast, 75% of farmers selling corn in central and southeast regions received prices up to 100% higher, since they sell directly to consumers (26). Accordingly, we assume that a 23% increase in producer prices, as reported by SIAP, affects surplus growers in west-central and north Mexico, while surplus growers in the rest of the country experienced only the 5% increase reported by the Bank of Mexico for consumer prices.

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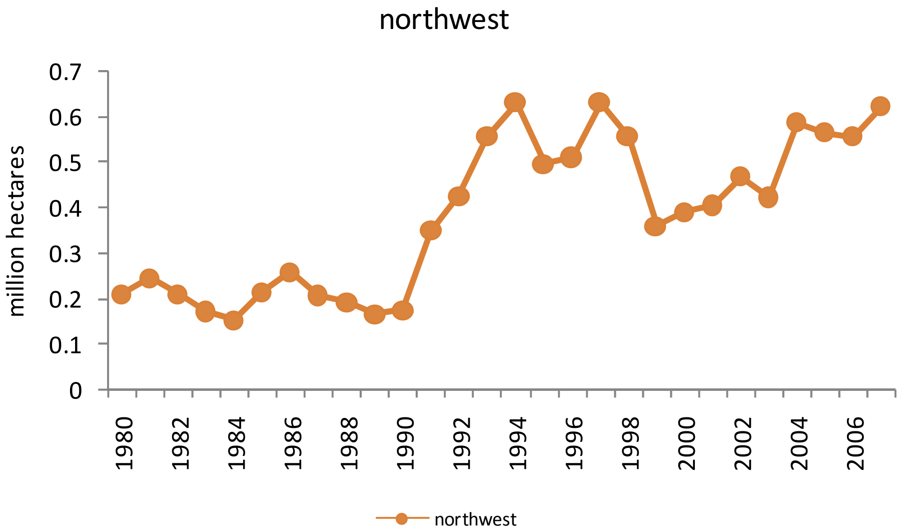

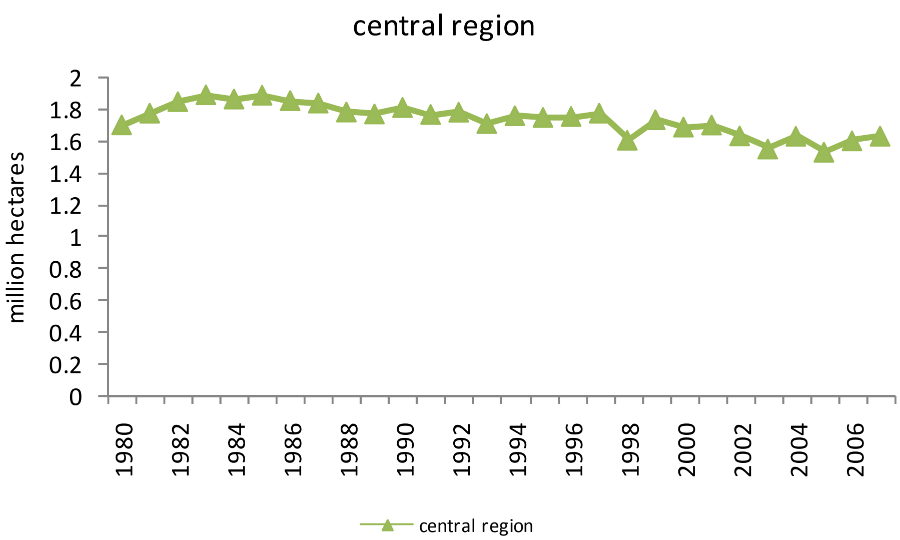

Fig. 1. Area in corn in Mexico's northwest and central regions, 1980-2007. Corn area is significantly less volatile wherever subsistence production is prominent (e.g., central Mexico) than where commercial agriculture predominates (e.g., the northwest). Our estimates of change in corn area correspond well with the observed volatility, suggesting that subsistence activities endow the entire agricultural sector with the ability to absorb economic shocks.

Table 1. Estimated percent changes in corn area in 2008. Our *ex ante* estimates correspond well with *ex post* government estimates in every region but the southeast, where corn area reportedly decreased due to a 20% drop in the state of Chiapas. We suspect that this reflects an error in the federal government's reporting. In 2008, corn output reached record highs in Chiapas (SIAP); the state government reportedly supported "around 800,000 hectares" of corn, compared to the 671,617 ha total in corn reported by the federal government (Gobierno de Chiapas, Comunicado 3621, October 12th, 2008).

	Government estimates[1]	Simulation estimates
Region		
Southeast	-5.1	1.6
Center	1.8	1.7
West-center	9.9	9.0
Northwest	12.3	15.8
Northeast	13.9	14.4
Mexico	3.5	5.7

1. Source: Sistema de Información Agroalimentaria y Pesquera (SIAP), Mexico <www.siap.gob.mx>

Table 2. Percentage change in rents and wages in 2008. Although international prices drove corn rents up, supply responses pressed wages and cropland rental rates up. Changes in wages and cropland rental rates depressed surplus rents in labor-intensive crops below the baseline. Livestock rents increased slightly. Changes in the opportunity costs of land at the forest margin reveal the ultimate balance.

	Rents					Wages
	Corn	Other crops	Cropland rental rates[1]	Livestock	Opportunity costs of forest land[1]	
Southeast	6.5	0.0	3.0	0.2	2.0	0.2
Center	5.7	-0.1	0.4	0.1	0.3	0.1
West-center	23.4	-0.1	5.7	0.9	5.2	2.0
Northwest	27.8	0.0	8.4	0.6	7.2	1.9
Northeast	30.8	0.1	1.1	0.0	0.4	0.0

1. Rental rates for cropland are equal to the composite cropland rents in the model; the opportunity costs of land at the forest margin are composite rents for all agricultural land, *i.e*., cropland plus pastures (Ref. 13).

Table 3. Percentage response to corn price changes in Mexico by 2008. Aggregate, nationwide responses to corn-price changes (a), can be disaggregated into responses by absentee producers (b) and rural households (c), which in turn can be disaggregated based across households (d to g) based on landholdings (see Methods section). Each of these groups' responses can be disaggregated further still according to geographical region (Table 4, SI Table 5-8).

	(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)
Production							
Corn	5.8	12.2	0.0	-25.0	-5.0	-5.5	11.9
Other crops	-1.3	-0.5	-2.7	-6.0	-0.3	-0.4	-4.7
Livestock	-0.8	-0.6	-1.5	-2.1	-1.3	-1.1	-1.1
Non-ag			-1.4	-2.0	-1.9	-	-0.9
Ag value added	3.0	3.9	0.9	-6.7	-2.5	-1.0	3.8
Factor use							
Labor	0.1	1.9	-1.4	-1.7	-1.6	-0.9	-0.5
Corn land	9.4	15.4	-1.8	-37.5	-15.9	-12.4	17.3
Other cropland	-1.5	-0.5	-4.0	-5.9	-0.3	-0.3	-5.4
All cropland	0.2	1.8	-3.6	-13.2	-6.0	-2.0	-2.0
Pasture	-1.0	-0.8	-1.6	-1.5	-2.5	-2.9	-1.1
Income							
Nominal income		3.9	0.5	0.1	0.0	0.1	2.1
Real income		3.9	0.02	0.0	-0.8	-0.6	1.0

Supporting Information

Table 4. Percentage response to corn price changes in West-central Mexico by 2008

	(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)
Production							
Corn	6.4	16.4	-6.2	-26.4	-15.6	-20.6	20.0
Other crops	-1.9	-1.3	-2.9	-6.4	-1.6	-1.5	-1.6
Livestock	-2.8	-2.4	-3.1	-2.9	-3.2	-2.8	-3.5
Non-ag			-3.1	-3.4	-2.0	-	-2.0
Ag value added	6.0	8.6	0.7	-11.3	-6.8	-4.9	10.0
Factor use							
Labor	0.3	6.1	-4.9	-7.9	-6.1	-4.9	1.8
Corn land	9.0	21.4	-14.0	-40.4	-31.7	-35.7	37.3
Other cropland	-1.8	-1.2	-3.3	-6.4	-1.5	-1.5	-1.6
All cropland	0.3	2.9	-5.7	-14.7	-15.1	-8.7	4.7
Pasture	-3.5	-3.3	-4.2	-3.8	-4.1	-3.7	-4.4
Income							
Nominal income		6.3	0.9	0.2	0.2	0.1	4.1
Real income		6.3	0.5	0.0	-0.5	-0.6	3.3

Table 5. Percentage response to corn price changes in Northwest Mexico by 2008

	(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)
Production							
Corn	13.4	12.3	16.7	13.8	29.2	15.8	16.8
Other crops	-3.6	-0.5	-12.8	-5.6	-1.1	-3.8	-13.0
Livestock	-2.3	-2.1	-4.9	-4.5	-2.5	-31.3	-3.0
Non-ag	0.0		-2.2	-2.3	-1.9	-	-1.9
Ag value added	6.3	7.7	1.8	0.2	1.8	10.8	1.7
Factor use							
Labor	0.1	4.6	-4.1	-3.5	-2.3	33.4	-4.4
Corn land	15.8	15.7	15.9	11.5	36.8	16.0	16.1
Other cropland	-4.1	-0.5	-12.8	-5.6	-1.1	-3.8	-13.0
All cropland	0.3	3.4	-7.8	-1.3	19.5	12.6	-8.1
Pasture	-3.4	-2.7	-7.7	-5.1	-3.1	-31.8	-3.6
Income							
Nominal income		9.2	2.9	0.7	1.0	11.4	5.0
Real income		9.2	2.1	0.7	0.9	10.4	3.5

Table 6. Percentage response to corn price changes in Southeast Mexico by 2008

	(a) Mexico (b + c)	(b) Non-rural producers	(c) Rural households (d to g)	Rural households (d) Landless	Rural households (e) Small-holders (<2 ha)	Rural households (f) Medium-holders (2-5 ha)	Rural households (g) Large-holders (>5 ha)
Production							
Corn	0.4	4.7	-0.5	-	-4.1	-2.7	4.8
Other crops	-0.6	-0.8	-0.4	-	-0.5	-0.5	-0.3
Livestock	-0.4	-0.4	-0.4	-0.5	-0.4	-0.4	-0.4
Non-ag			-0.1	-0.2	-	-	-0.2
Ag value added	2.3	2.1	2.4	-0.5	-2.7	-1.6	5.6
Factor use							
Labor	0.1	0.9	-0.1	-0.4	-1.3	-1.1	1.2
Corn land	1.6	5.2	-0.8	-	-10.0	-8.6	8.1
Other cropland	-0.7	-0.8	-0.3	-	-0.4	-0.5	-0.3
All cropland	0.3	1.0	-0.6	-	-7.0	-6.6	4.2
Pasture	-0.6	-0.6	-0.6	-0.7	-0.6	-0.6	-0.6
Income							
Nominal income		1.0	0.2	0.0	0.0	0.0	0.7
Real income		1.0	-0.6	0.0	-1.1	-0.5	-0.9

Table 7. Percentage response to corn price changes in Central Mexico by 2008

	(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)
Production							
Corn	0.7	5.5	-2.3	-	-2.4	-4.6	2.4
Other crops	-0.1	-0.1	-0.2	-	0.0	-0.2	-0.4
Livestock	-0.1	-0.1	-0.1	-0.1	0.0	-0.1	-0.1
Non-ag			0.0	-0.1	-	-	-0.1
Ag value added	0.3	0.5	-0.2	-0.1	-0.7	-0.6	0.6
Factor use							
Labor	0.0	0.2	-0.3	-0.1	-0.3	-0.4	-0.1
Corn land	1.7	6.8	-5.2	0.0	-7.7	-9.8	3.8
Other cropland	-0.1	0.0	-0.2	0.0	0.0	-0.2	-0.4
All cropland	0.0	0.4	-0.7	0.0	-1.5	-1.0	-0.1
Pasture	-0.1	-0.1	-0.2	-0.2	-0.1	-0.2	-0.2
Income							
Nominal income		0.6	0.1	0.0	0.0	0.0	0.4
Real income		0.6	-0.5	-0.1	-0.6	-0.8	-0.4

Table 8. Percentage response to corn price changes in Northeast Mexico by 2008

	(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)
Production							
Corn	14.1	10.3	18.5	-13.5	25.6	28.9	17.2
Other crops	-0.2	-0.1	-0.6	-1.2	-0.1	0.0	-0.6
Livestock	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-ag	0.0		0.0	0.0	-	-	0.0
Ag value added	0.4	0.3	0.9	-0.3	9.1	13.9	0.9
Factor use							
Labor	0.1	0.1	0.0	-0.1	1.0	7.3	0.0
Corn land	14.4	11.0	27.1	-33.9	51.0	91.9	26.6
Other cropland	-0.3	-0.1	-0.7	-1.3	-0.1	-0.1	-0.6
All cropland	0.1	0.2	-0.2	-2.0	4.0	35.8	-0.3
Pasture	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Income							
Nominal income		0.3	0.2	0.0	1.7	3.8	0.5
Real income		0.3	0.1	0.0	1.3	3.5	0.3