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Potential for Uncertainty about Indirect Effects of Ethanol on Land Use in the Case of Brazil

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Abstract: The indirect effects of ethanol on land are a focus of recent US biofuel literature and policy. The experiments presented here highlight the sensitivity of land use changes to assumptions about the ability of land to be converted from one use to another and the ease with which decision makers can make these conversions. By varying parameters governing land use in a simulation model, indirect effects on land use can be varied no less widely. Extending this result, there is an inverse relationship between the responsiveness of land allocation, which is a key element of overall supply response in the medium-term, and the magnitude of price effects: for a given shock, greater land response dampens the scale of price changes and lower land response is associated with greater price effects. Moving beyond agricultural commodity markets alone, Brazilian ethanol markets may be as sensitive to prices as US markets are sometimes believed to be. If so, then changes in Brazilian trade may represent a substantial part of the market response to changes in US ethanol consumption at least over certain ranges. With uncertainties about area and ethanol market effects taken into account, a particular path of US imports may be associated with any number of land use effects.

The carbon footprint of biofuels is argued to be highly dependent on the indirect effects of biofuels on land use and, in particular, on deforestation. The potential for carbon emissions generated through land use change, raised by Searchinger et al. (2008a, 2008b) invites further consideration given the magnitude of land use effects. Here, the parameters associated with indirect effects of biofuel policies in the US on land allocation elsewhere are explored.

Supply and demand responses to price signals are at the heart of indirect effects of US policies on land use. US biofuel policies themselves do not directly affect or dictate how land is used in the US, let alone in other countries. The principal tools of the current US biofuel policy regime are mandated minimum levels of biofuel use, tax credits per gallon of biofuel blended, and tariffs on imports, none of which dictates land use directly. In each case, the line of causality from US biofuel policy to land use must go through markets. Policies to encourage biofuel use lead to greater demand for biofuels to the extent they affect consumer behavior. Rising biofuel demand tends to raise biofuel prices. Higher prices bring about greater production, which requires more feedstock purchases. As biofuel processors buy more feedstocks, such as corn or vegetable oil, competition among users will tend to bid up prices of these goods which in turn will encourage more supply. Agricultural commodity producers will attempt to increase supply by allocating more land to the crops with the higher returns and converting land from other uses than crop production if it is profitable to do so. For land use in other countries, interactions through trade must be added to these links, as quantities of net exports from the US are reduced

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by the feedstock purchases of biofuel processors, leading to rising world prices which may be transmitted into other countries, leading to changes in land use outside the US.

Each stage along this path depends on behavior by producers, consumers, and traders. We briefly explore the implications of different assumptions about responsiveness of land use in Brazil to price signals. Brazil is widely seen as a potential or even likely source of more agricultural area in response to higher prices.

2. Indirect Land Use Effects of Ethanol

Searchinger et al. (2008a, 2008b) extrapolate from an estimate of biofuel effects on markets to changes in land use which they claim to have dramatic effects on the carbon footprint of biofuel. The authors state, “We calculated that an ethanol increase of 56 billion liters [or 14.8 billion gallons], diverting corn from 12.8 million ha of US cropland, would in turn bring 10.8 million ha of additional land into cultivation. Locations would include 2.8 million ha in Brazil, 2.3 million ha in China and India, and 2.2 million ha in the United States” (2008a). The market results are based on a model that is a modified version of the FAPRI-MU models for the United States agricultural commodity and biofuel markets plus reduced-form trade equations to represent the rest of the world (2008b, footnote 9). Authors infer the land conversion implicit in the model of greenhouse gas emissions that they use (GREET). But they judge the basic model results to be implausible as regards land effects: first, the amount of corn area diverted to ethanol is considered to be too low and, second, the land converted to crop use in the basic model results is drawn from pasture and unused crop area (2008b). Authors approach the question of land conversion by using data about total land use in the 1990s to infer the bilateral conversions, such as from forest to crops, and applying these changes to area results from a partial equilibrium model (2008b).

The response of land use to prices is a topic of current research. Much of the research is being undertaken by researchers working on variants of the GTAP global general equilibrium model with a representation of biofuel markets and detailed land data. For example, Birur, Hertel, and Tyner (2007, 2008) use such a variant, GTAP-E, that includes biofuels in the energy sector and agro-ecological zones (AEZs) for land use. Base data represent 2001, and these are updated in part to 2006 to help calibrate biofuel equations before the effects of US and EU mandates are explored. Land allocation within each AEZ is simulated in a series of stages, with the highest stage separating land among pasture, crop, and forest uses and a second stage to allocate cropland to different crops. Ranges of change in broad land use categories due to biofuel-related factors from 2001 to 2006 vary for each region in size and even in direction, but in Brazil cropland rises by 2.8%, forest area falls by 0.5%, and pasture are also falls by 0.4% (Birur, Hertel, and Tyner, 2008).

Golub, Hertel, and Sohngen (2007) describe the land allocation system characteristic of these efforts based on GTAP in some detail, noting an iterative process between GTAP and a timber model based on Sohngen and Mendelsohn (2006). Authors go further to explore various representations of land allocation within each AEZ: (1) homogeneous and mobile, (2) heterogeneous or of limited mobility using a constant elasticity of transformation (CET) specification, and (3) heterogeneous or of limited mobility using a set of nested decisions, first between agricultural and forestry and then agricultural land use is divided into cropland and pasture uses, both using CETs. Authors also introduce a land supply curve based on a land conversion cost that is asymptotic with respect to total land. The FASOM model (Adams et al, 1996) is a basis for forestry-to-cropland conversion elasticities in many GTAP-based studies, as well as Schneider and McCarl (2005), and the FARM model is also a key input for many GE studies, such as Ahammad and Mi (2005). Two specifications of land allocation are investigated by Gurgel, Reilly, and Paltsev (2007), who question constant elasticity specifications.

General equilibrium studies, such as those listed above, typically assume heterogeneity of goods based on country of origin. This assumption is not the basis of many partial equilibrium models such as the FAPRI model system. In this representation, agricultural goods are typically modeled at a level of detail that may defy the assumption of differences based on country of origin. Banse, van Meijl, and Woltjer (2008) observe that at least several “existing studies treat land exogenously” (p 4). This claim perhaps over-states the problem in that land devoted to crops is almost certainly endogenous in most models of agricultural commodities. But the broader point holds that the area response to prices as represented in partial equilibrium models might be reviewed in light of recent successes with the staged tree approach of recent general equilibrium model experiments.

This line of discussion leads to a question. If land allocation is decomposed into a series of behavioral equations in a partial equilibrium model, how sensitive are biofuel analysis results to varying assumptions about parameters that represent responsiveness to price signals?

3. Methods

We address this question using the FAPRI-MU model of key US agricultural commodity and biofuel markets and a stylized representation of world agricultural and biofuel markets. The first of these models is related to the biofuel and agricultural market representation used by Searchinger et al. (2008b). Those authors adapted an earlier version of this model. The model used here incorporates US bioenergy policies as set out by law passed in late 2007 and updates market representations for recent events. Another difference is that some equations intended to give detailed regional results within the US are aggregated into single equations. A fundamental difference with respect to Searchinger et al. is that those authors assumed very elastic ethanol demand and supply. The potential for US biofuel expansion in the model used here is limited by the potential of ethanol in particular to overcome hurdles of distribution and adoption, as well as delays in building production capacity, as described in FAPRI-MU (2008).

The representation of world commodity markets is a stylized model of wheat, rice, corn, other coarse grain, sugar, soybean, rapeseed, sunflower, palm, vegetable oil, oilseed meal, beef, pork, and poultry markets. Argentina, Brazil, Canada, China, India, Indonesia, the European Union, and Mexico are identified separately, and reduced form net trade equations are used to represent the rest of world. The Brazilian ethanol market is also represented separately. For purposes of responses to shocks in US markets, each country or region responds to changing world prices depending on price transmission of world prices to domestic markets and then on to consumer and producer prices. For the US, price transmission is typically unity because US border prices are indicator world prices in most cases. In the case of Brazil, a greater-thanproportionate price transmission of 1.2 is assumed for sugar, ethanol, and the oilseed complex, and unitary price transmission for most other crops. If there is a partly fixed margin between world and local prices of relevant crops and crop products that are exported from Brazil, then a 1% change in the world price could lead to greater than a 1% change in domestic prices. Then, producers and consumers respond to these price signals. Consumer response is dictated by cross-price elasticities that are based on a common Hicksian demand matrix for each of three sets of countries, with these categories established based on level of per capita income. The Slutsky equation is used to calculate Marshallian elasticities that represent the conditions of each country, so local differences manifested in varying expenditure shares are reflected in the applied elasticities. The Brazilian ethanol market follows in style the US model, but is simpler in its representation. Ethanol demand is responsive to relative gasoline-to-ethanol prices, particularly around the point of energy equivalence, with some delays. Ethanol production responds with greater delays to net returns to sugar-based ethanol production but, over time, continues to respond to any sustained change in net returns. Apart from the US and Brazil, the small ethanol net trade of the rest of the world ethanol market is reduced to a single equation with price elasticity of -1, and the world price balances trade among these two countries and this aggregate. Oilseeds are converted into vegetable oil and meal equivalents, which are both price-clearing markets, and oilseed prices are functions of these prices.

The links between livestock and crop markets are represented through feed markets, as well as in pasture area as described below. Supplies of livestock products depend on output prices and input cost indices, with these cost indices reflecting feed costs. Feed demand for grains and oilseed meal are tied to livestock product output.

Crop supply in partial equilibrium models is often represented as the product of yield and area allocated to the crop, and this model is no exception. Yields are driven largely by estimated trends that are bound to a plausible range, but do also respond to prices to some extent and with delays to reflect the impacts of price signals through research and development. USDA Foreign Agriculture Service (FAS) Production, Supply, and Distribution (PSD) data serve as the basis for crop and livestock product supply and use data. World indicator prices of the FAPRI-MU model and exchange rates determine domestic national price levels.

Broad land allocation rests largely on FAO land use data. Land allocation is simulated in a nested tree approach. Constant elasticities to regulate shifts in land among crops uses at the lowest stage are calibrated based on the assumption that a 1% change in relative prices will lead to 0.1% of total crop land being reallocated, which leads to larger area elasticities for individual crops, with cross-effects calibrated to maintain adding up in the base data. A fixed-weight index of crop prices multiplied by yields represents the value of land allocated to these uses in the next higher stage. In that stage, the uses are land to these annual crops, pasture, palm, sugar, and permanent crops or groves. Thus, the crop revenue index is compared to (1) the price of land in pasture which is tied to the beef price; (2) the price of land used for palm which depends, through the palm oil price, on the vegetable oil price; (3) revenues from sugar; and (4) the price of permanent crops or groves which is determined by macroeconomic variables in the absence of corresponding commodity models. In each case, the ratio of land allocated to an alternative use relative to land allocated to annual crop use is a function of the relative land use price to the crop land price index. At the next higher stage, land is allocated to these agricultural uses or forest based on relative prices or price indices. Other land use is assumed to increase with the ratio of a price linked to GDP growth (that is exogenous in these experiments) relative to the average price of land allocated to forest or agricultural uses. Total land of a country or region is held constant.

This nested representation is quite similar to methods being applied in the context of GTAP work in overall structure, albeit without the distinction of AEZs within country. The partial equilibrium model has other limits. While prices of permanent crops and forestry are not exogenous, they will not respond in the scenarios that follow. Any broader economic effects that may be increasingly relevant in poorer countries are ignored. Parameters are not estimated, although parameters are tested in simulation and judged to be plausible. Uncertainty about parameters relating to land allocation is the subject of the next section.

4. Results

The purpose of the experiment is to see how changes in US markets affect world land use under alternative assumptions of behavioral response. The experiment is an increase in the petroleum price from $125 to $160 per barrel, but only the direct effects on US markets are introduced. The direct effects of the petroleum price change on biofuel markets and agricultural supplies in all other countries, including Brazil, are ignored, even though they could be quite important. The effects of the higher petroleum price in the US are (1) increased demand for substitute sources of motor fuel, ethanol and biodiesel, and (2) increased agricultural production costs. Thus, as observed in recent years, the higher petroleum price will have a two-fold effect on US agricultural markets, namely demand shifts outward and supply shifts backward, both of which will cause prices to rise.

Additional effects, such as on transportation costs or on the wider economy, are not included. These omissions are by no means unimportant, and preclude extrapolating on the basis of this study the effects of petroleum prices on the sector, much less to the specific case of recent price increases in petroleum and agricultural commodity prices. The economic effects are presumably mixed, but would dampen income at least in countries that import petroleum and likely decrease their food demand while at the same time contributing to inflation. The effects of higher transportation costs also depend on a countries’ position as exporter or importer and on relative transportation costs. Rising transportation costs would lower prices for at least some agricultural commodity exporters, such as Brazil and the US, but could also lead to a reallocation of trade flows that actually favor some exporters so the effect on any particular exporting country is ambiguous.

By way of motivation, this analysis is intended to highlight uncertainty about land use effects of biofuel expansion. A less theoretical motivating explanation is a hypothetical tax on petroleum of some sort, such as one to offset carbon emissions or to recognize some other externality, imposed only by the US. Even in this case, any number of important complications is ignored.

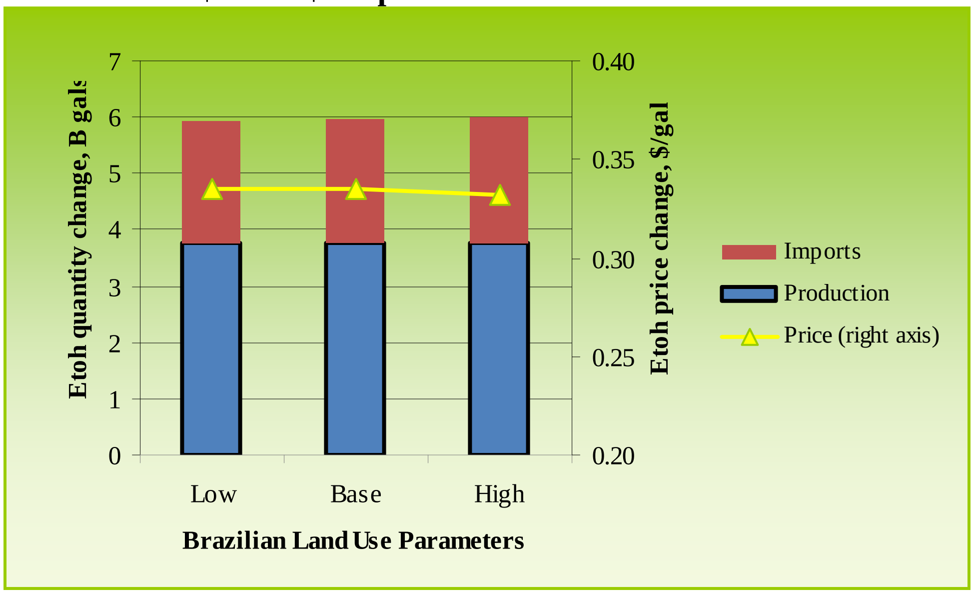
The implications of these two effects on Brazilian area allocation are investigated under alternating assumptions of sensitivity. The parameters governing Brazilian area allocation noted in passing above are set at each of three levels: (the “Base” case) 0.05 for the other land class elasticity, 0.10 for the parameter governing the trade-off between forest and agricultural uses, and 0.15 for the second-stage substitution between annual crop, palm, permanent crop, pasture, and sugar; ("Low" case) with no land use changes at the highest level, among agriculture, forest, and other land classes, and the parameter governing substitution at the next stage reduced by half relative to the base case, to 0.075; or ("High" case) increased to 1 for the trade-off between forest and agricultural uses and also to unity for substitution among second-stage agricultural uses, as well as an elasticity of other land classes increased to 0.1. The elasticities governing trade-offs among the annual crops are not changed. In each case, the model is first calibrated to a baseline for 2008 to 2017, and the effects of a scenario are calculated by comparing the simulated results with the change in petroleum price to the simulation results without the change.

The effects of $35 per barrel higher petroleum price on the US ethanol market are similar in all three cases (Figure 1). This reflects the sensitivity of ethanol consumption to relative prices. The change in ethanol consumption is an increase of approximately 6 billion gallons following a $35 increase in the petroleum price in average use over the period from 2010 to 2017. This increase of about 25% contrasts sharply with the doubling of ethanol use for an increase in the petroleum price by $10 per barrel found by Searchinger et al (2008b). The model used here assumes limits to ethanol expansion owing to the costs of greater E85 distribution and consumer adoption delays that are more relevant as ethanol use grows and approaches these limits. Another important assumption is that, despite this price signal, fuels other than E-85 with more than 10% ethanol, such as E20, do not become widely used. Thus, there would be more expansion for a given increase in the petroleum price starting from a lower initial petroleum price relative to the present experiment and there could be greater expansion if limiting factors were overcome more easily than assumed here. Nevertheless, the constraints to rapid expansion in ethanol use could still prove limiting at some point, but greater use of blends with more than 10% ethanol would lead to greater quantity effects and smaller price shift. As it is, the ethanol price increases 13%. The pattern of effects reflects the short-term constraints of the model in that the price effect is larger at first and the quantity change is smaller, whereas the quantity effect tends to grow over time as more adjustments take place and the price effects become smaller.

There are two implications of these ethanol market impacts on Brazil. First, the higher ethanol price leads to higher ethanol imports, almost all of which come from Brazil. Second, the higher price also encourages processors to produce and sell more ethanol, which indirectly drives corn and other commodity prices higher. This demand-induced price effect, plus the backward shift in US supplies owing to higher energy and fuel prices associated with the petroleum price increase, leads to higher crop prices in international markets. The prices are transmitted to Brazil, a leading agricultural commodity exporter.

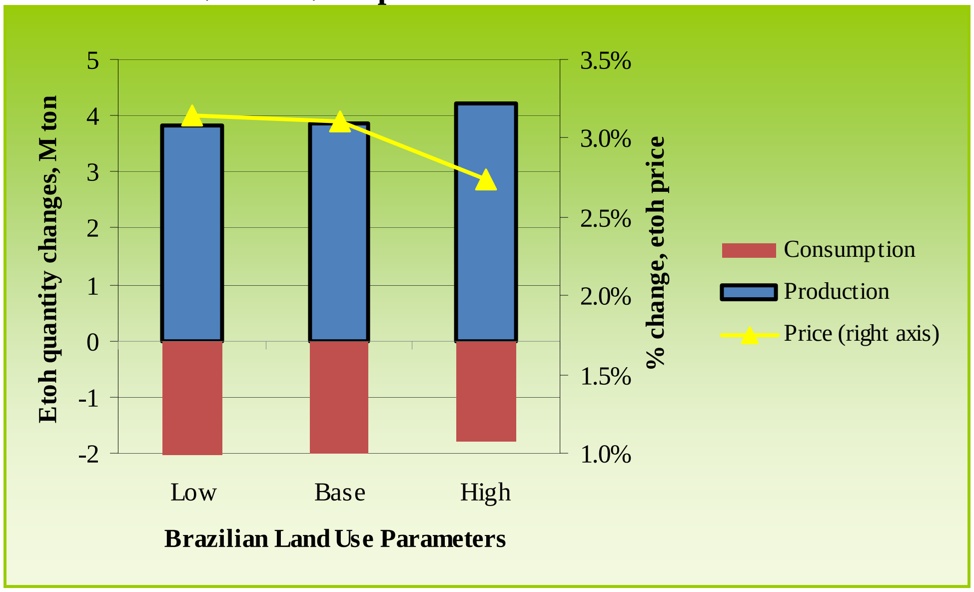
In these experiments, however, US imports of ethanol vary little, despite the changes in land allocation parameters for Brazil. This reflects the expectation that Brazilian ethanol demand is about as sensitive to relative prices as is US ethanol demand. An increase in US ethanol import demand is likely to be met by increasing production in Brazil or decreasing Brazilian use for even a narrow range of simulated price changes (Figure 2). The change in Brazilian exports is just under 6 million tons in all three cases, but the composition of supply and demand quantity changes depends on the extent to which land use changes. Given that yield response is less than 1% on average from 2010-2017 in any of these cases, supply response over this time period depends on the ability of producers to reallocate area among crops and to bring new area into agricultural use at the expense of other land classes.

Figure 1. Average 2010-17 effects on US ethanol market of petroleum price increase from $125 to $160 per barrel



Source: model simulation results, as described in text

Figure 2. Average 2010-17 effects on Brazilian ethanol market of petroleum price increase from $125 to $160 per barrel



Source: model simulation results, as described in text

The effects of changes in US markets brought about by an increase in the petroleum price and related costs of production on land use in Brazil depend on the chosen land use parameters, as well as on market signals. The first-round effects of the higher petroleum price on the US are higher ethanol demand and higher costs of agricultural production, leading to higher prices overall but the most pronounced price effects are on ethanol and corn markets.

For Brazil, the corn price effect is large, but so too is the effect on the sugar market as demand for sugar to convert into ethanol increases. Area is reallocated accordingly (Table 1). Area is pulled into sugar and corn production, but only to a limited extent as all crop prices tend to increase. Moreover, the substitution between sugar and other uses is assumed to be limited as compared to the case of corn, so the increase in sugar area is proportionally less than the increase in corn area even though the price increases are of the same order of magnitude. Land is pulled into crop uses from other purposes, such as perennials. In practice, falling perennial area would lead to price effects that would dampen some of this initial impact, but this effect is not included here. Offsetting effects limit the impact on palm and pasture area because in both cases the rising value of land maintained in these uses, as determined by the roughly 4.5% increase in vegetable oil price and approximately 1.5% higher beef prices, counteracts some part of the greater value of land shifted into crops.

Table 1. Average 2010-17 Brazilian land use changes from increase in petroleum price from $125 to $165 per barrel

Land use class	Parameters governing Brazilian land use					
Changes in absolute	Low		Base		High	
or relative terms	thou ha	percent	thou ha	percent	thou ha	percent
Top Levels						
Other Land Classes	0.0	0.00%	-29.9	-0.03%	-54.9	-0.05%
Forest	0.0	0.00%	-77.1	-0.02%	-819.2	-0.18%
Agriculture	0.0	0.00%	106.9	0.04%	874.1	0.30%
Agriculture Land Uses						
Annual Crops	86.2	0.11%	204.1	0.27%	1683.6	2.20%
Pasture	-87.6	-0.04%	-104.4	-0.05%	-846.2	-0.43%
Perennial Crops	-9.2	-0.12%	-15.5	-0.21%	-87.1	-1.16%
Palm Groves	0.1	0.16%	0.2	0.36%	1.4	2.47%
Sugar	10.5	0.18%	22.5	0.39%	122.5	2.12%
Annual Crops						
Wheat	-10.7	-0.60%	-7.7	-0.43%	29.4	1.64%
Corn	121.8	0.83%	146.2	0.99%	447.9	3.04%
Other Grains	-4.2	-0.37%	-2.3	-0.20%	21.5	1.86%
Soybeans	-34.9	-0.16%	-2.4	-0.01%	400.7	1.84%
Rapeseed	0.0	-0.86%	0.0	-0.70%	0.0	1.23%
Sunflower	-0.4	-0.57%	-0.3	-0.41%	1.1	1.55%
Rice	-13.6	-0.46%	-8.7	-0.29%	52.7	1.76%
Other Crops	28.3	0.08%	79.3	0.23%	730.2	2.14%

Source: model simulation results, as described in text

Land is drawn from forest and other classes into agriculture. The results for broad land uses do vary with parameters, as expected, with as much as several hundred thousand hectares shifting in the case of higher elasticities selected for this illustrative example. Of course, at the low end of the parameter values there is far little movement in area, and consequently less potential to increase area in sugar, corn, and other agricultural activities. This implies a lower supply response in Brazil overall and comparing the proportional price changes in the low and high parameter cases implies that the change in prices of sugar and soybeans could be at least one-quarter higher with the lower area response parameters.

Table 2. Average 2010-17 Brazilian land use changes from decrease in petroleum price from $125 to $90 per barrel

Land use class	Parameters governing Brazilian land use					
Changes in absolute	Low		Base		High	
or relative terms	thou ha	percent	thou ha	percent	thou ha	percent
Top Levels						
Other Land Classes	0.0	0.00%	32.8	0.03%	61.2	0.06%
Forest	0.0	0.00%	85.1	0.02%	916.9	0.20%
Agriculture	0.0	0.00%	-117.9	-0.04%	-978.1	-0.34%
Agriculture Land Uses						
Annual Crops	-92.3	-0.12%	-218.9	-0.29%	-1787.7	-2.33%
Pasture	85.3	0.04%	92.4	0.05%	759.8	0.39%
Perennial Crops	10.2	0.14%	17.2	0.23%	99.5	1.32%
Palm Groves	0.0	-0.05%	-0.1	-0.15%	-0.6	-1.03%
Sugar	-3.2	-0.06%	-8.5	-0.15%	-49.2	-0.85%
Annual Crops						
Wheat	8.0	0.44%	4.8	0.27%	-34.5	-1.92%
Corn	-236.0	-1.61%	-261.0	-1.78%	-567.2	-3.86%
Other Grains	1.4	0.12%	-0.6	-0.05%	-25.7	-2.22%
Soybeans	95.9	0.44%	61.4	0.28%	-365.1	-1.67%
Rapeseed	0.0	1.01%	0.0	0.84%	0.0	-1.22%
Sunflower	0.6	0.85%	0.5	0.68%	-1.0	-1.39%
Rice	8.5	0.29%	3.3	0.11%	-61.5	-2.05%
Other Crops	29.4	0.09%	-27.2	-0.08%	-732.7	-2.15%

Source: model simulation results, as described in text

To explore the sensitivity of the experiment to the levels of petroleum prices, a second set of experiments is conducted for a reduction in petroleum price, from $125 per barrel to $90, which is repeated again for each of the three sets of parameter values. There are reasons to expect asymmetry in the response. Ethanol production capacity is unlikely to be destroyed once it has been built, biofuel use mandates and regulatory uses of ethanol that are inelastic with respect to price, US ethanol imports will not be negative, and consumers' willingness to substitute one fuel for another may be very sensitive to the precise price ratio at which one fuel is cheaper than another. Nevertheless, at least for these price ranges and over a ten-year interval these results suggest responses that are only somewhat non-symmetrical. US ethanol price effects are greater in part because ethanol import reductions are limited. Less change in direct exports of ethanol from Brazil allow indirect effects to take a larger role in determining land reallocation, generating small effects on sugar area, and larger proportional changes in sugar and corn area than in the case of a rising petroleum price.

5. Summary

This illustrative experiment focuses on the uncertainties about behavioral responses of one country, Brazil, and of one type, land allocation. This uncertainty weighs on estimates of the indirect effects of biofuel demand on land use changes. The case explored here uses a stylized model that represents land use following a nested structure, with parameters governing broader categories varied over a range. The scenario is an increase in the petroleum price from $125 to $160 per barrel implemented on the basis of its effects on only US biofuel demand and agricultural costs of production. This could be motivated as a simulation of a US-only tax on petroleum use, but only by omitting important factors, and so is better considered as a mechanism to highlight indirect effects of US market events associated with petroleum price changes on land use in Brazil.

The ethanol market is judged to be extremely responsive to changes in relative prices at least at the levels explored in experiments. Higher motor fuel prices lead to increasing quantities demanded in the US, but also to a rapid decrease in ethanol use in Brazil if US importers bid up ethanol prices. Rising agricultural commodity prices for Brazilian agriculture add pressure to use land to produce these goods. It is nearly tautological to observe that the responsiveness of land use decision making to relative prices controls the magnitude of change, but ranging parameters over a wide range that seems broadly plausible as regards responsiveness in the coming years yields a similarly wide range of results.

Uncertainty about how to represent these fundamental characteristics of market participants' behavior might be manifested in differences among research results, with different analysts producing a range of results. While likely true in the case of the effects of US biofuel use on area in other countries, some part of this uncertainty may be obscured by differences in experiment design. For example, the results here are not fully comparable with Searchinger et al. (2008a), who allow a large increase in ethanol use over a 10-year period and consequently suggest that US ethanol use doubles with an increase in the petroleum price from $54 to $64 per barrel. They find that millions of hectares of new land would be brought into crop production in Brazil as an indirect consequence of a $10 increase in petroleum. In contrast, larger increases in petroleum prices to even higher levels explored here result in far less dramatic changes in ethanol use as some constraints are imposed. The simulations here suggest that indirect effects of a $35 change in petroleum price through petroleum-ethanol substitution in the US are first and foremost reallocation of land already used for crops. Moreover, the more direct effects on ethanol exports from Brazil and, consequently, on sugar prices, can play an important role alongside indirect effects through corn and soybean markets.

The changes in US ethanol markets are largely invariant with respect to changes in Brazilian area in these stylized experiments. Brazilian exports meet US requirements by some combination of consumption and production changes in this representation. If true, then an expansion of US ethanol use can, within some limits at least, be met by changing ethanol use in Brazil as much as by changing land use.

Another result from this analysis relates to the interaction of price and area effects. The larger the area effect in Brazil and the more additional land brought into production, the smaller the market price changes will be over time. On the other hand, the smaller the reallocation of area to agricultural uses in Brazil, the larger the price effects. An implication is that concerns about land effects and agricultural commodity price increases should reflect the fact that these two possible outcomes of increasing biofuel production are mutually offsetting to some extent.

Finally, some limitations of this experiment are reiterated. The petroleum price increase effects were only imposed on the US, so Brazilian ethanol demand did not shift out. While this might be taken as a simulation of a US-only tax on petroleum use, it is not and is more clearly viewed as an experiment to highlight indirect effects. The equilibrium also does not extend to gasoline and crude oil markets, so changes in ethanol use have no effect on gasoline and petroleum markets. Finally, although it is not certain that parameters based only on events of the past or the recent run-up on commodity prices would be better, the parameter ranges used here are illustrative rather than carefully calculated to reflect expected land use sensitivity to relative prices in the next ten years.

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